EDITED BY

ALAN McKINNON | MICHAEL BROWNE
MAJA PIECYK | ANTHONY WHITEING

GREEN LOGISTICS

3RD EDITION

IMPROVING THE ENVIRONMENTAL SUSTAINABILITY OF LOGISTICS

The Chartered
Institute of Logistics
and Transport

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Green Logistics

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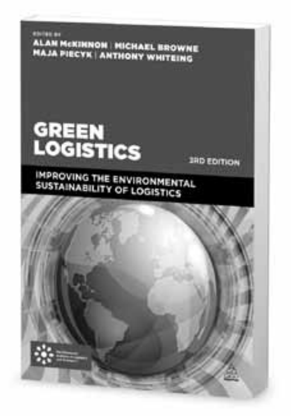
THIRD EDITION



Green Logistics

Improving the environmental sustainability of logistics

Edited by Alan McKinnon, Michael Browne, Maja Piecyk and Anthony Whiteing

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PART ONE

Assessing the environmental effects of logistics

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01

Environmental sustainability
A new priority for logistics managers

ALAN McKINNON

Introduction

Logistics is the term widely used to describe the transport, storage and handling of products as they move from raw material source, through the production system to their final point of sale or consumption. Although its core activities have been fundamental to economic development and social well-being for millennia, it is only over the past 50 years that logistics has come to be regarded as a key determinant of business performance, a profession and a major field of academic study. During this period the dominant paradigm for those managing and studying logistics has been commercial. The prime, and in many cases sole, objective has been to organize logistics in a way that maximizes profitability. The calculation of profitability, however, has included only the economic costs that companies directly incur. The wider environmental and social costs, traditionally excluded from the balance sheet, have been largely ignored – until recently.

Over the past 10–15 years, against a background of increasing public and government concern for the environment, companies have come under mounting pressure to reduce the environmental impact of their logistics operations. This impact is diverse, in terms of the range of externalities and the distances over which their adverse effects are experienced. The distribution of goods impairs local air quality, generates noise and vibration, causes accidents and makes a significant contribution to global warming. The impact of logistics on climate change has attracted increasing attention in recent years, partly because tightening controls on pollution and road safety improvements have alleviated the other environmental problems, but also because new scientific research has revealed that global warming presents a much greater and more immediate threat than previously thought.

The Intergovernmental Panel on Climate Change (IPCC, 2014) estimates that in 2010 the movement of freight accounted for roughly 43 per cent of all the energy used in transport and around 12 per cent of total global energy consumption. This corresponds to a share of approximately 10 per cent of energy-related CO_2 emissions worldwide. The inclusion of warehousing and materials handling is likely to add around 2–3 per cent to this total. The World Economic Forum and Accenture (2009) have estimated that logistical activity accounts for roughly 5.5 per cent of total global greenhouse gas (GHG) emissions (including all the other GHGs, such as methane and nitrous oxide, and not simply CO_2). They suggest that 'logistics buildings' emit 9–10 per cent of the total, with the rest coming from freight transport. Trucks and vans are responsible for two-thirds of these transport GHG emissions. Eom *et al* (2012) have also shown how, at a national level, freight-related carbon emissions per capita increase more or less in line with income per capita (at constant prices). Emissions from international transport are also rising steeply as trade volumes expand and globalization criss-crosses the planet with complex 'value chains' (McKinnon, 2014). It has been estimated by the UK Committee on Climate Change (2008: 306) that in the case of shipping 'unconstrained growth could result in global CO_2 emissions growing two to three times current levels by 2050... At this level they would, in 2050, account for 15–30 per cent of all CO_2 emissions permitted under our preferred global emission reduction scenarios'. In the light of these calculations and trends, it is hardly surprising that governments and intergovernmental organizations are developing carbon abatement policies for the freight transport sector.

Making logistics 'sustainable' in the longer term will involve more than cutting carbon emissions. Despite recent improvements, the potential still exists to cut the other environmental costs of logistics by a significant margin. Furthermore, sustainability does not only have an environmental dimension. Sustainable development was originally portrayed as the reconciliation of environmental, economic and social objectives (Brundtland Commission, 1987). The expressions 'triple bottom line' and 'people, profit, planet' are often used in the business world to convey this notion of a three-way trade-off. The concept also underpins government strategies on sustainable distribution, such as that of the UK government (Department for Transport, 2008). In practice, however, many of the measures that reduce the environmental impact of logistics, the so-called 'green-gold' measures, also save money, avoiding the need to trade off economic costs against environmental benefits. While the main focus of this book is on ways of reducing the environmental effects of logistics, frequent reference is also made to their economic and social implications.

For the purposes of this book, we define 'green logistics' as the study of the environmental effects of all the activities involved in the transport, storage and handling of physical products as they move through supply chains in both forward and reverse directions. It assesses the nature and scale of these effects and examines the various ways in which they can be reduced.

The issues discussed in the book are topical, important and currently engaging the attention of company managers and public policy makers in many countries around the world. They are examined from both corporate and public policy perspectives. The book aims to provide a broad overview of technical, managerial, economic and policy aspects of green logistics. It contains case studies and examples of the types of initiatives that can be taken at different levels, ranging from those within a single company to those that span an entire supply chain and possibly involve businesses in several countries. The book also explores the range of approaches and analytical tools available to academics and practitioners working in the field of green logistics.

Green logistics is a relatively young but rapidly evolving subject. In the four years since the first edition of this book was published a substantial body of new research has been undertaken on the subject, examples of companies 'greening' their logistics have multiplied and many governments have been intensifying their efforts to reduce the environmental damage done by freight movement.

The remainder of this chapter lays a foundation for the book by reviewing the development of the subject over the past six decades. It also presents an analytical framework for the study of green logistics and concludes with a brief outline of the other 17 chapters.

A brief history of green logistics research

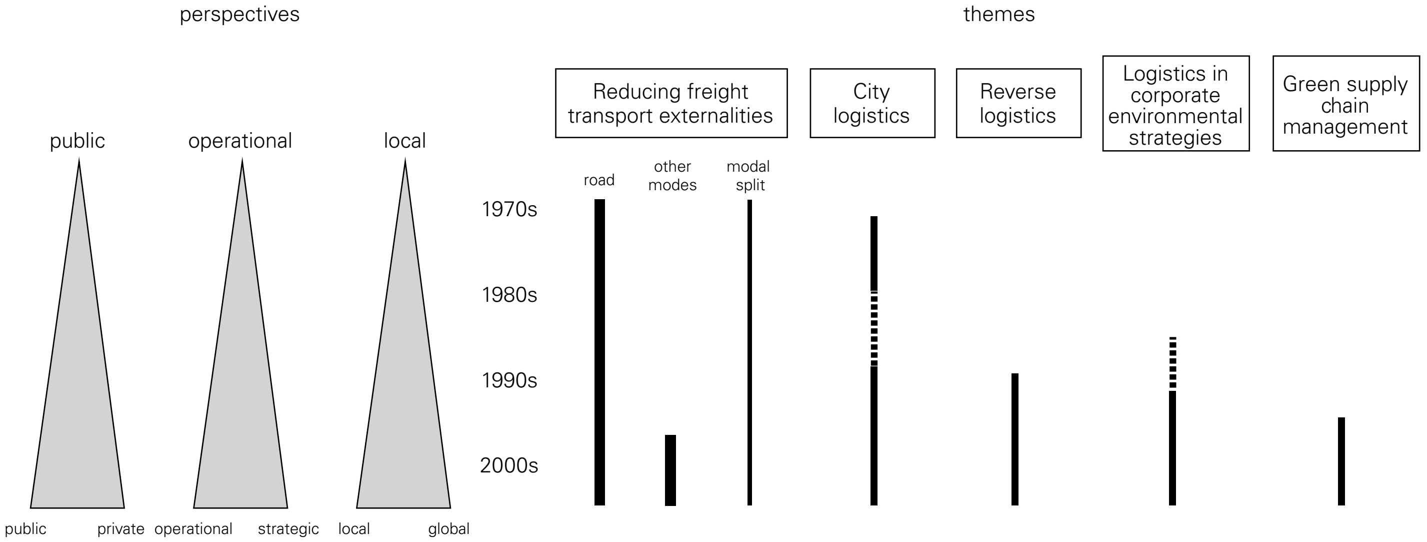
It is difficult to decide when research on green logistics began. One possible starting point would be the publication of the first paper on an environmental theme in a mainstream logistics or transport journal. This, however, would ignore a large body of earlier research on the environmental effects of freight transport undertaken before logistics gained recognition as a field of academic study. While concern was expressed about the damaging effects of freight transport in the 1950s, most of the substantive research on the subject dates from the mid-1960s. Murphy and Poist (1995: 16) assert that: 'prior to the 1960s, there was relatively little concern regarding environmental degradation. For the most part, the environment's ability to absorb wastes and to replace resources was perceived as being infinite'. This review is therefore confined to the past 50 years, but it 'casts its net wide' to capture a broad assortment of relevant literature in journals, books and reports. In their review of 10 logistics, supply management and transport journals over the period 1995–2004, Aronsson and Huge-Brodin (2006) found that only 45 papers out of 2,026 (2.2 per cent) addressed environmental issues. When the publication horizons are extended by time and type of output, however, one uncovers a large, well-established and vibrant field of research.

What we now call 'green logistics' represents the convergence of several strands of research that began at different times since the 1960s. Figure 1.1 groups these strands under five headings: reducing freight transport externalities, city logistics, reverse logistics, corporate environmental strategies towards logistics, and green supply chain management. This extends the threefold classification of green logistics research adopted by Abukhader and Jonsson (2004), which comprises environmental assessment, reverse logistics and green supply chains. Figure 1.1 also proposes a tentative chronology for research activity on these topics and depicts three more general trends that have altered the context and priorities of the research. These are shown as wedges to reflect a broadening perspective.

1. *Public-to-private*: much of the early research was driven by a public policy agenda as newly emergent environmental pressure groups began to lobby for government intervention to mitigate the damaging effects of freight movement and public agencies sought to improve their understanding of the problem and find means of addressing it. Through time, this public sector interest in the subject has been complemented by a growth in private sector involvement in green logistics research as businesses have begun to formulate environmental strategies both at a corporate level and more specifically for logistics.
2. *Operational-to-strategic*: a second general trend has been a broadening of the corporate commitment to green logistics, from the adoption of a few minor operational changes to the embedding of environmental principles in strategic planning.
3. *Local-to-global*: in the 1960s and 70s the main focus was on the local environmental impact of air pollution, noise, vibration, accidents and visual intrusion. No reference was made to the global atmospheric effects of logistical activity. Indeed in the 1970s some climate models predicted that the planet was entering a new ice age! The transcontinental spread of acid rain (from sulphur emissions) and depletion of the ozone layer (caused mainly by chlorofluorocarbons) during the 1980s demonstrated that logistics and other activities could have a more geographically extensive impact on the environment. With climate change now the dominant environmental issue of the age, the impact of logistics on global atmospheric conditions has become a major focus of research.

The context within which research on green logistics has been undertaken has also been evolving in other ways. Over the past 40 years, logistics has developed as an academic discipline, extending its original focus on the outbound movement of finished products (physical distribution) to companies' entire transport, storage and handling systems (integrated logistics) and then to the interaction with businesses upstream and downstream (supply chain management). This has extended the scope of green logistics research in terms of the functions, processes and relationships investigated

FIGURE 1.1 Evolving perspectives and themes in green logistics



(McKinnon, 2003). Other major contextual trends include the growth of environmental awareness, the proliferation of environmental regulations, and the development of national and international standards for environmental reporting and management that many companies now adopt as part of their corporate social responsibility (CSR) programmes. In this edition of the book we include, for the first time, a chapter on the CSR aspects of green logistics. Partly as a result of all these trends, the volume of data available to green logistics researchers has greatly expanded and companies have become more willing to support research in this field.

In reviewing the development of green logistics as a field of study, one detects international differences in research priorities. Although a survey by Murphy and Poist (2003) of samples of US and non-US companies found strong similarities in the environmental perceptions and practices of logistics management, research efforts have tended to be skewed towards topics of national interest. In the UK, for example, much of the early research on green logistics was a response to a public dislike of heavy lorries. In Germany, research on reverse logistics was stimulated by the introduction of radical packaging-waste legislation in the early 1990s. Until recently, reverse logistics attracted much more attention from US researchers than other aspects of green logistics, with much of the corporate interest in the subject related to its impact on costs and profitability rather than on the environment.

Reducing freight transport externalities

Much of the early research on the environmental impact of logistics was motivated by the growth of lorry traffic at a time when trucks were much noisier and more polluting than today. Numerous studies were conducted in the 1970s to assess the nature and scale of these effects, many of them in the UK. Their focus was on the local environmental impact of lorries. Reports published by environmental pressure groups catalogued the environmental damage they were causing and demanded government action to contain the 'lorry menace'. Campaigners were particularly alarmed by official forecasts that freight traffic volumes would continue to grow steeply for the foreseeable future. In the UK, the government responded by setting up an inquiry to examine the effects of lorries on the environment and explore ways of minimizing them (Pettit, 1973). This led to the formation of the Lorries and the Environment Committee, an organization which between 1974 and 1979 published several reports on ways of rationalizing the movement of freight by road. The UK government, nevertheless, felt it necessary to commission a much wider investigation of 'lorries, people and the environment'. The report of this inquiry (Armitage, 1980) provided a useful review of lorry-related externalities, the causes of road freight growth and the options for mitigating its environmental effects. It was preoccupied, however, with local planning and regulatory issues, and antagonized environmental groups at the time by recommending an increase in the maximum gross lorry weight from 32 to 44 tonnes. At an international level, the OECD (1982) also published a report on the effects of heavy trucks on the environment and explored ways in which they might be reduced.

Advances in vehicle technology and tightening regulations on emission levels gradually reduced transport externalities per vehicle-km. It was recognized, however, that much of the environmental improvement being achieved at the individual vehicle level was being eroded by the underlying growth in road freight traffic (Adams, 1981; Whitelegg, 1995). Reducing the environmental burden imposed by freight transport would, therefore, entail much more than improved fuel efficiency and lower exhaust emissions. More radical measures to contain the growth of road freight traffic would be required. This might be difficult to achieve, however, without jeopardizing future economic growth. Bennathan, Fraser and Thompson (1992: 7) had established, for a sample of 17 developed countries, that 'the partial elasticity of ton-kilometres by road with respect to GDP [was] about unity (1.02)'. This meant that road freight traffic was growing almost exactly in line with the economy.

Individual sectors of the economy, however, were experiencing rates of freight traffic growth well above the average and faster than the rate at which output was growing. Paxton (1994) showed how wider sourcing of food products was increasing the demand for freight transport or what she called 'food miles'. Around the same time, Böge (1994) conducted a much-publicized study in Germany of the amount of road transport generated by the production and distribution of a pot of strawberry yoghurt. By mapping the supply chains of all the ingredients and components contained in this product she was able to demonstrate that for every pot of yoghurt sold in a German supermarket, a truck had to travel nine metres. She went on to assess the environmental impact of all the related freight transport, using this case study to illustrate how the logistical requirements of even a fairly cheap basic product could be responsible for significant amounts of pollution and noise.

These and other studies highlighted the need for more research on the process of road freight traffic growth and the extent to which it could be influenced by public policy interventions. This need was addressed by a plethora of studies conducted in several countries during the 1990s. These studies examined, to varying degrees, three methods of decoupling economic growth from road freight traffic levels: reducing the transport intensity of the economy (generally defined as the ratio of road tonne-kms to GDP), altering the freight modal split (to displace freight on to alternative modes) and improving vehicle utilization (to reduce the ratio of vehicle-kms to tonne-kms). This three-pronged approach became known as 'avoid, shift, improve' (ASI) and has since been widely deployed in green logistics research. Table 1.1 lists some of the major freight-rationalization studies undertaken during the 1990s and shows which of the three decoupling options they considered.

TABLE 1.1 Freight transport rationalization studies conducted during the 1990s

Author/organization	Study area	Date	Modal split	Transport intensity	Vehicle utilization
Hey *et al* EURES/ Greenpeace	Europe	1992	*	*	*
Peeters/Werkgroep 2000	Netherlands	1993	*		*
DIW/ifeu/IVA/HACON	Germany	1994	*		*
Royal Commission on Environmental Pollution	UK	1994	*	*	*
Plowden and Buchan/Civic Trust	UK	1995	*	*	*
Bleijenberg/CE	Europe	1996	*	*	*
Holman/T&E	Europe	1996	*	*	*
Pastowski/Wupperthal Institute	Germany	1997		*	
Schipper *et al*/International Energy Agency	OECD	1997	*	*	*

Towards the end of the 1990s, the late Lee Schipper extended the ASI framework to include the carbon content of the energy used in transport (Schipper and Marie-Lilliu, 1999). His ASIF framework, adopted by the IPCC (2014), assesses opportunities for reducing the level of transport *activity* (ie avoid), altering the modal *structure* of the transport system (ie shift mode), reducing the energy *intensity* of the transport operation (ie improve efficiency) and cutting the carbon content of the *fuel*.

During the 1990s research on the greening of freight transport began to adopt a broader logistical perspective, partly in recognition of the fact that the restructuring of companies' logistical systems was one of the main drivers of freight traffic growth. Research by McKinnon and Woodburn (1996), McKinnon (1998) and Cooper, Black and Peters (1998) identified a series of logistics and supply chain trends responsible for freight traffic growth. The nature of the relationship between these trends and freight traffic growth in different countries and sectors was subsequently investigated by two

European Commission-funded projects called REDEFINE and SULOGTRA. As discussed in Chapter 18, there was much interest among public policy makers around the late 1990s/early 2000s in the potential for decoupling freight traffic growth from general economic growth (European Commission, 2001). Ironically, over the previous decade the link had been broken in Europe, with freight tonne-kms growing at a faster rate than the EU economy as a whole. The policy aim, however, was to decouple these variables in the opposite direction. Evidence of this 'positive' form of decoupling had begun to emerge in some countries, such as the UK and Finland, stimulating research into the reasons for it occurring (Tapio, 2005; McKinnon, 2007). If the underlying growth in freight movement were to slacken, it would be easier for governments to make logistics more environmentally sustainable (DETR, 1999a). The main goal, however, should be to decouple increases in freight-related externalities, rather than increases in freight traffic volumes, from economic growth. This involves manipulating a series of key logistical parameters, each of which is amenable to public policy initiatives. In a later section of this chapter, we present an analytical framework built around these key parameters, which has its heritage in the earlier studies outlined above and can serve as a model for the greening of logistics.

In this section we have charted the development of research into ways of reducing freight-related externalities at national and international levels. It is in towns and cities, however, where high freight traffic and high population densities coincide, that these externalities are at their greatest. A separate strand of green logistics research has focused on the specific issues raised by the distribution of goods in urban areas. As a recent review by Arvidsson *et al* (2013) demonstrates, much of the research done on road freight efficiency has had a strong urban focus.

City logistics

The first major studies of the distribution of freight in urban areas were conducted in the 1970s and early 1980s. Major cities such as London and Chicago commissioned, usually for the first time, surveys of freight movements, while academics began to research specific aspects of urban freight systems, often exploiting the new supply of urban freight data. This research was comprehensively reviewed by Ogden (1992), who identified the 'minimization of adverse effects' as one of the three main issues addressed by goods movement research. Many of the urban freight studies conducted at this time, especially in the United States, emphasized the other two issues of 'economic development' and 'transport efficiency'. Efficiency and environmental concerns converged in one of the most extensively researched urban freight topics at the time, namely the 'small order problem' (Jackson, 1985). The dispersal of freight in small consignments by poorly loaded vehicles to a multitude of locations was found to impose high economic and environmental costs. Numerous studies were then done to find ways of consolidating loads and, thereby, cut traffic levels, energy use, emissions and costs (eg Rushton, 1979). The most popular idea was to set up transhipment or consolidation centres in and around urban areas where inbound loads could be disaggregated and outbound loads aggregated. Feasibility studies at that time, particularly in the UK, suggested that the insertion of these centres into companies' supply chains would be disruptive, expensive and would yield, at best, only modest environmental benefit (Button and Pearman, 1981).

The 1980s and early 1990s was a relatively fallow period for research on urban freight, partly because funding for large-scale urban goods transport studies dried up. Ogden (1992: 12) suggests that 'the decade of the 1980s may be described as a time of consolidation. While many of the aspirations of the early 1970s did not come to fruition, there has been at least in some quarters a clearer recognition of the role of freight, and ways of accommodating it'. Many of the environmental problems associated with the urban movement of freight in heavy lorries remained unsolved, however (Civic Trust *et al*, 1990). Partly for this reason, there was a major revival of interest in the subject during the 1990s and 2000s, supported by multinational research initiatives in Europe. As part of the European COST 321 programme, the effectiveness of a range of urban freight measures on 'ecology, traffic, economy and safety' was assessed across 28 cities in 11 European countries (European Commission, 1998). More recently EU-funded programmes such as BEST Urban Freight Solutions (BESTUFS) and STRAIGHTSOL have fostered research and dissemination in this field. Japanese researchers have also been particularly active in the study of city logistics (eg Taniguchi *et al*, 2001). Greater priority is now being given to environmental issues in urban freight research, despite the fact that, over the past 30 years, the tightening of pollution and noise limits on new vehicles has greatly reduced localized freight-related externalities while much freight-generating activity has migrated from inner urban areas to suburban and out-of-town locations. Other new strands in urban freight research in the past decade include the increase in the diversity and extent of service-related transport to commercial and residential locations, as well as the growing importance of home deliveries. The economic contribution of goods and service transport to major cities is also gaining wider recognition. This is beginning to result in a reconsideration of the priority given to urban freight transport in decisions concerning the allocation of road space and transport investment. There has also been a resurgence of interest in the scope for urban consolidation centres in specific sectors, including retailing and construction, based on new business models (Browne *et al*, 2005b). A landmark symposium on city logistics research was organized jointly by the United States government and European Commission in 2013, bringing together around 50 specialists in the field from Europe and North America to take stock of the impressive range of studies undertaken in the field and to identify 'hot topics' for future research (Transportation Research Board, 2014).

Reverse logistics

Jonathan Weeks, a former chairman of the UK Institute of Logistics, defined logistics as 'the movement of materials from the earth through production, distribution and consumption back to the earth'. This incorporates the return of waste product and packaging for reuse, recycling and disposal, an activity that is now regarded as a key part of green logistics. Research interest in this topic developed in the early 1990s when governments and businesses began to reform the management of waste, reducing the proportion of waste material being dumped in landfill sites or incinerated and increasing the proportion that was recycled and reused. This fundamentally transformed the logistics of waste management and stimulated research interest in the return flow of product back along the supply chain. In a White Paper prepared for the Council of Logistics Management, Stock (1992) set out an agenda for future academic research on this topic. He used available statistical data from the United States to highlight the scale of the problem, assessed the current state of knowledge and identified a series of research issues requiring further investigation. An early contribution by Jahre (1995) showed how the basic principles of logistics, such as those of postponement and speculation, could be applied to the return flow of waste from homes. In their state-of-the-art review some years later, however, Carter and Ellram (1998) lamented the lack of theory development and empirical research in this field. They identified a series of 'drivers and constraints' in reverse logistics and suggested that they become the foci of future 'theoretically grounded' research (p 99). Over the past decade, there have been many more theoretical and analytical contributions to the reverse logistics literature (eg Dekker *et al*, 2004; Bernon *et al*, 2011; Bai and Sarkis, 2013), reflecting a greater emphasis on the optimization of return flows of waste and other products. Rather than examine the return movement of products in isolation, researchers are increasingly regarding supply chains as 'closed loops' and looking at ways of integrating the management of product flows in different directions. As Guide *et al* (2003: 3) explain, 'In the forward supply chain, the customer is typically the end of the process. However, a closed-loop supply chain includes the returns processes and the manufacturer has the intent of capturing value and further integrating all supply chain activities'. Most of these activities are commercially driven, though by promoting the recovery and reuse of products, many also yield environmental benefits.

Corporate environmental strategies

Prior to the 1980s, companies' environmental initiatives were typically ad hoc and reactive, often implemented in response to government regulations or public protest. It thereafter became more common for businesses to formulate environmental strategies based on wide-ranging assessments of their impact on the environment. In a sample of 133 US firms surveyed by Murphy and Poist (1995: 16), 61 per cent had a 'formal or written environmental policy', almost three-quarters of which had been introduced since 1980. With such a strategy in place, the efforts of different departments to 'green' their operations could be more effectively coordinated and the business as a whole could become more proactive in environmental management. New international standards, such as ISO 14000, were introduced to accredit companies' environmental programmes and help customers ensure that suppliers had the required environmental credentials. As with quality management standards, however, this accreditation became more of a business 'qualifier' than a competitive differentiator. For a company wanting to extract more value from the adoption of green practices it was necessary to make the environment a key element in the business model.

It is against this background that companies have been developing environmental strategies for their logistics operations. Some companies claim to have had a specific environmental policy for logistics for many years; a survey by PE International (1993) in the UK, for example, found that 19 per cent of companies had such a policy. The survey by Murphy and Poist (1995), undertaken around the same time, may have found that 60 per cent of logistics managers belonged to companies 'with formal or written environmental policies' (p 16), but these managers reported that they had only a 'minor role in both policy formulation and implementation'. This ran counter to the view of Wu and Dunn (1995: 20) that 'because the nature of logistics management is cross-functional and integrative and since so many logistical activities impact on the environment, it makes sense for logistics managers to take the initiative in this area'. In their seminal paper they went on to illustrate the numerous ways in which a company could reduce the environmental impact of each stage in its value chain, extending from the procurement of supplies to the after-sales service. This outlined the scope of what they termed 'environmentally responsible logistics' (ERL).

More recent surveys have revealed the widening diffusion of green logistics/supply chain strategies across the business world and suggested that transport and distribution activities have a prominent role in these strategies (Insight, 2008; Eyefortransport, 2007). The Insight survey of 600 supply chain professionals across Europe, the United States and Japan in 2008 found that an average of 35 per cent of their companies had a green supply chain strategy, with this proportion rising to 54 per cent for firms with an annual turnover in excess of $1 billion. Of the various activities covered by these strategies, logistics was the one that the largest proportion of companies (81 per cent) had modified for environmental reasons (Insight, 2008).

These surveys have also provided empirical support for a claim frequently made in the academic literature (eg Wu and Dunn, 1995; Aronsson and Huge-Brodin, 2006) that, in many spheres of logistics management, economic and environmental objectives are closely aligned. Research by Rao and Holt (2005: 912) suggested that 'if they green their supply chains not only would firms achieve substantial cost savings, but they would also enhance sales, market share, and exploit new market opportunities to lead to greater profit margins'. A more recent analysis of a large US database has confirmed that adopting 'environmentally and socially responsible practices' in supply chain management does help companies to improve their financial performance (Wang and Sarkis, 2013). It seems too that, reversing the causality, those firms that most effectively apply logistics best practice in terms of economic efficiency and customer service are also the best placed to green their logistics operations. In an international questionnaire survey of 306 logistics managers, Goldsby and Stank (2000: 199) found 'strong empirical evidence of a positive relationship between overall logistics competence and the implementation of ERL'.

This does not necessarily mean, however, that applying commercial best practice in logistics automatically minimizes its environmental impact. As companies do not have to bear the full cost of this impact (for reasons discussed in Chapter 4), the cost and service trade-offs that logistics managers make generally underestimate environmental effects. The resulting decisions may optimize logistics operations in economic terms to the detriment of the environment. Numerous studies have illustrated how practices such as the centralization of inventory (Matthews and Henrickson, 2003), just-in-time (JIT) replenishment (Rao, Grenoble and Young, 1991; Whitelegg, 1995; Bleijenberg, 1996) and wider sourcing of supplies (Garnett, 2003) can carry a significant environmental penalty. It has frequently been argued that if companies factored all environmental costs into logistical trade-off analyses more sustainable systems would be created, characterized by more dispersed inventory, longer order lead times and more localized sourcing.

Other research, however, has challenged the conventional view that inventory centralization, JIT and globalization are inevitably bad for the environment. McKinnon and Woodburn (1994) and Kohn and Huge-Brodin (2008), for instance, contend that the centralization of distribution systems can reduce the environmental impact of logistics by, *inter alia*, consolidating freight flows. Garreau, Lieb and Millen (1991), Tracey *et al* (1995) and the Department of the Environment, Transport and the Regions (1999b) showed how companies can implement JIT in ways that do not generate much additional freight traffic, while Smith *et al* (2005) and others assert that minimizing the distance goods travel from suppliers need not minimize their environmental footprint when measured on a life-cycle basis.

Green supply chain management

Green (or sustainable) supply chain management (GSCM) can be defined as the 'alignment and integration of environmental management within supply chain management' (Klassen and Johnson, 2004). It is based on the recognition that an individual firm's environmental impact extends well beyond its corporate boundaries. The origins of GSCM can be traced back to two functional areas in which companies' environmental responsibilities interfaced with external agencies: green purchasing/supply and reverse logistics.

Companies applying green principles to their internal operations naturally wish to ensure that their purchases of goods and services come from suppliers that also meet certain minimum environmental standards. At the very least, they want to minimize any environmental liability associated with purchased goods and services (Sarkis, 2000). Lamming and Hampson (1996: s61) envisaged 'the prospect of environmental soundness becoming a recognized feature of a supplier's overall performance'. A US survey by Gavaghan *et al* (1998) examined the extent to which companies were using four sets of environmental criteria in assessing suppliers, under the headings of regulatory compliance, environmental management systems, eco-efficiency and green design. The greening of purchasing activities has since become a fertile area of research considering issues such as the environmental criteria for supplier selection and environmental accreditation (eg Genovese *et al*, 2013). Walton, Handfield and Melnyk (1998), Bowen *et al* (2001), Seuring and Muller (2008) and others adopted a broader supply management perspective on the subject, discussing ways in which companies can work with their suppliers to improve their joint environmental performance. A key element in these collaborative initiatives is the physical movement of products between supply chain partners. In their definition of 'green supply' Vachon and Klassen (2006: 797), for example, include 'cooperation between organizations to minimize the logistical impact of material flows'.

Some authors have argued that research on GSCM has its origin in the reverse logistic studies undertaken in the 1990s. Van Hoek (1999), for example, saw the main locus of environmental research in logistics as being within the reverse channel for waste products, and advocated the extension of this research effort to environmental management of the whole chain from raw material source to after-sales service. The detailed review of literature on green supply chain management undertaken by Srivastava (2007) also exhibits a strong bias towards reverse logistics, devoting only a brief paragraph to the environmental effects of 'forward logistics' and giving 'logistics and distribution' a fairly subordinate role within his GSCM framework. This framework, like that of Sarkis (2003), is based on a broad definition of GSCM that encompasses product design, all stages of manufacturing and distribution and all aspects of reverse logistics. Physically distributing products is seen as only one component in a much more broadly defined GSCM system. It is worth recalling, however, that in the survey by Insight (2008) four-fifths of the companies that were greening their supply chains had instigated measures related to logistics, a much higher proportion than were modifying other elements in the chain.

Detailed reviews of the academic literature on green/sustainable supply chains can be found in Carter and Easton (2011) and Min and Kim (2012). Carter and Easton examined the content of 80 papers published between 1991 and 2010 mainly in seven specialist logistics and supply chain journals. Min and Kim conducted a more extensive review of 67 journals and found 519 relevant papers, revealing the true scale, diversity and maturity of this field. As its scope has widened it has developed greater analytical depth. Srivastava (2007) found that a diverse range of mathematical and statistical techniques have been applied to the analysis of GSCM. Researchers have also adopted and adapted principles and techniques from the long-established field of life cycle analysis (LCA) in assessing environmental impacts across the 'end-to-end' supply chain (eg Faruk *et al*, 2001; Browne *et al*, 2005a; Rizet *et al*, 2012). Recent developments in the carbon auditing of supply chains have drawn heavily on LCA (Carbon Trust, 2007), and many new software tools (or 'carbon calculators') have been constructed to help companies and researchers to analyse carbon footprints at supply chain, company, process, facility and even product levels. The feasibility, cost and usefulness of carbon auditing end-to-end supply chains at a product level have, nevertheless, been questioned (McKinnon, 2010).

Green logistics: Rhetoric and reality

A large body of survey evidence has accumulated to show that companies around the world are keen to promote their green credentials through the management of logistics. It is difficult to gauge, however, how far this reflects a true desire to help the environment as opposed to enhancing public relations. In concluding their assessment of the 'maturity' of the green supply chain, Insight (2008: 7) argues that 'when companies take action, they are typically taking the easy route of reputation and brand protection on green messaging'. This scepticism is echoed by Gilmore (2008) who argues that 'the corporate support for green is as much for the potential to sell new products and technologies as it is about saving the planet'. Research by Wolf and Seuring (2010: 99) also found 'limited evidence of environmental issues constituting a buying criterion' for third-party logistics (3PL) services, with the 'traditional performance objectives, such as price, quality and timely delivery', continuing to dominate the purchasing decision.

On the other hand, surveys of the CEOs of large global 3PLs indicate that they 'have made important commitments to environmental sustainability improvements' over the past few years, partly because of an 'organizational desire to do the right thing with respect to environmental concerns' but also in response to 'pressures from customers' (Lieb and Lieb, 2010: 532). A more recent survey of 10 logistics service providers (LSPs) by Colicchia *et al* (2013: 208) also found 'customers to be a major driver' but noted that 'sometimes LSPs complain about a lack of real commitment from customers' to environmental issues. Largely independently of their customers, many of the world's leading LSPs have declared reasonably ambitious targets for reducing the carbon intensity of their operations over a 10–15-year period (McKinnon and Piecyk, 2012).

Surveys have enquired about the key drivers behind company initiatives to green their logistical systems and supply chains (Table 1.2). Although the survey methodologies, sample sizes and composition and questionnaire formats have varied, the same general messages have emerged, suggesting a strong emphasis on corporate image, competitive differentiation, cost saving and compliance with government regulation. Rather curiously, none of these

TABLE 1.2 Key drivers for the greening of logistics and supply chains % of companies mentioning the driver

Eyefortransport (2007)	Aberdeen Group (2008)	Insight (2008)
'Key drivers for instigating green transport/logistics'	'Top five pressures driving the green supply chain'	'Main drivers for green logistics'
Improving public relations (70%)	Desire to be thought leader in sustainability (51%)	Optimize logistics flow (18%)
Improving customer relations (70%)	Rising cost of energy/ fuel (49%)	Improve corporate image (16%)
Part of their corporate responsibility agenda (60%)	Gaining competitive advantage/ differentiation (48%)	Reduce logistics costs (15%)
Financial return on investment (60%)	Compliance with current/ expected regulation (31%)	Achieve regulatory compliance (15%)
Government compliance (60%)	Rising cost of transportation (24%)	Satisfy customer requirements (14%)
Decreasing fuel bills (60%)		Differentiation from competitors (11%)
Increasing supply chain efficiency (55%)		Develop alternative networks (10%)
Decreasing risk (50%)		
Improving investor relations (38%)		

surveys makes explicit reference to the need to protect the environment. In business terms, after all, the most fundamental of all green objectives should be to maintain a physical environment that can support a high level of economic activity in the longer term. On the other hand, it is very encouraging that companies responding to these surveys recognize that a healthy stream of conventional business benefits can flow from the greening of logistics (Table 1.3).

Green logistics is now regarded as good business practice and something that can have a positive impact on many financial and operational metrics.

TABLE 1.3 Benefits of greening supply chains
% of companies mentioning the benefit

Aberdeen Group (2008)	Insight (2008)	APICS/PwC (2014)
'Best-in-class goals for sustainability initiatives'	'Benefits of the green supply chain'	'Value realized from sustainable supply chain initiatives over past 2 years'
Reduce overall business costs (56%)	Improve brand image (70%)	Cost reduction (43%)
Enhance CSR (54%)	Satisfy customer requirements (62%)	Environmental impact (reductions in waste, carbon, energy savings etc) (35%)
Improve profits (48%)	Differentiate from competitors (57%)	Customer satisfaction (25%)
Reduce waste/improve disposal (43%)	Reduce logistics costs (52%)	Revenue gains (19%)
Improve visibility of green supply drivers (41%)	Establish a competitive advantage (47%)	Compliance improvements (19%)
Increase use of recyclables/reusables (37%)	Optimize logistics flow (40%)	Reduction in supply risk (17%)
Improve fuel efficiency (35%)	Expand to new markets (38%)	Market share gains (16%)
Reduce emissions (33%)	Optimize manufacturing (35%)	Employee acquisition, engagement and retention (9%)
Win new customers/develop new products (26%)	Reduce manufacturing costs (32%)	Brand protection and license to operate (8%)
Reduce use of toxic materials (19%)	Other (2%)	Market size gains (6%)
Improve employee satisfaction (9%)		None (22%)

In the most recent of the surveys quoted in Table 1.3 a significantly higher proportion of the 162 US businesses responding (a third of which have annual sales in excess $1 billion) had 'realized value from sustainable supply chain initiatives' in the form of cost savings than from their environmental impact (PwC/APICS, 2014: 32). The same study, however, also found firms encountering four major challenges to the implementation of these initiatives, each reported by 38–39 per cent of the respondents: lack of internal leadership and resources, inability to measure the 'impact on shareholder value', confusion about the scope of the initiatives and related 'company goals' and a lack of demand for these initiatives from customers. So, although corporate momentum is building for the greening of supply chains, there are still some major obstacles to be overcome.

Future scenarios

This chapter has so far reviewed green logistics research past and present. In recent years several studies have considered how the greening of companies' supply chains will progress over the next few decades. PwC and the Supply Chain Management Institute (2009), for example, looked 20 years ahead and asked how 'supply chains will evolve in an energy-constrained, low-carbon world'. Partly on the basis of a real-time Delphi survey of 48 experts in 20 countries they conclude that cutting carbon emissions will be a greater challenge for logistics managers than maintaining an adequate supply of fuel. By 2030, supply chain design and the location of logistics facilities will be strongly influenced by the cost of energy and carbon. Christopher (2011) also anticipates that the availability of water will become a key supply chain driver in some sectors.

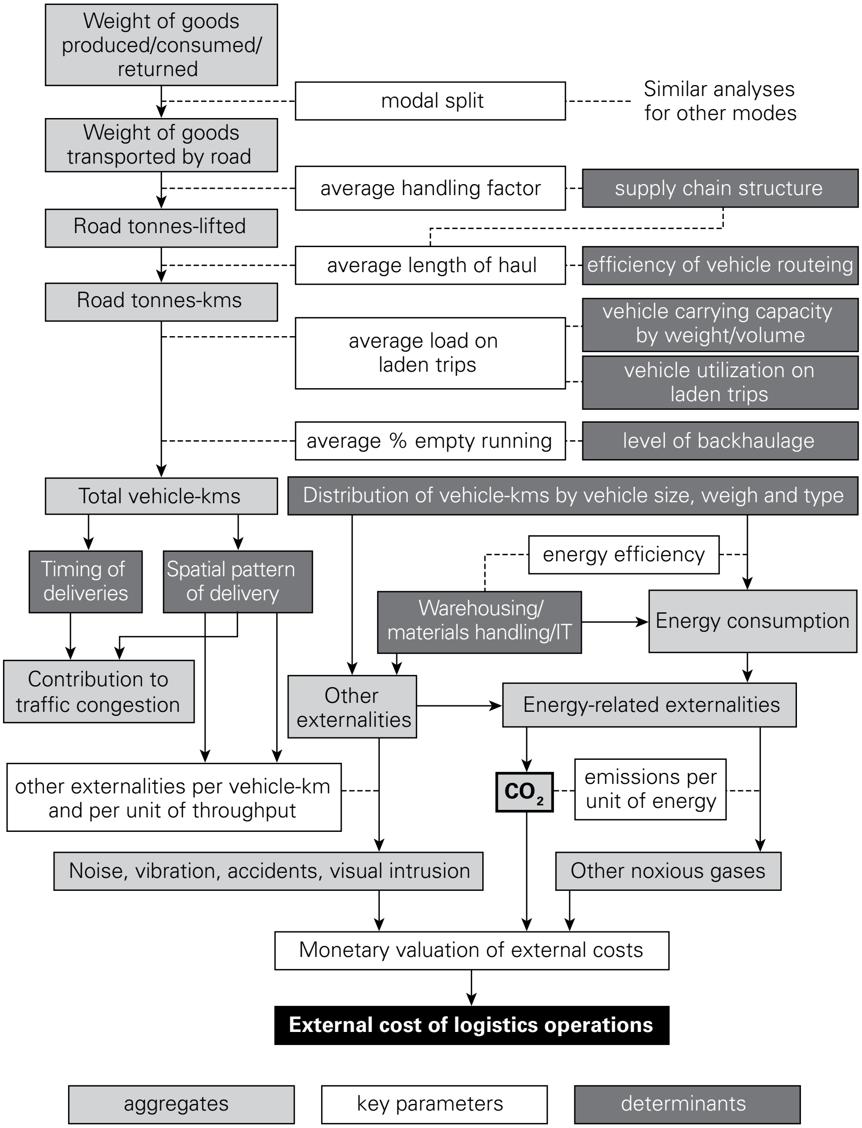
The environment also features very prominently in the set of five scenarios of life in 2050 constructed by the logistics company Deutsche Post/DHL (2012). One scenario, entitled 'mega-efficiency in mega-cities', is characterized by new, more sustainable urban structures, green growth and high carbon efficiency in production and logistics. At the other extreme, the 'untamed economy – impending collapse' scenario envisages 'unchecked consumption', 'rejection of sustainable development', a 'massive increase in demand for logistics and transport services' and a world of 9 billion people heading for an ecologically catastrophic 6°C temperature rise by 2100. The greening of logistics over the next 40 years, as part of a more general drive for sustainability, should help to minimize the risk of such a scenario materializing.

A series of postscripts has been included in this edition of the book which discuss the possible impact of a series of developments that may have a major impact on green logistics over the next few decades: 3D printing, distribution by drone (or 'autonomous transport'), the physical internet and the concept of 'peak freight'.

A model for green logistics research

A model has been devised to map the complex relationship between logistical activity and its related environmental effects and costs (Figure 1.2). These effects and costs mainly arise from freight transport operations and, for this reason, most of the boxes and links in the diagram are associated with the

FIGURE 1.2 Analytical framework for green logistics



movement of goods. Reference is also made, however, to externalities from warehousing, materials handling and logistics IT activities. The model can be applied equally to the outbound movement of goods (forward logistics) and the return flow of products back along the supply chain (reverse logistics). In essence it decomposes the relationship between the material outputs of an economy and the monetary value of the logistics externalities into a series of key parameters and statistical aggregates. This relationship pivots on a set of nine key parameters:

- Modal split: the proportion of freight carried by different transport modes. Following this split, subsequent parameters need to be calibrated for particular modes. As road is typically the main mode of freight transport within countries, the rest of Figure 1.2 has been defined with respect to this mode.
- Average handling factor: this is the ratio of the weight of goods in an economy to freight tonnes-lifted, allowing for the fact that, as they pass through the supply chain, products are loaded onto vehicles several times. The handling factor serves as a crude measure of the average number of links in a supply chain.
- Average length of haul: this is the mean length of each link in the supply chain and essentially converts the tonnes-lifted statistic into tonne-kms.
- Average payload on laden trips and the average per cent empty running are the two key vehicle utilization parameters. Average payload is normally measured solely in terms of weight, though as the average density of freight is declining, for reasons discussed in Chapter 11, and an increasing proportion of loads is volume- rather than weight-constrained, it would be helpful to measure the physical dimensions of freight consignments. Very little data is available, however, to permit a volumetric analysis of vehicle loading (McKinnon and Leonardi, 2009).
- Energy efficiency: defined as the ratio of distance travelled to energy consumed. It is a function mainly of vehicle characteristics, driving behaviour and traffic conditions.
- Emissions per unit of energy: the quantity of CO_2 and noxious gases emitted per unit of energy consumed can vary with the type of energy/fuel, the nature of the engine converting this energy into logistical activity (such as movement, heating, refrigeration, IT) and exhaust filtration systems. For consistency, full well-to-wheel assessments should be made of the various pollutant emissions, wherever possible.
- Other externalities per vehicle-km and per unit of throughput: not all logistics-related externalities are a function of energy consumption. Allowance must also be made for other environmental effects such as noise irritation, vibration and accidents. This can be expressed either

with respect to vehicle-kms in the case of transport, or with reference to the throughput of warehouses, terminals etc.

- Monetary valuation of externalities: the final stage in the framework converts physical measures of logistics-related externalities into monetary values. Money then becomes the common metric against which the environmental effects can be compared. This valuation also makes it possible to assess the extent to which environmental costs are recovered by the taxes imposed on logistical activity.

By altering these nine critical parameters, companies and governments can substantially reduce the environmental impact of logistics. Businesses devising green logistics strategies and government ministries developing sustainable logistics policies need to exploit this full range of parameters rather than rely on a few narrowly defined initiatives. As the 'determinant' boxes in Figure 1.2 illustrate, modifying the parameters requires different levels of logistical decision making. McKinnon and Woodburn (1996) differentiated four levels:

- Strategic decisions relating to numbers, locations and capacity of factories, warehouses, shops and terminals.
- Commercial decisions on product sourcing, the subcontracting of production processes and distribution of finished goods. These establish the pattern of trading links between a company and its suppliers, distributors and customers.
- Operational decisions on the scheduling of production and distribution that translate the trading links into discrete freight flows and determine the rate of inventory rotation in nodes across the supply chain.
- Functional decisions relating to the management of logistical resources. Within the context defined by decisions at the previous three levels, logistics managers still have discretion over the choice, routeing and loading of vehicles and operating practices within logistical facilities.

There has been a tendency for firms to confine green initiatives to the bottom end of this decision-making hierarchy where they usually yield economic as well as environment benefits. These functional-level initiatives typically focus on truck fuel efficiency, backloading, vehicle routeing and energy conservation in warehouses. Although they are very welcome, much of their environmental benefit can be offset by the effects of higher-level strategic and commercial decisions, relating for example to inventory centralization or wider sourcing, which make logistics systems more transport intensive and hence environmentally intrusive. The challenge is now for companies to instil green principles into the strategic planning of logistics and coordinate environmental management at all four levels of decision making. As Aronsson and Huge-Brodin (2006: 414) observe, there has been a 'lack of theories and models for connecting different logistics decisions on different hierarchical decision levels to each other and to their environmental impact'.

Outline of the book

The green logistics framework in Figure 1.2 provides a structure for this book. Each of the nine key parameters is addressed by at least one chapter. Some chapters discuss more general issues that underpin efforts by companies and governments to make logistics more environmentally sustainable. The chapters have been grouped into five sections.

The remaining chapters in Part One assess the environmental effects of logistics, consider how they can be evaluated in monetary terms and ask to what extent these environmental costs are covered by taxation. In the first of these chapters, Piecyk, Cullinane and Edwards look at various ways in which freight transport adversely affects the environment over different geographical scales. They also consider the imposition of environmental standards on freight transport and show how environmental impacts can be measured at both macro and micro levels. This measurement theme continues into the next chapter, where Piecyk explains how carbon emissions from logistical activity can be audited at company, supply chain and individual product levels. Standard procedures are outlined and a case study used to show how a company can assess the carbon footprint of its road freight transport operation. The final chapter in this part, by Piecyk, McKinnon and Allen, deals with the monetary valuation of the environmental, infrastructural and congestion effects of freight transport, using case studies from different countries to illustrate the application of the 'polluter pays' principle.

Part Two takes a strategic perspective on green logistics. Chapter 5, by Piecyk and Björklund, examines the links between CSR and green logistics. The following chapter, by Harris, Sanchez-Rodrigues, Naim and Mumford, reviews the current state of knowledge on the design of freight transport networks and location of the key nodes within supply chains. It shows how environmental metrics can be incorporated into the strategic design of logistics networks and assesses the impact of uncertainty on the planning of freight transport systems. Another strategic determinant of the environmental effect of logistics is the choice of transport mode. In Chapter 7, Woodburn and Whiteing consider the environmental benefits of shifting freight from road to rail and waterborne transport and then review, with the help of case studies, what governments, freight operators and shippers can do to promote the use of these greener modes. In Chapter 8, McKinnon, Allen and Woodburn also adopt a cross-modal perspective in forecasting the future potential for greening trucks, vans, freight trains, aircraft and ships. They focus on opportunities for technical improvements that would allow freight to be carried in larger quantities, more energy efficiently and with less pollution per tonne-km. The concluding chapter in this part, by Baker and Marchant, assesses the environmental impact of warehousing and examines the broad range of design, construction and operational measures that can be applied to minimize this impact and possibly even create, in the longer term, carbon-neutral warehousing.

Part Three takes more of an operational perspective on greening logistics. It starts with the contribution by Eglese and Black, which begins by defining the vehicle routeing and scheduling problem (VRSP) and then explores some of the problems that arise when trying to solve this problem in the real world, such as dealing with specified time windows, backhauling, mixed vehicle fleets and traffic congestion. This is followed by a chapter by McKinnon on ways of improving vehicle utilization to achieve both environmental and economic savings. He considers the various ways of measuring vehicle fill and the logistical trade-offs that companies must make in trying to raise vehicle load factors and cut empty running. Chapter 12, by McKinnon, explores the opportunities for improving fuel efficiency in the road freight sector. He argues that companies need to deploy a broad range of technical, behavioural and operational measures within properly coordinated fuel management programmes. The concluding chapter in this part, by Leonardi, Cullinane and Edwards, weighs up the costs and benefits of freight operators switching from conventional fossil fuels to alternative energy forms such as biofuels, hydrogen, natural gas and battery power. Much of their chapter focuses on the sustainability of biofuels, an issue that is proving particularly contentious.

In Part Four authors address four key issues that have generated a good deal of discussion in the field of green logistics in recent years. In recognition of the fact that much of the environmental impact of logistics is concentrated in urban areas, the chapter by Allen, Browne and Holguín-Veras reviews a range of initiatives, such as the establishment of consolidation centres and creation of environmental zones that can improve the sustainability of freight deliveries in towns and cities. Chapter 15 by McKinnon, Wang, Potter and Edwards considers how the development of e-commerce, at both the business-to-business (B2B) and business-to-consumer (B2C) levels, is influencing the environmental footprint of logistics operations. Cherrett, Maynard, McLeod and Hickford then address a series of operational issues in the expanding field of reverse logistics. Their chapter examines the various options for recycling, refurbishing and reusing waste products, assesses the impact of waste regulations and considers how the return flow of waste can be made more environmentally sustainable. The 'food miles' debate, which has extended well beyond academic circles into the public domain, is comprehensively reviewed by Garnett in Chapter 17. She asks whether, in environmental terms, 'further is worse' and shows how the issue is much more complex than is generally suggested in the media.

In Part Five, the final chapter provides a public policy perspective on green logistics. McKinnon reviews the objectives of sustainable logistics policies and the various measures that governments can use to influence the key parameters in the green logistics framework (Figure 1.2) and thereby decouple the environmental effects of logistics from the growth of the economy.

As the free market on its own is unlikely to deliver the necessary level of environmental improvement, particularly in terms of climate change, governments will play a critical role in the future development of green logistics.

This new edition of the book concludes with a series of short postscripts on the possible impact of a series of recent developments on green logistics written by the editors: distribution by drones, 3D printing, the physical internet and the concept of ‘peak freight’. Each of these developments has the potential to reduce logistics’ impact on the environment, though it is too early to tell what their net effect may be.

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02

Assessing the external impacts of freight transport

MAJA PIECYK, SHARON CULLINANE and JULIA EDWARDS

Introduction

Logistics is responsible for a variety of externalities, including air pollution, noise, accidents, vibration, land-take and visual intrusion. This chapter examines these various externalities and discusses how their impact can be assessed. As climate change is now considered to be the most serious environmental challenge facing mankind, the main focus will be on greenhouse gas (GHG) emissions from freight transport.

In measuring the environmental effects of logistics it is important to distinguish first-order and second-order impacts. The first-order environmental impacts are those directly associated with freight transport, warehousing and materials-handling operations. Second-order impacts result indirectly from these logistics operations and take various forms. For instance, advances in logistics have facilitated the process of globalization so that goods are now sourced from previously little-developed parts of the world. Partly to accommodate the consequent growth in freight traffic in such areas, governments have expanded transport infrastructure and this has often encroached on sensitive environments. The increase in air freight and other traffic resulting from global sourcing is a first-order effect, whereas the increase in infrastructure, such as road building in vulnerable areas, is a second-order effect. In this chapter we concentrate on the first-order impacts and make only brief reference to the wider, second-order effects. Since the majority of the first-order impacts emanate from the transport of goods, rather than their storage and handling, the attention will focus on this activity. Chapter 9 specifically examines the environmental impact of warehousing.

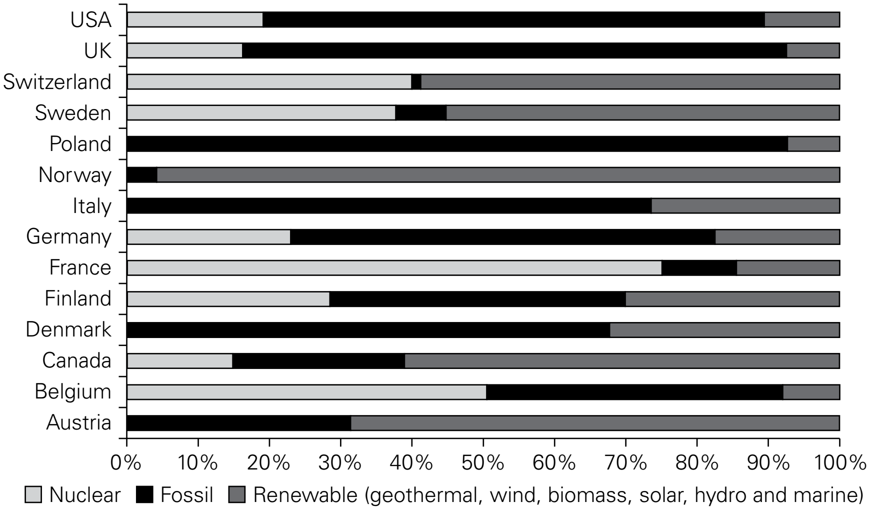
External impacts

Atmospheric emissions

Emissions from freight transport largely depend on the type of fuel used. As discussed in Chapter 13, various alternative fuels now exist. However, the main fuel used by goods vehicles continues to be diesel, with relatively small amounts of freight moved in petrol-engined vans. Trucks and vans emit pollution mainly because the combustion process in their engines is incomplete. Diesel and petrol contain both hydrogen and carbon. If it were possible to achieve perfect combustion, 100 per cent of the hydrogen would be converted into water and all the carbon into CO_2. However, because combustion is not complete, tailpipe emissions of pollutants such as hydrocarbons, carbon monoxide and nitrogen oxides result (Holmen and Niemeier, 2003).

In most countries, relatively small amounts of freight are moved in electrically powered road vehicles or freight trains. In the case of these operations, the pollution arises at the point where the electricity is generated and the nature of that pollution depends on the primary energy source used. In countries such as Norway, France and Switzerland, where only a small proportion of electricity is produced using fossil fuels, the carbon intensity of electrified rail freight services is very low (Figure 2.1). However, other environmental problems associated with, for example, nuclear power generation need to be considered, if the assessment is to include a broader range of externalities. In countries where both electrified and diesel railway

FIGURE 2.1 Electricity production by energy source



SOURCE: Observ'ER (2011)

TABLE 2.1 Standard road transport fuel conversion factors: Direct GHG emissions

Fuel type	Total units used	Units	×	Kg CO_2e per unit	Total
Petrol*		litre		2.2144	
Diesel*		litre		2.6008	
CNG		kg		2.7072	
LPG		litre		1.4929	

* retail station biofuel blend
SOURCE: Defra (2013)

systems are in operation, the carbon intensity of rail freight transport will also depend on the percentage of services operated by the two types of traction. In the UK, for instance, electric traction accounts for around 5 per cent of freight train mileage, whereas 40 per cent of all rail traction in this country is electrified (DECC, 2010).

Diesel and petrol have slightly different environmental impacts as their mix of pollutant emissions varies. Diesel engines emit more CO_2 per unit of energy, but because they are more energy efficient, the overall impact of diesel engines on CO_2 emissions is less than that of an equivalent-sized petrol engine (Schipper and Fulton, 2003). The standard fuel GHG conversion factors for various types of fuel are given in Table 2.1. Diesel engines emit much higher levels of particulate matter and nitrogen oxides than an equivalent petrol-powered engine (Holmen and Niemeier, 2003). It is difficult to measure emissions of particulates precisely, because of their ultra-fine nature. PM10 particles, for instance, have a radius of 10 microns or less (a micron is a hundredth of a millimetre). Measuring these particles when the vehicle is stationary is difficult enough; measuring them under different driving conditions and speeds introduces additional complexities. Calculating the impact of these tiny soot particles on human health presents further problems, although there is growing evidence of their effects on respiratory problems as well as on general morbidity (Pope *et al*, 2002).

The pollutants emitted by transport can be divided into local, regional and global effects (see Table 2.2). Local pollutants remain close to the source of the emission. At the kerbside of major roads, concentrations of the primary pollutants can be two to three times higher than the background urban level, while inside vehicles travelling along major roads, concentrations can be on average five times higher than the background levels (RCEP, 1994). Regional effects can occur far away from the source of the emission

TABLE 2.2 Geographical extent of pollutant effects

Effect	PM	HM	NH_3	SO_2	NOx	NMVOC	CO	CH_4	CO_2	N_2O
Global										
Greenhouse – indirect					X	X	X	X		
Greenhouse – direct								X	X	X
Regional										
Acidification			X	X	X					
Photochemical					X	X	X			
Local										
Health and air quality	X	X	X	X	X	X	X			

PM – particulates, HM – heavy metals, NH_3 – ammonia, SO_2 – sulphur dioxide, NOx – oxides of nitrogen, NMVOC – non-metallic volatile organic compounds, CO – carbon monoxide, CH_4 – methane, CO_2 – carbon dioxide, N_2O – nitrous oxide

SOURCE: Adapted from Hickman *et al* (1999)

and affect wider geographical areas, sometimes spanning several adjoining countries. GHG emissions, on the other hand, affect the global atmosphere. The same pollutants, such as sulphur dioxide or nitrogen dioxide, can have an adverse effect on the environment over differing distance ranges.

We turn first to the global effects as they have become the main cause of environmental concern. This is partly because scientific discoveries over the past two decades have revealed the severity of the climate change problem, but also because tightening controls on the emissions of other noxious gases have eased pollution problems at local and regional levels.

Global effects of atmospheric pollution

According to the United Nations Inter-governmental Panel on Climate Change (UN IPCC, 2013), scientific evidence that human activity is the main cause of global warming is now 'unequivocal', and 'since the last assessment [UN IPCC, 2007], the scientific knowledge gained through observations, theoretical analyses, and modelling studies has continued to increase and to strengthen further the evidence linking human activities to the ongoing climate change' (2013, p 123). It explains that 'greenhouse gases are the gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by the earth's surface, the atmosphere itself, and by clouds' (UN IPCC, 2007, p 82). The greenhouse effect arises because GHGs and some particles in the atmosphere allow more sunlight energy to filter through to the surface of the planet relative to the amount of radiant energy that they allow to escape back up to space. The UN IPCC (1996) lists 27 greenhouse gases. These were combined into six categories in the Kyoto Protocol agreed in December 1997 (United Nations, 1998), namely:

- carbon dioxide (CO_2);
- methane (MH_4);
- nitrous oxides (NOx);
- hydrofluorocarbons (HFC);
- perfluorocarbons (PFC);
- sulphur hexafluoride (SF_6).

Nitrogen trifluoride (NF_3) was added to the list in the second Kyoto Protocol commitment period (2013–2020).

Greenhouse gas emissions are defined as the total mass of a GHG released to the atmosphere over a specified period of time. GHG emissions tend to be reported in carbon dioxide equivalents (CO_2e), which are calculated by multiplying the mass of a given GHG by its global warming potential (GWP). The GWP is a measure of the effects of various GHG emissions relative to those of an equivalent mass of CO_2 over a set time period, normally 100 years. In the UK an official set of GWPs for reporting purposes is published by Defra based on international guidance produced by the IPCC (Table 2.3). From the values in Table 2.3, it can be seen that, for example, methane has 21 times the global warming effect of CO_2 over 100 years and sulphur hexafluoride almost 24,000 times.

At a global level, the movement of freight accounts for nearly 45 per cent of all the energy consumed by transport with heavy goods vehicles (HGVs) using over half of that (UN IPCC, 2014). In the UK, transport accounts for around a quarter of total energy-related CO_2 emissions, with freight transport responsible for approximately 8 per cent (McKinnon, 2007). Rail and waterborne transport together represented just under 8 per cent of freight-related CO_2 emissions, with domestic air freight producing a negligible proportion. The remaining 92 per cent were attributed to road freight transport. In 2010, road freight vehicles emitted over 23 million tonnes of CO_2e, split in the ratio 72:28 between HGVs and light goods vehicles (LHGs) (or vans).

TABLE 2.3 The global warming potential (GWP) of the greenhouse gases listed in the Kyoto Protocol

Greenhouse gas	Global Warming Potential (GWP)
Carbon dioxide (CO_2)	1
Methane (CH_4)	21
Nitrous oxide (N_2O)	310
Hydrofluorocarbons (HFCs)	140–11,700
Perfluorocarbons (PFCs)	6,500–9,200
Sulphur hexafluoride (SF_6)	23,900

SOURCE: Defra (2013)

Regional effects of atmospheric pollution

Airborne pollutants can diffuse widely from their original source, particularly when carried by the prevailing winds. The two main examples of air pollution extending over extensive areas are:

- Acid rain. This is caused by the emission of sulphur dioxide and nitrogen oxides into the atmosphere. It interferes with the growth of flora and fauna and with water-life. Mainly as a result of the adoption of low- and ultra-low-sulphur diesel in the trucking sector and, to a lesser extent, by rail freight companies, land-based freight transport is now responsible for a very small proportion of acid rain. The high sulphur content of the bunker fuels used in shipping presents a much more serious environmental problem, particularly around ports, although the International Maritime Organization (IMO) has implemented new regulations under Annex 6 of its MARPOL convention to radically reduce SOx emissions (IMO, 2008).
- Photochemical smog. Photochemical smog is caused by the reaction of sunlight with nitrogen dioxide, especially during periods of still, settled weather (ie high pressure). It can extend over whole urban regions. Such smog can cause loss of lung efficiency and is thought to exacerbate asthma problems.

Local effects of atmospheric pollution

These effects are experienced in the immediate vicinity of the pollution source, where the concentration levels are high.

- Nitrogen oxides (NOx). Nitric oxide and nitrogen oxide result from combustion at high temperatures where nitrogen and oxygen combine. Short-term effects are rarely noticed but long-term exposure to fairly low levels can affect the functioning of the lungs. At higher levels, emphysema may occur (EPA, 2008).
- Hydrocarbons (HCs). Hydrocarbons result from the incomplete combustion of organic materials. Included within this category are volatile organic compounds (VOCs). Many hydrocarbons, such as benzene, are known to be carcinogenic, though the actual levels likely to cause damage are not known precisely (US Department of Health and Human Services, 1999).
- Ozone (O_3). Ozone is formed when nitrogen oxides and VOCs react with sunlight. Exposure to high levels of ground-level ozone can lead to respiratory problems and nausea. Children, asthmatics and the elderly may be more susceptible or vulnerable to the effects (Royal Society, 2008).
- Particulates. Particulates come in various sizes and from a variety of sources. In the case of vehicles, the majority take the form of soot emitted by diesel engines, particularly those that are badly tuned. There are concerns over the likely carcinogenic effects, particularly of the smaller PM10 particles (EPA, 2009). These particles are also linked to respiratory and cardiovascular problems and to asthma. It has been estimated that in the UK, PM10 pollution causes the premature deaths of 12,000–24,000 people annually and adds £9.1–£21 billion to the national health budget (Rogers, 2007).
- Carbon monoxide (CO). Carbon monoxide results from the incomplete combustion of carbon-based fuels. It binds well with haemoglobin, which carries oxygen around the body. It binds 200 times more easily than oxygen and so reduces the circulation of oxygen. At low levels of exposure, perception and thought are impaired but at high levels it can cause death (HPA, 2009).
- Sulphur dioxide (SO_2). Fossil fuels, particularly diesel, contain sulphur. When they are burned in the engine, the remaining sulphur is converted into sulphur dioxide, an acidic gas which is then emitted through the exhaust pipe. Normally, it causes irritation to the eyes, nose and throat of those exposed to it. At low levels it may also temporarily make breathing difficult for people with predisposed respiratory illness, such as asthma (HPA, 2008).

Road traffic emissions are a major cause of smog in large cities. In March 2014, high air pollution levels prompted the French authorities to impose major car traffic restrictions in Paris. Motorists with even-numbered plates were not allowed to drive in the city on Monday 17 March. In 2013, Beijing authorities announced a scheme under which cars with odd and even licence plates will be banned from the city's roads on alternate days whenever serious air pollution persists for three consecutive days. In October 2011, all traffic was banned from the streets of Milan for 10 hours on Sundays. Traffic restriction measures are aimed primarily at passenger cars. Sustainability strategies for city logistics are discussed in Chapter 14.

Noise pollution

The environmental impacts of traffic noise differ from those of GHGs or air pollutants in the fact that most of the noise effects are restricted to the time of emission (Doll and Wietschel, 2008). However, road traffic noise tends to be continuous and thus considered a more serious problem than noise caused by other transport modes (for instance railway or aircraft noise), which are intermittent. Adverse effects of traffic noise include annoyance, communication problems, sleep disturbance, problems with concentration and impaired cognitive functioning resulting in loss of work productivity. Prolonged exposure to traffic noise may result in physiological effects such as cardiovascular diseases or irreversible loss of hearing, as well as in mental health problems (Den Boer and Schroten, 2007). Children living in areas with significant levels of noise pollution display higher levels of anxiety and problems with school behaviour (Matsuoka *et al*, 2011). Traffic noise also has an adverse effect on residential property values and rents (Efthymiou and Antoniou, 2013). Currently, around 30 per cent of the European Union's population is exposed to road traffic noise and 10 per cent to rail noise levels above 55 dB(A). Data on aircraft noise exposure is less reliable, though it is thought that around 10 per cent of the EU population may be highly disturbed by air transport noise (EEA, 2003). According to Watts *et al* (2006), in the UK 'over 90 per cent of the population hear traffic noise whilst at home and about 10 per cent regard their exposure to this source of noise as highly annoying' (p 1). This, however, relates to all traffic and HGVs are only one of the sources of the problem.

Trucks generate road noise in three ways:

- propulsion noise (power train/engine sources), which dominates at low speeds (less than 50 kmph);

- tyre/road-contact noise, which is the main cause of noise at speeds above 50 kmph;
- aerodynamic noise, which increases as the vehicle accelerates.

European vehicle noise standards for individual vehicles were introduced in the early 1970s (Directive 70/157/EEC), when the permitted noise emissions for trucks were set at 80 dB(A). Noise standards have been tightened several times since then (Affenzeller and Rust, 2005). Significant reductions in noise levels have been achieved by technical advances in engine design, tyres and the aerodynamic profiling of vehicles. Nevertheless, overall noise levels have not improved, as the growth and spread of traffic in space and time have largely offset both technological improvements and other abatement measures (INFRAS, 2004).

The European Union in 2001 launched regulations that limited the levels of noise generated by vehicle tyres (Directive 2001/43/EC). Tyre noise was targeted specifically for two reasons. First, tyre rolling noise is generally the main source of noise from trucks at medium and high speeds (Sandberg and Ejsmont, 2002); and second, as tyres are replaced more frequently than vehicles, implementing tyre noise standards was considered to be one of the fastest ways to achieve road noise reductions.

In addition to quietening the vehicle, it is possible to cut noise levels by altering the acoustic properties of the road surface. FEHRL (2006) outline a range of noise-abatement measures that can be applied in the design and construction of road infrastructure. In Europe, the recent **Quie**tening the **E**nvironment for a **S**ustainable **S**urface **T**ransport (QUIESST) project, co-funded by the European Community's Seventh Framework Programme, investigated surface transport noise-abatement solutions for road and rail (2009–2012) (Oltean-Dumbrava *et al*, 2013).

As in road transport, technological improvements in air transport, mainly from engine improvements and airframe design, have substantially reduced the noise of individual aircraft, but these performance improvements have again been eroded by the growth of air traffic (Janić, 2007).

It should also be noted that, in some situations, there may be trade-offs between reducing noise and reducing other environmental impacts. For instance, Cooper *et al* (1994) and Palmer and Piecyk (2010) identify the scheduling of deliveries during evenings and nights as one of the ways to reduce fuel consumption and CO_2 emissions. This, however, may increase noise irritation at night, particularly in residential areas. Hence, a decision needs to be made as to which environmental and operational aspects are given priority and, as a result, the level of noise irritation may limit the scope for a night-time delivery that would reduce CO_2 emissions.

The Dutch programme PIEK ran at a national scale between 1999 and 2009, with the aim of promoting early morning, late evening and night deliveries. The scheme promoted the use of quieter vehicles, and low-noise loading and unloading of trucks (Browne *et al*, 2012).

In 2009, the UK Department for Transport (DfT) established a partnership with the Freight Transport Association (FTA) and the Noise Abatement Society (NAS), in order to investigate and promote the potential benefits from relaxation of night curfews on delivery vehicles meeting tight noise standards. This involved setting up and running quiet delivery demonstration trials at five retail outlets across England. The trials demonstrated that night-time deliveries can be undertaken without adversely affecting neighbouring residents, bringing substantial operational benefits to the companies involved (FTA, 2011).

Vibration

Vibration caused by heavy vehicles may result in serious damage to roadside buildings (Doll and Wietschel, 2008). Sharp and Jennings (1976) differentiate two types of damage to buildings that can be caused by traffic-related vibration:

- Architectural damage: it relates to cracking of plaster and other brittle material, which can be annoying to property owners but does not pose a risk to the structural integrity of the building.
- Structural damage: it implies that the building itself is at risk of subsidence or collapse.

According to Wardroper (1981), lorry traffic causes two types of vibrations:

- Airborne (low frequency) vibrations: they easily penetrate windows and walls causing objects to rattle on shelves and/or floors to vibrate under people's feet. However, they would reach 'an intensity beyond human tolerance' (p 98) before the level at which minimal architectural damage is caused.
- Ground-borne vibrations: these can be harmful to buildings even when they are barely perceptible. They may cause serious damage as pressures are redistributed below ground and exert an intensified impact at foundation level. Ground-borne vibrations can cause architectural damage at the level when they are 'strong enough to annoy householders' (p 98). When they reach the point of being 'unpleasant' they can cause structural damage as well.

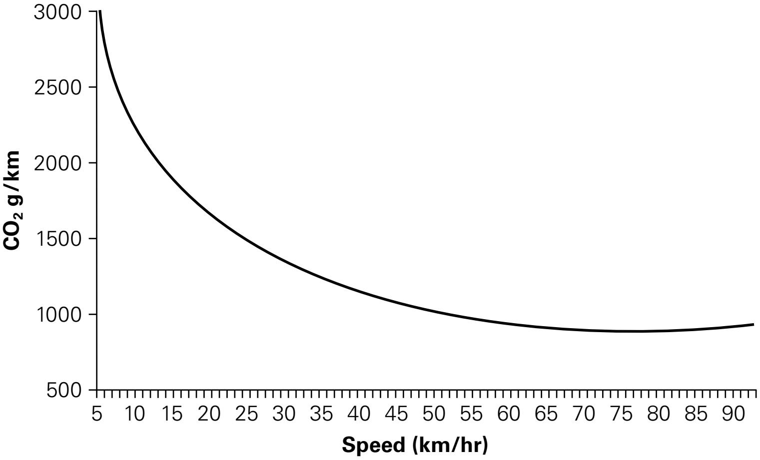
Vibration from road traffic can be reduced by improved suspension and tyres. However, as 'vibration from road traffic is a result of fluctuations of wheel contact load which are caused by their passage over road surface irregularities or discontinuities in the road profile [...], the best way of minimizing traffic-inducted vibration would appear to be the maintenance of smooth road surfaces' (Sharp and Jennings, 1976: 139).

Congestion

According to Goodwin (2004: 7), 'congestion is defined as the impedance vehicles impose on each other, due to the speed–flow relationship, in conditions where the use of a transport system approaches its capacity'. Hence, a vehicle cannot reach the speed attainable in free-flowing traffic conditions.

Congestion results in time losses and causes additional direct operating costs for road transport users (Piecyk and McKinnon, 2007). It also contributes to excessive fuel use and, thus, to increased CO_2 and air pollutant emissions. In the US, fuel wasted as a result of congestion, lost productivity, and reduced mobility on the urban road network is estimated to cost road users \$85 billion annually (Taylor *et al*, 2013). According to Doll and Wietschel (2008), 10 per cent of congestion costs can be attributed to negative environmental impacts of increased fuel consumption. Figure 2.2 shows the impact of vehicle speed on CO_2 emissions per vehicle-km (for an articulated vehicle with over 40 tonnes gross vehicle weight). As can be seen, driving at speeds lower than 30 kmph causes a significant increase in fuel

FIGURE 2.2 Vehicle speed and CO_2 emissions: Articulated vehicle over 40 tonnes gross vehicle weight



SOURCE: Test-cycle data supplied by Department for Transport consumption and CO_2 emissions per vehicle-km. Congestion is a significant source of stress to professional delivery drivers, and increased driving time means longer exposure to high concentrations of exhaust pollution (Matsuoka *et al*, 2011).

Road freight transport contributes to congestion to a lesser extent than passenger travel. It has been estimated that cars contribute 50 per cent of the total social costs associated with congestion, while HGVs account for only 27 per cent of this total (Smith *et al*, 2005). Further, the logistics sector is one of the most affected by congested infrastructure. Within the area of transport and distribution, congestion imposes adverse effects on economic efficiency and competitiveness by increasing costs and reducing the reliability of logistics schedules (McKinnon, 1998, McKinnon *et al*, 2009). Supply chains in which delivery times are heavily restricted by customer time windows and schedules, and where average distances between depots and customer locations are long are particularly vulnerable to congestion (Figliozzi, 2011). Mitigation of the negative economic and environmental impacts is likely to become one of the top priorities for logistics managers in the future. For example, the UK Department for Transport expects that, by 2040, lost seconds per mile on English roads will increase by 61 per cent, whereas average speed will decrease by 9 per cent (DfT, 2013). This will result in significant increases in the associated direct and indirect costs of road freight operations. For instance, Taylor *et al* (2013) estimate that a 20 per cent increase in travel times experienced by trucks in Washington State would add over $14 billion of increased operating costs to freight-dependent industries, such as manufacturing, retail and wholesale trade, agriculture, construction and timber products.

Congestion can also affect other transport modes. For instance, there are concerns that congested rail infrastructure in the UK may inhibit continued growth of rail freight and modal shift from road (FTA, ND). Congestion at major ports has also become an important issue in global supply chains.

Accidents

Transport results in many fatalities and serious injuries each year. In 2009, UK- and foreign-registered HGVs were involved in 7,749 road accidents on Britain's roads; 289 people were killed and 1,236 seriously injured in road accidents involving HGVs (Department for Transport, 2010). Apart from personal injury, death or material losses for those involved, accidents cause delays and general inconvenience for other road users. They also amplify the effects of congestion (McKinnon, 1998).

Although HGVs have a lower overall frequency of involvement in traffic accidents, there is a significantly higher probability of them being involved in a fatal accident (Table 2.4) as compared to other motor vehicles. This reflects the fact that trucks travel mostly on major roads (88 per cent of the total vehicle-kms travelled by HGVs in 2009) at relatively high speeds and have greater momentum, due to their heavier weight.

TABLE 2.4 Vehicle involvement rates by accident severity in the UK, 2009 (rate per billion vehicle miles)

Severity	HGVs	Cars
Killed	16.3	5.2
Killed or seriously injured	87.7	66.3
No of accidents	427.6	584.2

SOURCE: Department for Transport (2010)

In the EU19, the total annual number of fatalities in accidents involving HGVs fell from 7,867 in 2001 to 4,576 in 2010. Approximately a quarter of these fatalities resulted from accidents in urban areas (ERSO, 2014).

Land use and biodiversity

Logistics activity also has an impact on land use. Land is being taken for development of transport infrastructure and the extraction of the related building materials (Button, 1990). Transport infrastructure also causes both a direct and an indirect loss of habitat. The direct loss refers to the physical presence of roads, railway tracks, distribution facilities or terminals and the conversion of the greenfield land into a built-up area. McKinnon (2009) estimated that warehousing sites occupied around 23,500 hectares of land in the UK in 2007, representing 0.8 per cent of non-agricultural and forestry land. The indirect loss refers to the fragmentation and/or degradation of ecosystems due to the presence of transport infrastructure, which reduces the capability of an ecosystem to sustain its original biodiversity (Geneletti, 2003).

Waste

Waste associated with freight transport includes waste oil or scrapped vehicles themselves. In a wider perspective, it also includes abandoned spoil tips and rubble from infrastructure works (Button, 1990). Giannouli *et al* (2007) developed a model for assessing the waste produced from road vehicles, both during vehicle operation and at their end-of-life disposal. The modelling results indicate that the UK is the second largest contributor, after Germany, to annual waste arising from in-use and end-of-life vehicles in EU15. It was estimated that annual vehicle-related waste produced in the four countries responsible for the vast majority of the total waste from road transport (Germany, UK, France and Italy) is going to increase from around

14 million tonnes in 2000 to over 21 million tonnes in 2020. Further, more than 70 per cent of the overall annual waste from road transport is produced from end-of-life vehicles, with ferrous parts being a predominant source of waste from the scrapped vehicles (66 per cent of the total). Tyres and operating liquids are the two biggest components of in-use waste (43 per cent and 35 per cent of the total in-use waste, respectively). Unfortunately, although the model distinguishes road vehicle categories, detailed results for HGVs are not presented separately.

Visual intrusion

One of the minor social impacts of freight vehicles and logistics infrastructure is their visual intrusion. This means that their presence often spoils the surrounding landscape and/or the outlook from residential properties. Visual intrusion is difficult to measure because it is a highly subjective factor. It was assumed, for example, by Sharp and Jennings (1976, p 142) that its impact would be greater in 'more beautiful and historic urban landscapes of Britain'. However, some aspects of visual disturbance are affected by factors other than aesthetic appeal. For instance, 24-hour lighting at distribution centres, railheads and ports can adversely affect nearby residential areas and cause difficulty sleeping at night for the local population (Matsuoka *et al*, 2011). With respect to freight vehicles, two surveys of public responses to different sizes of lorry conducted by the Transport and Road Research Laboratory found that no clear preferences could be established (Rosman, 1976). The study tested people's reactions to different vehicle size combinations, each with the same overall carrying capacity: one HGV with a capacity of 16 tonnes, two of 8 tonnes and four of 4 tonnes. Similar proportions of respondents favoured the one 16-tonne and four 4-tonne vehicle combinations, suggesting that the public had no clear preference on this issue. Size of the vehicle was identified as the second most bothering factor, after noise, for the participants. However, it is not clear if vehicle size is directly correlated with visual intrusion. The design of the vehicle can also influence public perceptions. Sharp and Jennings (1976), however, concluded that, as 'there is no obvious way in which vehicles can be made more beautiful or aesthetically acceptable', the only solution would be to designate alternative routes for HGVs to follow (p 142).

Environmental standards

Environmental standards can be divided into two types: those that are mandatory and those that more environmentally responsible companies meet voluntarily. The former type is mostly technical, while the latter type is often more management orientated.

Mandatory standards

EURO emission standards

Since the early 1990s, emissions from diesel-engined HGVs have been strictly controlled by EU legislation. New HGVs have been the subject of progressively tightening environmental standards, known as EURO emission standards. Emissions of nitrogen oxides and particulate matter have been targeted particularly and will be almost negligible after 2013 (Table 2.5). One vehicle manufacturer has produced an enhanced environmentally friendly vehicle (EEV) that, compared with Euro V standards, emits 50 per cent less soot, 87 per cent less CO and 88 per cent less HC. Many responsible logistics companies have been proactive, implementing the standards before the enforcement date. However, there has been some concern that, due to a change in engine technology necessary to achieve the new tighter standard, Euro VI will have a fuel consumption penalty. A report by Hill *et al* (2011) projects this penalty to be 'circa 3 per cent for early Euro VI engines, evolving closer to zero within 3 years of introduction due to technological developments' (p 117). Thus, in a longer term, implementation of the Euro VI emission standard should not have negative effects on CO_2 emissions from road freight transport.

EU Sulphur Directive

The Sulphur Content of Liquid Fuels Directive (1999/32/EC) regulates sulphur emissions from ships by limiting the maximum sulphur content in marine fuel. It was amended by Directive 2012/33/EU limiting the maximum

TABLE 2.5 Emission standards for heavy-duty diesel engines (g/kWh)

Tier	Date of implementation	CO	HC	NOx	PM
Euro I	1992 (>85kw)	4.5	1.1	8.0	0.36
Euro II	1998	4.0	1.1	7.0	0.15
Euro III	2000	2.1	0.66	5.0	0.10
Euro IV	2005	1.5	0.46	3.5	0.02
Euro V	2008	1.5	0.46	2.0	0.02
Euro VI	2013	1.5	0.13	0.4	0.01

SOURCE: www.nao.org.uk

sulphur content of the fuels used by ships operating in European sulphur emission control areas (SECAs), ie the Baltic Sea, the North Sea and the English Channel, to 1 per cent. This will be further reduced to 0.1 per cent from January 2015. In EU waters outside SECA, the current maximum limit of 3.5 per cent will become 0.5 per cent from January 2020. Apart from buying low-sulphur fuels, operators can also comply with the sulphur emissions limits in other ways, for example using liquid natural gas (LNG)-powered ships or vessels equipped with exhaust gas cleaning systems (or 'scrubbers') (Institute for Shipping Economics and Logistics, 2010).

Voluntary/management standards

Environmental management standards (EMS)

Environmental management was first developed as a response to new environmental regulations being imposed on companies. It soon evolved beyond its initial, narrow, technical approach as managers started to perceive environmental issues as realities that needed to be incorporated into business strategy (Walley and Whitehead, 1994). Environmental management has both short- and long-term consequences, affecting the current performance and long-term sustainability of businesses. Carbon management is a relatively new part of this process, gaining in significance in light of the climate change threat. Carbon management should not, however, be implemented in isolation. It is important to create one comprehensive environmental strategy and understand the potential trade-offs between its constituent parts. The Institute of Environmental Management and Assessment (IEMA, 2008) defines an EMS as 'a structured framework for managing an organization's significant impact on the environment'. These impacts can include business waste, emissions, energy use, transport and consumption of materials and, increasingly, climate change factors. Recognition of EMS can be achieved through accredited certification to one (or more) of the main standards or schemes available. The three most recognized standards are the Eco-Management and Audit Scheme (EMAS), ISO 14001 and BS8555.

Eco-Management and Audit Scheme (EMAS)

This is a voluntary Europe-wide standard introduced by the European Union and applied to all European countries. It was formally introduced into the UK in April 1995. According to the Institute of Environmental Management and Assessment (IEMA, 2008), the aim of EMAS is 'to recognize and reward those organizations that go beyond minimum legal compliance and continuously improve their environmental performance'. Participating organizations must regularly produce a public environmental statement, checked by an independent environmental verifier that reports on their environmental performance.

ISO 14000 and 14001

For companies that want certification of their environmental credentials there exists a series of international standards, namely the ISO 14000 series. These are a set of voluntary standards and guideline references for companies aiming to minimize their environmental impact. ISO 14001, which was published in 1996, is the only standard in the ISO 14000 series for which certification by an external authority is available, and concerns the specification of requirements for a company's environmental management system.

BS8555 Environmental Management System: Guide to the phased implementation of an environmental management system including the use of environmental performance evaluation

This UK standard was published in 2003. BS8555 provides advice on how to implement a generic EMS, and can be used as a route towards EMAS and ISO 14001. The standard is designed to help companies to evaluate their performance and to define their policy, practices, objectives and targets in relation to the environment. It requires the support of senior management, and describes policies for the benefit of both staff and the general public.

Measuring the environmental impact of freight transport

Macro-level assessment

Although the importance of measuring the environmental impact of pollution is universally recognized, in practice it is complex and there is no single, agreed method of so doing. Instead, there are several measurement methods, all yielding slightly different figures. The UK government makes a distinction between emissions from the 'end user' and emissions from 'source'. End-user figures include an estimate of emissions from upstream sources such as power stations and refineries, which are allocated to activities that use the electricity or fuel. This estimate equates to the 'well-to-wheel' definition. Source figures, on the other hand, allocate emission estimates according to where the fuel is consumed and do not include the emissions from upstream sources. In the freight transport sector this 'source' category includes all emissions from the combustion or evaporation of fuel used for all activities associated with moving freight. Tailpipe emissions are an even narrower category of exhaust emissions released by the operation of the vehicle. This category refers to the pollution that is emitted from the tailpipe (or the exhaust pipe) of a vehicle.

An important distinction can be made between top-down and bottom-up approaches to the estimation of energy use and emissions (McKinnon and Piecyk, 2009). The former approach measures total fuel consumption by transport and uses standard conversion factors to translate it into macro-level emission figures. In the UK, however, diesel fuel purchases are not differentiated by vehicle type at point of sale, making it very difficult to estimate the quantity of fuel consumed by freight vehicles (as opposed to buses and diesel cars). As far as road freight is concerned, the bottom-up approach is now deemed the more accurate. This involves surveying a large sample of HGV operators (as done by the Continuing Survey of Road Goods Transport in the UK) and enquiring about the distances their vehicles travel and quantities of fuel consumed. These fuel consumption estimates are grossed-up for the truck fleet as a whole and converted into emission values. No comparable surveys of fuel consumption are undertaken in the UK for rail, air and shipping services, making it difficult to derive UK-specific emission estimates for these modes.

Within Europe, several organizations have compiled databases showing the environmental impact of the different freight transport modes (eg INFRAS, 2004; IFEU, 2008; TREMOVE, 2008). Table 2.6 summarizes one set of energy consumption and emissions estimates for the most atmospheric pollutants. It highlights the wide variations in the levels of emissions per

TABLE 2.6 Average emission factors for freight transport modes within Europe

		EC (kj/tkm)	CO_2 (g/tkm)	NOx (mg/tkm)	SO_2 (mg/tkm)	NMHC (mg/tkm)	PMdir (mg/tkm)
Aircraft		9,876	656	3,253	864	389	46
Truck >34–40-t	Euro 1	1,086	72	683		75	21
	Euro 2	1,044	69	755		55	10
	Euro 3	1,082	72	553	90	54	12
	Euro 4	1,050	70	353		59	2
	Euro 5	996	66	205		58	2
Train	Diesel	530	35	549	44	62	17
	Electric	456	18	32	64	4	4.6

EC – energy consumption NMHC – non-methane hydrocarbons

SOURCE: IFEU, 2008

tonne-km and potential benefits of shifting freight to more environmentally friendly transport modes, such as rail and water. The opportunities for modal shift are discussed in Chapter 7.

One must exercise caution, however, in interpreting comparative environmental data for freight transport modes (McKinnon, 2008), as the relative environmental performance of a particular mode can be affected by:

- differing assumptions about the utilization of vehicle capacity;
- use of tonne-kms as the denominator, misrepresenting modes specializing in the movement of lower-density cargos;
- extrapolation of emissions data from one country to another with different transport and energy systems;
- allocation of emissions between freight and passenger traffic sharing the same vehicles (such as aircraft and ferries);
- neglect of emissions associated with the construction and maintenance of infrastructure;
- restriction of the analysis to emissions at source rather than ‘well-to-wheel’ data.

Micro-level assessment

The externalities associated with freight transport can be disaggregated in various ways:

- By geographical area: local authorities now closely monitor air quality and noise levels and, in some cases, can attribute these environmental impacts to particular categories of traffic. Transport for London, for example, estimated that prior to the introduction of the Low Emission Zone, road transport accounted for roughly half of all NOx and PM10 emissions in central London, with most of them coming from the exhausts of HGVs (Fairholme, 2007).
- By company: an increasing number of businesses, as part of their corporate social responsibility (CSR) programmes, are monitoring the environmental impact of their freight transport operations. Major logistics companies such as UPS and DHL now publish annual environmental reports detailing the levels of pollutant emissions from their transport fleets.
- By customer: some companies can now estimate the environmental effects of distributing their products to particular customers. They can offer their clients distribution by different modes and routes, each with a differing set of environmental impacts.
- By product: life cycle analysis (LCA) is a ‘technique to assess the environmental effects and resource costs associated with a product, process, or service’ (Environmental Protection Agency, 2006: 1). It generally does this on a ‘cradle-to-grave’ basis from raw material

> source through production, distribution and consumption to the point where the materials return to the earth. Freight transport is an integral part of this process and can have its environmental impacts disaggregated to product level in the course of LCA (Browne *et al*, 2005).

In recent years, the assessment of environmental impacts at the company and product levels has been focused on GHG emissions. As climate change has risen up political and corporate agendas there has been a steep growth of interest in carbon footprinting. Unlike LCA, which inherently analyses a broad range of external effects, carbon footprinting is confined to GHG emissions. The next chapter examines in detail how it is being applied both by individual companies and across supply chains.

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03

Carbon auditing of companies, supply chains and products

MAJA PIECYK

Introduction

In recent years, international organizations and national governments have been setting greenhouse gas (GHG) emission reduction targets for the next 10–30 years. The UK Climate Change Act sets a target to reduce the country's GHG emissions by 80 per cent by 2050 against a 1990 baseline. In 2011, the EU announced a target to cut transport GHG emissions by 60 per cent by 2050, relative to the 1990 level. At a micro-level, proactive companies are establishing internal GHG reduction targets (Table 3.1). Recently, one of the main UK logistics trade bodies, the Freight Transport Association (FTA), set a voluntary target for members of its Logistics Carbon Reduction Scheme. This will involve reducing road freight emissions by 8 per cent, relative to the level of business activity, between 2010 and 2015 (FTA, 2011).

A number of measures have already been implemented, or are likely to be introduced in the near future, to help meet these targets, including mandatory or voluntary GHG reporting programmes, emission trading schemes, carbon or energy taxes, regulations, and/or the imposition of energy efficiency and emissions standards for buildings and equipment (Piecyk and McKinnon, 2010). Consequently, companies will need to understand and manage their GHG emissions so as to meet reporting and regulatory requirements, ensure long-term competitive advantage and be prepared for future government policies on climate change (WBCSD/WRI, 2004).

TABLE 3.1 Examples of corporate GHG reduction targets for logistical activities

Company	Time frame	GHG reduction target
Asda	2012–2015	60% reduction in absolute emissions from transport fleet (from a 2005 baseline)
DB Schenker	2006–2020	20% reduction in CO_2 emissions per tonne-km
Deutsche Post DHL	2007–2020	30% improvement in CO_2 efficiency, including subcontractors
John Lewis Partnership	2010/11–2020/21	15% reduction in absolute CO_2e emissions from transport
Tesco	2011–2020	25% reduction in distribution emissions per case of goods delivered

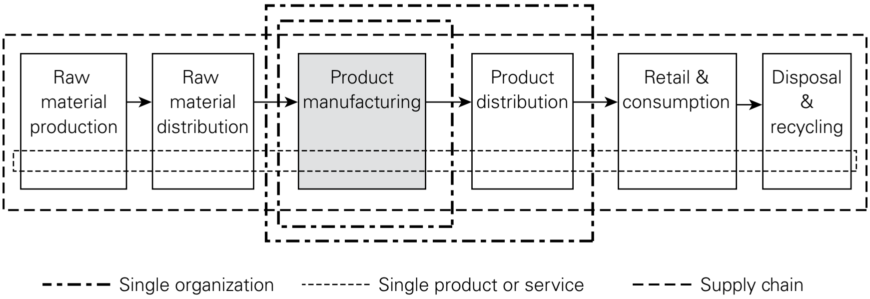
Examples of mandatory GHG emission reporting programmes

- In the UK, the Companies Act 2006 (Strategic Report and Directors' Reports) Regulations 2013 requires quoted companies[1] to report on GHG emissions for which they are responsible (Defra, 2013a).
- As of 1 October 2013, transport service providers operating in France are required to inform service users of their CO_2 emissions. This requirement, introduced by the French Decree No 2011–1336, applies to 'any private or public person organizing or selling a transport service for passengers, goods or moving purposes carried out using one or several means of transport, departing from or travelling to France, with the exception of services organized on behalf of the private or public person' (Article 2).

A common system of measurement needs to be found to enable a comparison of GHG emissions from different activities, individuals, organizations and products. This process has been termed 'carbon footprinting'. A carbon footprint can be defined as the total amount of carbon dioxide and other

GHGs (expressed in CO_2 equivalents – CO_2e) emitted directly and indirectly from an entity (Carbon Trust, 2006). Figure 3.1 illustrates three types of carbon footprint: at a product (either a good or a service), a single company or a supply chain level. Carbon auditing of a supply chain or a product is more complicated than the auditing of a single organization because it includes other actors upstream and downstream. One of the main challenges lies in defining the boundaries of the system to be carbon footprinted.

FIGURE 3.1 Different types of carbon footprint



SOURCE: Based on Carbon Trust (2006)

Carbon footprinting is supported by various bodies, in both the private and public sectors. Organizations undertake carbon footprinting for two main reasons. The first is to report GHG emissions internally or externally to a third party (eg to consumers, supply chain partners, or regulatory bodies). The second is to provide the data required for carbon management. Once the carbon footprint of a particular product's supply chain has been measured, opportunities for reducing it can be identified and prioritized.

Guidelines for carbon footprinting

Several guidelines have been published by different organizations to support companies in measuring, reporting and managing their carbon footprints. The most important include:

- The Greenhouse Gas Protocol: *A Corporate Accounting and Reporting Standard. Revised Edition* (WBCSD/WRI, 2004).
- PAS 2050: *Specification for the Assessment of the Life Cycle Greenhouse Gas Emissions of Goods and Services* (British Standards Institution, 2011a).
- ISO 14067, *Greenhouse Gases – Carbon Footprint of Products. Requirements and Guidelines for Quantification and Communication* (ISO 14067, 2013).

- ISO 14064:1, *Greenhouse Gases – Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals* (ISO 14064:1, 2006).
- The Japanese Ministry of Economy, Trade and Industry: *General Principles for the Assessment and Labelling of Carbon Footprint of Products* (METI, 2009).
- Industry- or activity-specific guidelines are also available. These include:
  - a report published by European Chemical Industry Council examining the options for measuring CO_2 emissions from transporting chemicals in Europe (McKinnon and Piecyk, 2010);
  - advice to companies on carbon reporting at an individual consignment level (World Economic Forum, 2010);
  - UK Department for Transport's guidelines on measuring and reporting GHG emissions from freight transport operations (DfT, 2010).

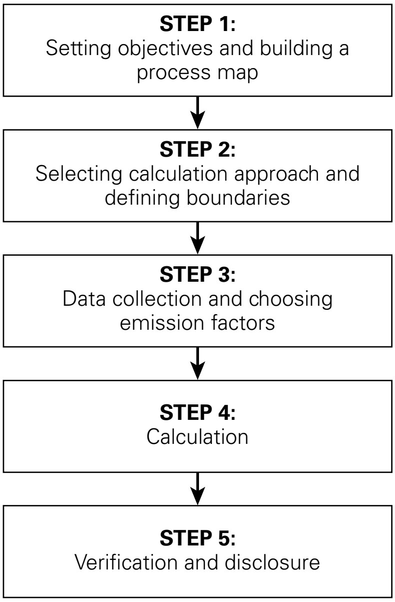
The published guidelines differ in their details but the main assumptions and methodologies are similar. The same GHG auditing and reporting principles ought to be applied to all aspects of the calculation of a company's carbon footprint. The following principles are now widely adopted (WBCSD/WRI, 2004; ISO 14064–2, 2006; British Standards Institution, 2011a):

- **Relevance**: a GHG emission report should appropriately reflect the environmental impact of the company, supply chain or service. It needs to contain all information that internal and external users need for their decision making.
- **Completeness**: all GHG emission sources within the chosen reporting boundary need to be included in the carbon footprint calculations. Any exclusions should be adequately justified and clearly specified in the GHG report.
- **Consistency**: calculation procedures should be applied in a manner that ensures that GHG emission data are comparable over time. If there are any changes in methodology, data or any other factors that may affect GHG emission estimates, these should be explicitly documented and justified.
- **Accuracy**: estimation of the GHG emissions should be compiled in such a way that it ensures maximum precision and minimizes the risk of both over- and under-reporting. Uncertainties should be reduced as much as possible to give internal and external users confidence in the integrity and credibility of the reported information.
- **Transparency**: information on GHG emissions should be reported in a factual, neutral and coherent manner based on a clear audit trail. Any assumptions should be clearly disclosed and appropriate references to the reporting guidelines and data sources need to be included in the report.

The carbon footprinting process

This process, as outlined by the British Standards Institution (2011b) and WBCSD/WRI (2004), is summarized in Figure 3.2. Each of these steps will now be examined in detail.

FIGURE 3.2 Steps to calculating the carbon footprint



Step 1: Setting objectives and building a process map

Measuring and reporting GHG emissions is a first step in a carbon management process. For the reporting company, environmental objectives can be achieved in synergy with other strategic and financial goals. In a wider perspective, final customers can also benefit from improvements in the sustainability of businesses and industries, although these gains may be more difficult to measure directly.

Typically, the benefits of environmental auditing and management include (Defra, 2006):

- **Compliance with legislation:** this is the minimum requirement that companies must meet.
- **Better use of resources and cost savings:** measures to mitigate emissions often reduce costs as they focus on reducing waste, transport, energy consumption and the like, and promote more efficient use of resources.

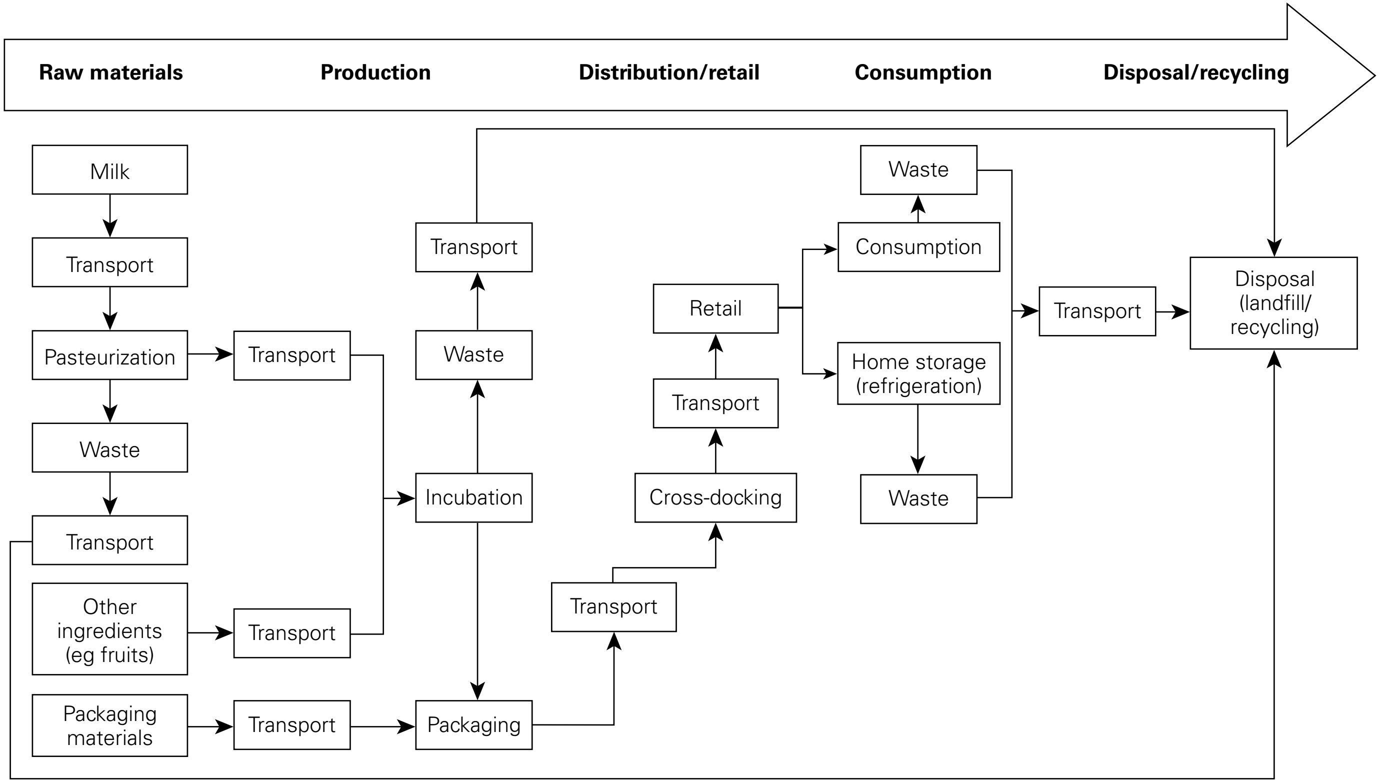
- **Competitive advantage**: by demonstrating to the public that their activities are environmentally friendly, companies can promote a green image. As customers are becoming more environmentally aware, a company's green credentials can exert greater influence on customer behaviour.
- **Improved attractiveness as a potential supplier**: as organizations are increasingly requiring their suppliers and contractors to conform to their environmental standards, reporting on environmental performance can help to confer a preferred-supplier status.
- **Increased attractiveness to the investment community**: the sustainability of operations is becoming an important factor in investment decision making. Documenting how the environmental risks are reduced can also be required by insurers.
- **Product and service innovation**: measuring and managing environmental impacts drives innovation in product and service development, helping to secure new markets or safeguard existing ones.
- **Employee recruitment**: a good environmental reputation can be an important factor in an employee's choice of employer.

At this stage, the objectives of the carbon footprint exercise should be agreed, as they help to determine the methodology to be applied. For example, if the main objective is to obtain ISO 14000 series certification, the ISO guidelines must be followed. If a company intends to use the carbon footprint internally, it can decide which guidelines to apply but the methodology used should be explained in the final report.

A process map identifying all materials, activities and processes that contribute to the carbon footprint should be constructed. The complexity and scope of this map will depend on the type of carbon footprint required, in particular the level of disaggregation (eg at supply chain, company, business unit, facility or product level). The carbon footprinting of a product will typically be based on the life cycle assessment; in other words, it will include all product-related emissions from the raw material source, throughout the manufacturing and distribution stages, to impacts related to its use, disposal or recycling (Environmental Protection Agency, 2006). A sample process map has been constructed for yoghurt to illustrate the stages in the production and distribution system for which carbon data would have to be collected (Figure 3.3).

The process map will be drawn at a relatively high level at the initial stage and can be refined during the carbon footprinting process. Having a graphical representation of the processes involved helps to identify the main sources of emissions and guides data collection process.

FIGURE 3.3 Process map for yoghurt



SOURCE: Adapted from British Standards Institute (2011b)

Step 2: Selecting the calculation approach and defining boundaries

In the next stage, the scope for the carbon footprint calculations needs to be defined. In the case of a company or supply chain carbon footprint, the organizational boundaries will be particularly important. The company may comprise one or more facilities and include wholly owned operations, joint ventures and/or subsidiaries. In setting the organizational boundaries a company effectively defines 'businesses and operations that constitute the company for the purpose of accounting and reporting GHG emissions' (WBCSD/WRI, 2004).

There are two approaches to consolidating GHG emissions within a boundary (ISO 14064-1, 2006):

- The control approach: the boundary is drawn to include all the activities over which the company has financial and/or operational control.
- The equity share approach: the organization assumes partial responsibility for GHG emissions from facilities in which it holds a share of the equity.

In order to avoid double-counting of emissions, it is important to ensure that when a facility is controlled by several organizations, they all adopt the same consolidation approach. Further:

> where possible, organizations should follow the organizational boundaries already in place for their financial accounting, provided these are explicitly explained and followed consistently. When applying these concepts, the underlying assumption of 'substance over form' should be followed. That is, GHG emissions and removals should be quantified and reported in accordance with the organization's substance and economic reality and not merely its legal form.
>
> ISO 14064–1, 2006

This means that the boundaries of the carbon footprinting analysis should be set in a way that reflects business reality, fits with other requirements already in place (eg accounting reporting regulations) and is practical in terms of data collection.

After the organizational boundaries have been set, it is time to delimit the operational boundaries. This process involves identifying GHG emissions from the sources within the agreed organizational boundaries, grouping them into the categories listed below, and choosing the scope of reporting for indirect emissions.

The GHG emissions can be divided into three categories (WBCSD/WRI, 2004):

- Scope 1 emissions: these are direct GHG emissions from sources owned or controlled by the audited company, for instance emissions from combustion of fuel on site or in vehicles owned/controlled by the organization, from chemical reactions in production processes, and so on.

- Scope 2 emissions: these are indirect GHG emissions from the generation of electricity, heat, or steam purchased from external suppliers.
- Scope 3 emissions: other indirect GHG emissions – emissions, other than indirect GHG emissions, that are a consequence of the audited company's activities but arise from sources owned or controlled by other organizations; for instance, emissions from outsourced activities (such as logistics), waste disposal, product use, employee commuting, business travel in vehicles owned/controlled by other organizations and so on.

As a minimum, carbon footprinting should take account of Scope 1 and 2 emissions. The organization may also include Scope 3 emissions in the calculations. This is optional but considered to be good practice, particularly where the following circumstances apply (WBCSD/WRI, 2004):

- they are large relative to the Scope 1 and 2 emissions;
- they contribute to the organization's risk exposure;
- they are considered critical by key stakeholders (for instance customers, suppliers or investors);
- there are opportunities for emission reductions that can be exploited or influenced by the company.

As a minimum, all GHGs covered by Kyoto Protocol should be included in the assessment. There were six groups of GHGs in the first Kyoto Protocol compliance period. In the second compliance period (2013–2020), nitrogen trifluoride (NF_3) was added to the list (see Chapter 2). Other GHG emissions may also be included, such as CFCs, halons or HCFCs. However, these are already regulated by the Montreal Protocol, which dealt with their contribution to ozone depletion rather than global warming. The Greenhouse Gas Protocol provides guidance on the reporting of Kyoto GHG emissions. In 2013, the Greenhouse Gas Protocol standards were amended to include NF_3 (WBCSD/WRI, 2013). According to the British PAS 2050, all GHGs including those covered by the Montreal Protocol have to be included.

Step 3: Data collection and choosing emission factors

After establishing what needs to be included in the scope of carbon footprint calculations, the next step is to collect all the necessary data. A data collection plan should be prepared specifying what information is needed, the required format of the data and who holds or has access to the relevant records. Before requesting data from supply chain partners, it is considered good practice to introduce and explain the objectives of the project to them and, hopefully, get their buy-in and active support. When data is required from outside the organization, it is useful to have designated people in all companies involved, so that they can coordinate and manage the data collection process internally.

Primary data can be collected using either a top-down or a bottom-up approach. In a top-down approach, energy usage data is collected at an aggregate level, for example annual electricity consumption for the whole company. Where individual processes can be monitored separately and their specific energy requirements/GHG emissions can be measured, the carbon footprint can be built ‘bottom-up’ from these component measurements. Typically, some reconciliation between the two approaches will be needed. Because it is almost impossible to monitor all processes separately, the bottom-up estimates should be compared with the top-down results to ensure the accuracy of the carbon footprint calculation. In general, the top-down approach can provide reliable overall emission estimates, while the data collected using the bottom-up technique is more useful at later stages in the carbon management process when opportunities for efficiency improvements are being assessed.

As primary data is generally more reliable, it should always be considered first. Where it is not available, secondary data can be substituted. This usually comes in the form of generic emission factors for a given activity. In the course of life cycle analysis, inventories of data have been compiled on the emissions of different gases from a broad range of production, distribution, consumption and recycling/disposal activities. Industry-standard data on GHG emissions can be obtained from these inventories. Secondary data is often adequate for activities that make small contributions to total GHG emissions, and the time, effort and resources required to obtain primary data cannot be justified in such cases. The reasons why the organization decided to use secondary data instead of primary measurements should be explained in the final report. It is also important to consider the reliability and credibility of the source when obtaining the secondary data. Official government publications or recognized auditing standards should be the preferred sources of relevant energy-conversion and emissions factors.

Two other forms of secondary data are critical to the carbon footprinting calculation. These are the emission factors for different energy sources and global warming potential (GWP) of GHGs (Tables 2.1 and 2.3, Chapter 2). The official values for these should be applied to ensure comparability and consistency across different products, companies and supply chains.

Step 4: Calculation

The actual carbon footprint calculation at a company or a supply chain level is relatively straightforward. All computations can be performed using a basic spreadsheet package, though more sophisticated software packages are now available to facilitate the management and analysis of carbon data. The data are aggregated and the GHG emissions calculated by applying conversion factors for the different types of energy input or activity type.

They should then be converted to carbon dioxide equivalent (CO_2e) by using the relevant GWP factor listed in Table 2.1. It is worth noting what Defra recommends, that 'for consistency, all changes in greenhouse gas emissions should be expressed as carbon dioxide equivalent, rather than carbon equivalent. However, referring to carbon is an acceptable shorthand for carbon dioxide equivalent, so long as this is made clear, and all figures are in CO_2e' (Defra, 2008).

The calculations related to a product carbon footprint may require a slightly different approach. A process map will be very useful at this stage. It provides an overview of all the processes that a product undergoes at each stage in the end-to-end supply chain. If many different products are handled at a single site or moved on a single freight journey, a method must be found of allocating the emissions that are common to groups of products, for instance their share in warehouse electricity consumption or the fuel used by a truck. The calculation must also allow for any by-products of processes that are not accounted for separately. The emission values will be then summed to obtain a total carbon footprint of the product measured across its whole supply chain.

The issue of greenhouse gas sinks needs also to be considered. A GHG sink is defined as a 'physical unit or process that removes GHG from the atmosphere' (ISO 14064–1, 2006). Carbon storage may occur where carbon of biogenic origin forms part or all of an entire product, such as wooden furniture, or where atmospheric carbon is absorbed by a product over its life cycle. Emission reductions from storage of carbon in GHG sinks should be deducted from the total carbon footprint by applying appropriate removal factors. The detailed instructions on how to calculate the impact of carbon storage and what can be included in the assessment are provided in PAS 2050. Where a company in the supply chain engages in carbon offsetting (eg paying another company to cut CO_2 on its behalf), the quantities of CO_2 that are offset should not be deducted from the carbon footprint calculation. The general rule is that any changes to the footprint should be directly attributable to modifications to the product itself or the process involved in its production and distribution. Carbon reductions resulting from unrelated activities like the purchase of carbon credits or offsets do not qualify (British Standards Institution, 2011b).

Step 5: Verification and disclosure

Before reporting any GHG information, companies should try to verify their carbon footprint estimates to confirm their accuracy and consistency. Verification minimizes the risk of human error and of decision makers forming the wrong judgements on the basis of misleading carbon footprint information. The level of verification will depend on the main objectives of the carbon footprinting exercise. If the emissions data is only to be used internally, self-verification will usually suffice. This involves asking somebody else within the organization to check the collected documentation and all the calculations independently, in order to detect any errors or missing data. The verifier should be able to confirm that the carbon footprint information fulfils the criteria of relevance, completeness, accuracy, transparency and consistency.

If companies want to disclose the carbon footprint information publicly, independent verification by a third party is encouraged. The highest level of validation would be offered by an accreditation body providing official certification. Non-accredited third-party organizations also offer external validation services.

The final GHG report should present relevant information on GHG emissions, assessment boundaries, the methodology applied and the period of assessment. The required level of detail and scope of the report will also depend on the audience at which it is targeted and the main objective of the carbon footprinting process. However, it should always be based on the best available data at the time of publication, while being open and honest about its limitations (WBCSD/WRI, 2004). Additionally, if the carbon footprint is calculated periodically, information on trends in GHG emission levels should be enclosed.

Success factors in carbon footprinting

Measuring a carbon footprint is a challenging and time-consuming task, particularly if it covers the activities of more than one organization in the supply chain. It should be perceived as an ongoing long-term project that is likely to bring benefits to all the parties involved. Critical success factors for carbon footprinting include:

- senior management support, devoting the necessary attention and resources;
- buy-in from all partners involved and a good level of cooperation across the supply chain;
- adoption of straightforward data collection procedures incorporating standardized questions and data input formats that are aligned with other applications already in use;
- a timetable for the project with firmly defined milestones for the different steps in the carbon footprinting exercise;
- employee involvement and understanding of the environmental impact of the carbon auditing and reduction programme.

Case study: Carbon auditing of road freight transport operations in the UK

The logistics sector globally had a carbon footprint of around 2,800 megatonnes CO_2e in 2008, accounting for 5.5 per cent of the global man-made

GHG emissions. Road freight is responsible for the largest proportion (57 per cent) of the sector's total, followed by ocean freight (17 per cent), and logistics buildings (10 per cent) (World Economic Forum, 2009). Although, the focus of this section is on road freight transport, examples of other carbon footprint exercises in the logistics sector are shown in the box below.

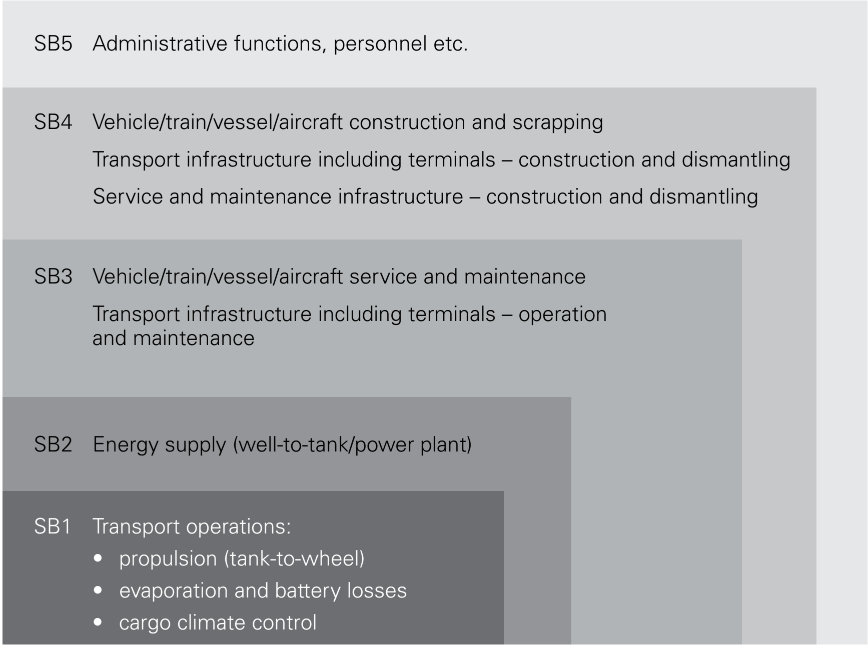
Examples of carbon footprinting studies focusing on logistics activities

- Johnson (2008) compares two types of forklift trucks and shows that 'fuel carbon footprints of electric and LPG forklifts are, in principle, about equal, while in actual practice, LPG's footprint is smaller than that of electricity' (p 1570).
- Edwards *et al* (2010) compare carbon footprints of 'last mile' delivery in conventional and online retailing.
- Leonardi and Browne (2010) propose a method for the calculation of the carbon footprint of maritime freight transport.
- Hua *et al* (2011) investigate how organizations manage carbon footprints in inventory management under the carbon emission trading mechanism.
- van Lier and Macharis (2014) measure GHG emissions from barge traffic in the Flanders region of Belgium on a life-cycle basis.

Although freight transport typically constitutes a relatively small part of the total carbon footprint of a product or service, it is an activity whose carbon intensity can be significantly reduced at little or no net cost (McKinnon, 2007). The Swedish Network for Transport and Environment (NTM), has differentiated five cumulative levels of system boundary, labelled SB1-SB5 (Figure 3.4).

At the first level, SB1, only the direct emissions from the transport operation are included. In the case of electrified rail and road transport operation, this also includes emissions from the electrical power source. At SB2 level, indirect emissions arising from the extraction, production, refining, generation and distribution of energy are included (these are also referred to as so-called 'well-to-tank' emissions). Level SB3 broadens the scope to include maintenance and servicing of vehicles and transport infrastructure. At SB4

FIGURE 3.4 System boundaries around transport operations for carbon measurement



SOURCE: McKinnon and Piecyk (2010)

level, emissions from the production of vehicles, construction of transport infrastructure and their subsequent scrappage and dismantling are included. The broadest level, SB5, adds emissions associated with the management of transport operations, ie office functions and the activities of staff (McKinnon and Piecyk, 2010).

CO_2 accounts for around 96 per cent of all direct GHG emissions from road transport (UK Air Quality Archive, 2008), thus the main focus should be on the CO_2 element. The latest set of conversion factors published by Defra (2013b) also contains emission factors for direct methane and nitrous oxide emissions as well as factors for indirect emissions associated with the extraction and transport of primary fuels, refining, distribution, storage and retailing of finished fuels. As such, the Defra data-set allows the users to calculate total SB1 and SB2 GHG emissions arising from their transport activities. The rest of this section focuses solely on direct (or SB1) GHG emissions.

The carbon footprinting of road freight operations would normally include Scope 1 and Scope 2 emissions, with Scope 3 emissions left to the reporting entity's discretion. All CO_2 emitted by freight vehicles owned and/or controlled by the company will be considered as Scope 1 emissions.

Scope 2 emissions would only arise from battery-powered operation of vans and small rigid vehicles recharged with purchased electricity from the grid. The transport of goods in vans or lorries owned or controlled by another entity would be classed as Scope 3 emissions (WBCSD/WRI, 2005).

Two approaches can be used to calculate CO_2 emissions from road freight operations:

- fuel based;
- activity based.

Fuel-based approach

The amount of fuel used in a carbon accounting period is multiplied by the standard GHG conversion factors for each fuel type (Table 2.1). Data on fuel consumption can be obtained from the following sources:

- Fuel receipts, showing the quantity and type of fuel purchased.
- Direct measurements of fuel use, for example, readings from fuel gauges or storage tanks.
- Financial records on fuel expenditures. Where no better data is available, reports on fuel expenditures can be converted to fuel consumption by using average fuel prices.

When using fuel receipts as the source of fuel consumption data, it is important to remember that not all fuel purchased may have been used in a calculation period. Any stocks remaining at the end of this period should be excluded from the carbon footprint estimate. Similarly, any fuel in the vehicle tank(s) at the beginning of the accounting period but purchased previously should be included in the calculations.

Activity-based approach

Emissions can be calculated by using activity-based conversion factors. In this case, data on activity level by vehicle type are needed. This should be available from a company's records, based, for example, on tachograph readings, despatch notes and other sources (WBCSD/WRI, 2005). The UK government produces a series of conversion tables to enable companies to convert their road freight activity levels into carbon footprints (Table 3.2).

Table 3.2 illustrates the fact that in terms of GHG emissions, for each category of vehicle (either rigid or articulated) the higher the gross vehicle weight (GVW) the higher the emissions per vehicle-km but the lower the emissions per tonne-km, suggesting that use of fewer, heavier vehicles is better for the environment than more, lighter vehicles. It is also interesting to note that on a tonne-km basis, rigid vehicles are actually more polluting than articulated ones. On a macro-level, it has been estimated that the heaviest articulated vehicles (with GVWs of over 33 tonnes) carry 75 per cent of all

TABLE 3.2 GHG conversion factors for heavy goods vehicles (vehicle-km and tonne-km basis, based on UK average load for each vehicle type)

Vehicle type (GVW tonnes)	Total vehicle-kms travelled	x	Conversion factor (kg CO_2e per vehicle-km)	Total direct GHG (kg CO_2e)	Total t-kms travelled	x	Conversion factor (kg CO_2e per t-km)	Total direct GHG (kg CO_2e)
Rigid >3.5t – 7.5t		x	0.59115			x	0.58396	
Rigid >7.5t – 17t		x	0.727571			x	0.35322	
Rigid >17t		x	0.974223			x	0.19186	
All rigids (UK average)		x	0.8315			x	0.24796	
Articulated >3.5t – 33t		x	0.890426			x	0.16159	
Articulated >33t		x	0.995873			x	0.08452	
All artics (UK average)		x	0.99587			x	0.08804	
All HGVs (UK average)		x	0.90765			x	0.12335	

SOURCE: Defra (2013b)

road tonne-kms (DfT, 2011) but are responsible for only around 47 per cent of all the external costs of road freight transport and for only 49 per cent of the total CO_2 emissions from HGVs. Conversely, rigid vehicles account for 48 per cent of the total external costs and 47 per cent of the CO_2 emissions while carrying only 22 per cent of all road tonne-kms (Piecyk and McKinnon, 2007). This is due to differences in the use patterns of these two categories of truck. Heavy articulated lorries move larger/heavier loads on long-haul, inter-urban trunk movements, where they achieve much higher energy efficiency than rigid vehicles, which typically distribute smaller, lighter loads on multiple-drop rounds within urban areas (DfT, 2011).

While vans (with a GVW of under 3.5 tonnes) run more kilometres per litre of fuel consumed than trucks, their much lower carrying capacity gives them a relatively high carbon intensity, expressed in terms of kg CO_2e per tonne-km (Table 3.3). Using a diesel-powered light commercial vehicle releases approximately the same GHG emissions as a small rigid vehicle per tonne-km, and a petrol-engined van produces considerably more.

The carbon footprint of road freight operations is strongly related to the capacity utilization of the vehicle. Table 3.4 shows its impact on carbon dioxide emissions for a typical articulated vehicle with a GVW over 33 tonnes. When a vehicle is empty, it still produces approximately two-thirds of the CO_2-related pollution of a fully laden vehicle, and the higher the vehicle capacity utilization, the lower the emissions per tonne of goods carried. Measures to improve vehicle utilization are examined in Chapter 11.

When deciding on the method of calculating carbon footprint, the fuel-based approach should be the preferred option as the fuel consumption records tend to be more reliable. However, if data are only available for an organization as a whole, this can require the calculation of a top-down estimate of the GHG emissions. In this case it may be difficult to disaggregate impacts by vehicle class. The activity-based (bottom-up) approach should then be used to allocate emissions to different vehicle classes in order to identify the most promising areas for improving energy efficiency and reducing GHG emissions. Disaggregated emissions data allow managers to target specific efficiency measures on particular categories of vehicles, types of operation or members of staff. Using both approaches simultaneously is not essential but it is a good way to validate calculations and ensure the reliability of the results.

In essence, the GHG emissions from road freight transport are a function of two factors: the nature of the vehicle and how it is used (Figure 3.5). In order to reduce GHG emissions from the road freight transport operation, managers can manipulate both sets of factors. As GHG emissions are directly proportional to the amount of fuel used, a reduction in fuel consumption will yield savings in CO_2e levels. Measures to improve the fuel efficiency of trucking are discussed in Chapters 8 and 11.

TABLE 3.3 Van/light commercial vehicle conversion factors based on a UK average vehicle load

Vehicle type (GVW tonnes)	Total vehicle-kms travelled	x	Conversion factor (kg CO_2e per vehicle-km)	Total direct GHG (kg CO_2e)	Total t-km travelled	x	Conversion factor (kg CO_2e per t-km)	Total direct GHG (kg CO_2e)
Petrol up to 3.5t		x	0.211149			x	0.687661	
Diesel up to 3.5t		x	0.250923			x	0.531951	
LPG up to 3.5t		x	0.264211			x	0.560122	
CNG up to 3.5t		x	0.241439			x	0.511844	

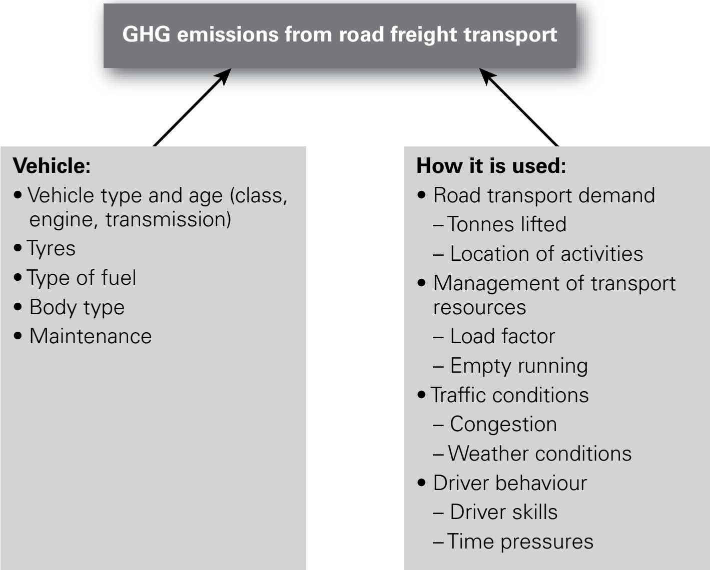
SOURCE: Defra (2013b)

TABLE 3.4 Conversion factors for one particular vehicle class at various capacity utilizations

	% weight laden	Total vehicle-kms travelled	x	Conversion factor (kg CO_2e per vehicle-km)	Total direct GHG (kg CO_2e)
Articulated vehicle >33t GVW	0		x	0.707793	
	50		x	0.940113	
	100		x	1.172433	
	62 (UK average)		x	0.995873	

SOURCE: Defra (2013b)

FIGURE 3.5 Factors affecting GHG emissions from road freight transport



Dividing GHG emissions among consignments on a road freight delivery

On ‘less-than-truckload’ (LTL) deliveries several consignments, belonging to different clients, share the same vehicle. These clients may request information about the amount of CO_2e allocated to their particular consignments. They may wish, for example, to factor this data into a calculation of their corporate carbon footprint or use it to estimate how much carbon offsetting they should purchase to make their distribution operation ‘carbon neutral’. Disaggregating the total amount of GHGs emitted by a freight delivery at a consignment level can be complicated (World Economic Forum, 2010). After all, the consignments can be moved between different locations and have differing weight, size and handling characteristics. A report published by the UK government acknowledges that ‘In practice, the mathematics required to definitively allocate carbon emissions from a specific multi-drop trip quickly become almost unworkably complex, requiring far more data than is likely to be available’ (DfT, 2010, p 33). It notes that there is no single objective way of making this allocation and suggests four methods, applicable to different types of delivery operation. In 2012, the European Committee for Standardisation (CEN) published internationally agreed standards for the measurement and reporting of energy consumption and CO_2 emissions from transport services at a disaggregated level (CEN, 2012). This standard, known as EN 16258, relates to freight movement by all transport modes, though does not currently apply to transport terminals and transhipment activities. Future editions of the standard will include terminal operation and transhipment.

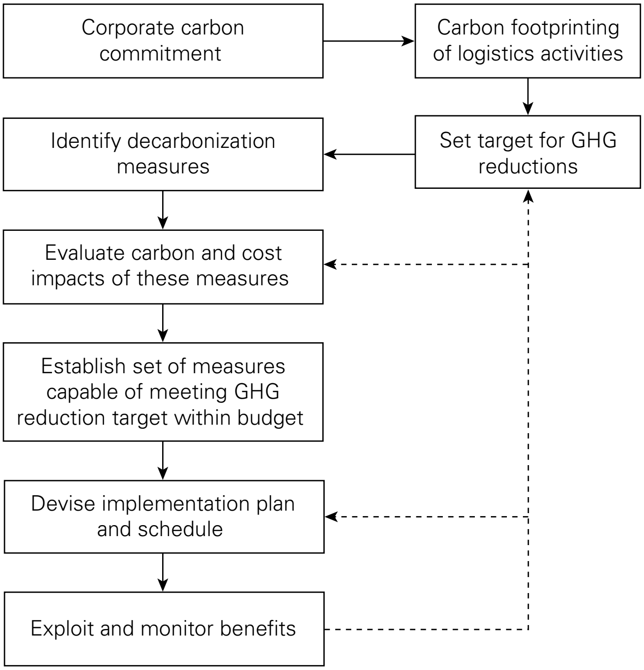
Next steps

As discussed earlier in the chapter, carbon footprinting should be the first step in a carbon management process. While various ways of reducing the GHG emissions from logistics activities are examined throughout the remainder of this book, this short section provides guidance on the development of a corporate decarbonization strategy for logistics.

A seven-stage procedure for developing a decarbonization strategy for logistics (Figure 3.6) was first developed by McKinnon (2011). It starts with an organization making a commitment to reduce GHG emissions from its logistical activities. The next step is to measure the logistics carbon footprint, preferably using a bottom-up approach. This helps to identify the most carbon-intensive processes and activities.

After the current carbon footprint and its likely business-as-usual trajectory are measured and understood by managers, a GHG reduction target can be set, possibly following guidelines advocated by McKinnon and Piecyk (2012). At the next stage in the procedure, a list of possible decarbonization

FIGURE 3.6 Development of a carbon reduction strategy for logistics



SOURCE: Adapted from McKinnon (2011)

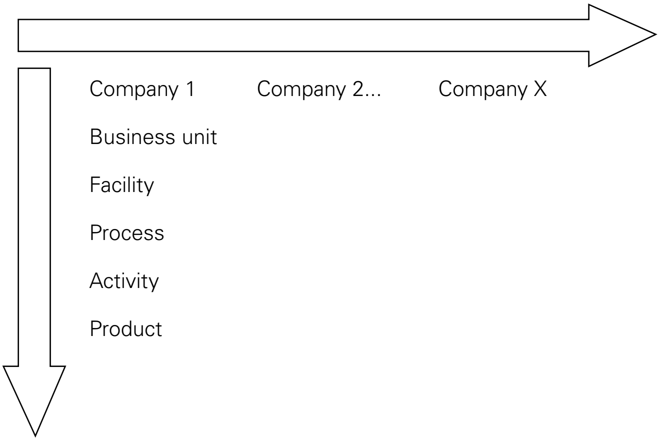
measures relevant to the company is compiled. The cost and carbon implications of each measure are then assessed to determine which combination of measures would achieve the target reduction in GHGs most cost-effectively. Use of reliable and unbiased data is essential to ensure the accuracy of this evaluation. Various tools can assist this process. For example, road freight transport operators can use the Carbon for Money Tool available at www.csrf.ac.uk to see a list of decarbonization measures for HGV fleets and get an estimate of the costs and carbon savings from particular packages of interventions.

At the seventh stage of the procedure, an implementation plan and schedule are devised. When the strategy is put into action, the economic and environmental impacts should be closely monitored. The results are then fed back into earlier stages of the procedure, making the development of the decarbonization strategy an ongoing and iterative process. As a result of these ‘feedback loops’, knowledge of logistics decarbonization accumulates within the business and measures become more finely tuned to its operational, financial and environmental requirements.

Conclusions

Although still a relatively new concept, the carbon auditing of business activities has evolved rapidly in recent years. To date it has been conducted mainly at a company level, promoted both by government regulation and voluntary initiatives such as the Carbon Disclosure Project (www.cdproject.net). It is now developing in vertical and horizontal dimensions (Figure 3.7). Its vertical extension involves the disaggregation of GHG data by business unit, process, activity and even product, giving managers deeper understanding of the carbon-generating characteristics of their businesses. At the same time, carbon footprinting is being extended horizontally from individual companies across supply chains, making it possible to track the amounts of GHGs released at different stages in the production and distribution of individual products.

FIGURE 3.7 Horizontal and vertical dimensions of carbon footprint



Several attempts have been made to use this data to label consumer products such as potato crisps and fruit juice. Given the complexity and high cost of product-level carbon auditing of supply chains, and uncertainty about consumer responses to carbon labelling, it is doubtful that this practice will become widespread, at least for the foreseeable future (McKinnon, 2010). Research suggests that the public finds it problematic to make sense of carbon labels, especially without the additional information needed to contextualize the product-specific carbon data. As a consequence, very little evidence has been found of consumers' willingness to use carbon labels for product selection (Upham *et al*, 2011). In January 2012, the supermarket chain Tesco announced that they had dropped plans to carbon-label their entire product range on the grounds that it was too time-consuming and expensive. The case study of carbon auditing in the road freight sector, however, illustrates how the disaggregation of GHG data to an activity, if not product, level can provide a quicker and more cost-effective means of finding opportunities for decarbonization within a logistics operation. As argued by McKinnon (2012), it is important in the carbon auditing of supply chains to measure emissions at a level appropriate for the intended purpose.

Note

1 A quoted company is defined as a company that is UK incorporated and whose equity share capital is listed on the main market of the London Stock Exchange UK or in an EEA State, or is admitted to trading on the New York Stock Exchange or Nasdaq.

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Evaluating and internalizing the environmental costs of logistics

04

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Introduction

All the environmental impacts of logistics impose costs. Some of these costs, arising for example from damage to business premises or injuries to employees, are borne by the company performing the logistics activities and appear in its balance sheet. Others have wider effects on the community and ecosystem that are not costed in the conventional sense and are excluded from a company's financial accounts. The term 'externality' is often used to describe these effects. A strong case can be made for estimating the costs of these externalities and 'internalizing' them within company budgets: in other words, applying the 'polluter pays' principle.

The proposition that wider environmental (or 'social') costs be internalized in higher taxes was originally advanced by Pigou (1920) and has been refined by other studies, many of which are reviewed in ECMT (1998), and more recently in Ricardo-AEA (2014). Environmental pressure groups have campaigned for many years for full internalization of the external costs of transport, arguing that, in the absence of such internalization, markets will be distorted to the detriment of the environment. National governments and international organizations, most notably the European Commission, have accepted the need for such internalization. The 'fair and efficient pricing' policy promoted by the European Commission (2001, 2006 and 2011) aims to ensure that all external damage caused by personal and freight movement is fully internalized in the price of transport. It argues that pricing should be fair, meaning that 'polluters' are obliged to pay the marginal social cost of their activities, and efficient, giving them an economic incentive to reduce the negative effects of these activities (EEA, 2006).

The Eurovignette Directive 1999 (1999/62/EC) put in place a framework that allowed member states to levy road charges on heavy goods vehicles for using roads on the Trans-European Network (TEN-T). However, these tolls and time-based charges could only be set at levels that reflected the maintenance and replacement of infrastructure; it prohibited the recovery of external costs such as air pollution and noise costs (European Council, 1999; Liepe *et al*, 2011). The Commission funded a major study of the issues to be resolved in applying the polluter-pays principle to transport (CE Delft, 2008; Baum *et al*, 2008) and then began negotiating with the European Parliament and Council of Ministers on how it could be implemented. In 2008 the Commission recommended amending the Eurovignette Directive to allow member states to levy tolls and time-based charges on HGVs on all motorways based not only on infrastructure costs, but also on air and noise pollution. A marginal social cost pricing methodology was proposed European Commission (2008). The amended Eurovignette Directive (2011/76/EU) relating to the charging of HGVs for use of major European motorways prescribes that, from 2013, member states may include air pollution costs in any charging structure for roads under the Trans-European Network and for comparable domestic motorways. This inclusion can be justified on the grounds that HGVs are the biggest road transport emitters of air pollution, accounting for approximately 40–50 per cent of road transport NOx emissions in EEA member countries (NERI, 2011). The recent classification of diesel engine exhaust fumes as being carcinogenic to humans (IARC, 2013) strengthens the case for linking charges to emissions. GHG emissions, on the other hand, are not covered by the Directive because of their global rather than local impacts (European Council, 2011).

HGV road user levy

From 1 April 2014, an HGV road user levy was introduced for all trucks with a revenue-earning payload weight of 12,000 kg and over which use the UK road network. The HGV levy rates are based on infrastructure costs, ie are aimed at ensuring these vehicles make a contribution to the wear and tear of the UK road network. The rates are based on time, axles and weight, with the heaviest vehicles paying the most. The scheme also aims to ensure fairer competition between UK hauliers and those from other countries. It is essentially a charging scheme for non-UK-registered HGVs, with costs remaining broadly neutral for the vast majority of UK-registered HGVs covered by it.

The levy can be paid on a daily, weekly, monthly or annual basis and there is a maximum daily charge of £10 and a maximum annual charge of £1,000. For UK-registered HGVs the levy will be paid alongside vehicle excise duty (VED) in a single transaction to minimize administration costs. For 90 per cent of UK-registered HGVs the cost of the levy will be fully offset by reductions in VED. For non-UK-registered HGVs, levy payments must be made before the vehicle enters the UK. There are online payment and 'pay and go' options (by telephone and at a limited number of point-of-sale terminals on ferries and truck stops). HGVs do not display any physical sign of payment; instead the levy payment is recorded in a database using the vehicle registration number as the unique identifier. This data is publicly available to allow anyone to check the levy status of an HGV (by entering its registration number). HGVs failing to pay the levy will receive a £300 fixed penalty notice (or, in the case of non-UK vehicles, be required to pay a deposit at the roadside).

There are approximately 260,000 UK-registered HGVs with a gross weight of more than 12 tonnes (out of a total UK HGV fleet of 465,500 vehicles). It is estimated that approximately 130,000 non-UK-registered HGVs enter the country each year, making a total of 1.5 million trips.

In Europe and elsewhere, companies and trade bodies often oppose internalization, partly as a matter of principle, but also because of the practical difficulties encountered in attaching monetary values to environmental and social effects and in devising an acceptable method of translating these values into charges on businesses and individuals.

In the next section, we review the arguments for and against internalizing the external costs of logistics. The third section explains how economists have placed monetary values on the range of environmental effects discussed in Chapter 2, primarily the emission of air pollutants and greenhouse gases, traffic noise and accidents. The remainder of the chapter provides several case studies which assess the external costs of goods vehicles, as well as schemes that aim to internalize these costs through charging systems.

Arguments for and against the internalization of environmental costs

The case for levying environmental taxes rests mainly on three arguments. First, on grounds of social justice, it seems only fair that a company should be made to pay for any damage that it inflicts on the environment. The environment, after all, should not be seen as a 'free good' that businesses and citizens can exploit and despoil with impunity. Second, internalizing environmental costs gives companies a financial incentive to reduce their level of pollution. It forces them, for example, to take account of environmental costs when appraising new investments. The third argument is that the imposition of environmental taxes raises additional revenue that can be used to fund a range of green initiatives, including:

- pollution-mitigation measures, such as noise barriers and double-glazing along busy roads;
- compensation for individuals and businesses adversely affected by the environmental effects;
- financial inducements to companies to 'green' their operations, reinforcing the effects of the environmental taxation.

There is no guarantee that governments will hypothecate 'green' taxes to finance environmental projects. But even where the revenue is absorbed into general taxation, some of it can still be spent on environment-related activities.

Numerous arguments have been advanced against internalizing the environmental costs of transport. Some object to this policy at a fundamental level while others question its practical application.

The economic logic underpinning the polluter-pays principle has been challenged by Coase (1960) and others, who reject the view of the environment being a 'victim' subject to harm inflicted by a polluter who must be charged accordingly. Their alternative view sees externalities as being caused by all the parties involved and the objective as finding the most economically efficient way of dealing with the problem. Coase advocated an alternative 'cheapest cost-avoider' principle that determines which party can prevent or mitigate the adverse environmental effects at minimum cost. This can be the polluter, in which case 'the cheapest cost-avoider analysis incorporates "polluter pays" as a possible outcome' (Schmidtchen *et al*, 2007). In other situations, however, it may be cheaper for the 'pollutee' to take the necessary action. For example, it might be cheaper to erect sound barriers along busy roads than to impose a charge on truck traffic to recover notional noise costs. It is argued that forcing the polluting company to pay for all the environmental damage caused does not necessarily maximize economic welfare. Some organizations representing the road freight sector, such as the IRU (2008), have used these arguments to challenge the current efforts of the EU to internalize the environmental cost of freight transport.

Maddison *et al* (1996), on the other hand, question the applicability of Coase's theory to transport. For them the key questions are who 'owns the relevant property right to the environmental amenity' and how the 'generator of the pollution' and the 'victim' can bargain. Given the huge number of organizations responsible for logistics-related externalities and the even larger number of 'victims', such negotiation would be impractical. The delayed effect of many of the externalities, such as climate change, also makes it impossible for those responsible for pollution today to enter into transactions with those who will suffer the consequences decades from now. Maddison *et al* also point out that 'some important environmental amenities, like air quality, [are] "public goods", meaning that the benefits of reduced pollution are not specific to the individuals who contribute to their upkeep.' So the 'cheapest avoider' principle also has significant shortcomings, particularly when applied in the transport arena.

Another complaint sometimes levelled at the polluter-pays principle is that there is no guarantee that internalizing environmental costs will raise the price of logistical activity sufficiently to induce the behavioural change necessary to get pollution down to an acceptable level. There is a greater likelihood of the desired environmental outcome being achieved if the extra tax revenue raised is invested in environmental initiatives. As mentioned earlier, however, it often goes into general taxation. The imposition of environmental taxes can also have an undesirable second-order effect by reducing the financial resources available to freight operators to upgrade their vehicle fleets and to introduce other green measures.

Further problems can emerge when the polluter-pays principle is not applied uniformly across a national economy. If it is being more rigorously applied in one sector than in others, this will cause market distortions and unfairness in the implementation of environmental policy. Market distortions can also occur geographically, where environmental costs are internalized to differing degrees and in different ways within neighbouring countries and regions. This is well illustrated by the European road haulage market where the proportion of environmental and congestion costs recovered by taxation varies enormously from country to country (see the case study on page 92 on the 'Internalization of external HGV costs'). As the variation in truck taxation is due mainly to differences in fuel duty, carriers can gain a competitive advantage by purchasing their fuel in countries where duty levels are low (indulging in a practice known as 'tank tourism') (ECMT, 2003). Foreign hauliers entering the UK market, for example, purchase almost all their fuel in neighbouring countries. It was estimated in 2008 that this gave them a 6–7 per cent price advantage in the UK market over domestic hauliers. This partly explains the steep increase in cabotage in the UK road freight market over the past decade.[1] Britain's 'fuel duty escalator' policy which, between 1994 and 1999, annually increased fuel taxes by 5–6 per cent in real terms, ostensibly for environmental reasons, largely precipitated the 'fuel crisis' of September 2000 when truckers and farmers blockaded oil refineries and blocked roads. This highlighted the difficulty of a single country trying to introduce a radical environmental tax policy unilaterally within an open, international market.

Some critics of internalization have also questioned the validity of the monetary valuations of externalities. They point to inconsistencies in the approaches and methods used, the large amount of subjective judgement that often has to be exercised and the general uncertainty about many of the values. Evidence of this uncertainty can be found when comparing the results of different studies of the environmental costs of transport (ECMT, 2003).

Estimates of the total external costs of transport in the EU in the early 2000s, for example, vary by a factor of four, between 129 billion euros (UNITE, 2003) and 650 billion euros (INFRAS, 2004). Such variability undermines confidence in the economic basis of internalization policies. Despite these reservations, the detailed review of internalization methodologies carried out recently for the European Commission concluded that 'the scientists have done their job. Although the estimation of external costs has to consider several uncertainties, there is consensus at a scientific level that external costs of transport can be measured by best practice approaches and that general figures (within reliable bandwidths) are ready for policy use' (CE Delft, 2008: 13).

The general message is that the internalization of environmental costs is not a panacea, is controversial and difficult to implement. Its effectiveness as a policy measure depends on the way in which it is applied and coordinated with other sustainability measures.

Monetary valuation of environmental costs

As discussed earlier, externalities are not normally taken into account in the decisions made by transport users. Internalization aims to correct this anomaly by increasing the price of transport services in proportion to all the relevant social and environmental costs imposed (Beuthe *et al*, 2002; Baublys and Isoraite, 2005). Placing an appropriate value on the external costs of freight transport is therefore fundamental to their internalization.

The external costs normally included in this calculation relate to the negative effects of air pollution, greenhouse gas emissions, noise, accidents and traffic congestion. Freight vehicles' contribution to the cost of providing, operating and maintaining transport infrastructure is not an externality as such, but has to be calculated to determine its share of the taxes paid by freight transport. It is out of the remaining taxes that the environmental and congestion costs can be recovered. For this reason, internalization calculations have to include freight vehicles' allocated share of infrastructure costs.

It is possible to attach monetary values to externalities in many different ways. A broad distinction can be drawn between methods that try to value the damage done to the environment, the so-called 'damage function' approach (Adamowicz, 2003), and those that estimate the cost of avoiding this damage.

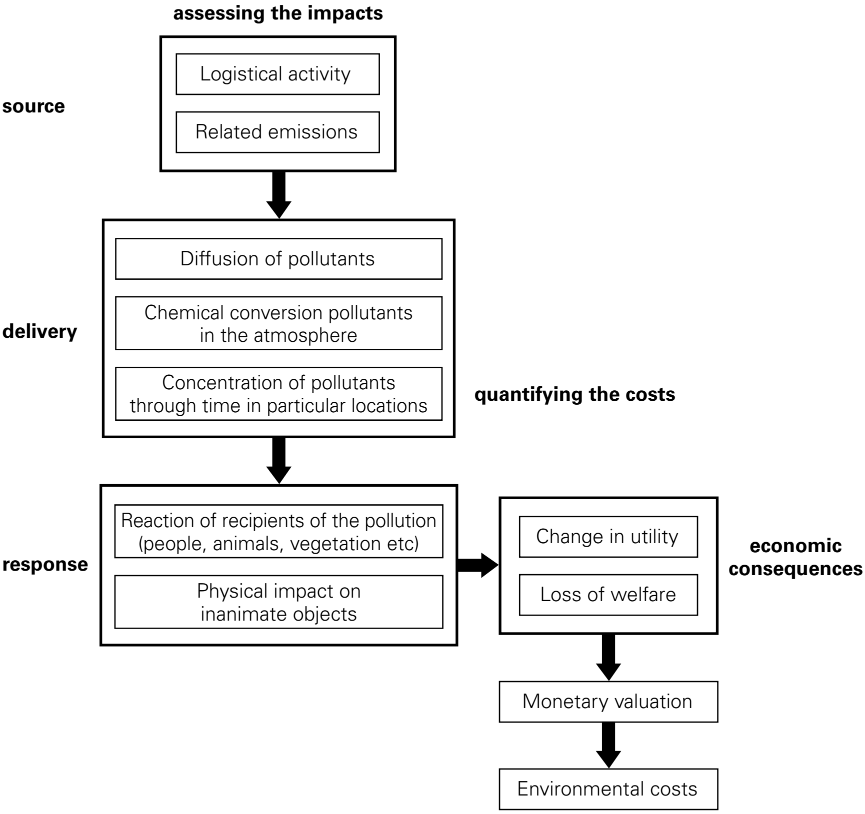
Cost of environmental damage

Some of the physical damage can easily be measured and costed. For example, a vehicle accidentally crashing into a building will inflict structural damage. This externality would be valued by adding the cost of repairing the damage to other losses incurred while use of the building is constrained. Often, however, the damaging effects of logistical activity are much less direct and observable. The adverse health effects of atmospheric pollution, for example, are much more difficult to quantify and cost. Freight vehicles, after all, may be only one of many sources of a particular pollutant, and that pollutant may be one of many factors contributing to ill-health. Placing a monetary value on health problems exacerbated by pollution, such as asthma, is also fraught with difficulty as it should take account of subjective valuations of the patient's reduced quality of life (and possibly death) as well as more tangible costs, such as the cost of providing medical treatment and loss of output while the patient is unable to work. Even if the degradation of a local environment affected by traffic pollution, noise and vibration does not cause significant health problems, local citizens can still perceive a loss of amenity and this too must be valued.

In making monetary valuations of environmental effects such as air pollution and noise, researchers generally employ the Impact Pathway Approach, originally devised for a major EU study called ExternE on the external costs of energy production (European Commission, 2003). This comprises a series of measurements, some assessing the physical impact of the emissions, others monetizing this impact (Figure 4.1). The approach starts by calculating the emissions from a logistics activity, charting their diffusion and, in the case of gases, their chemical conversion and concentration at different spatial scales. The next stage is an examination of the response of 'receptors' (eg people, animals, vegetation, physical objects) to these emissions, using so-called 'dose-response' models. These responses will normally be negative, representing losses of welfare and environmental quality. These losses are quantified and translated into monetary values. Two general methods are used to derive these monetary values (Mitchell and Carson, 1989):

- Stated-preference surveys: in these surveys people are generally asked how much they would be willing to pay (WTP) to have the externality removed or willing to accept (WTA) in compensation. The most commonly used stated-preference technique is the Contingency Valuation Method. This has three elements: 'a description of the scenario in which the respondent is to imagine himself placed; questions from which values are to be inferred… and questions relating to the respondent himself' (Maddison *et al*, 1996). The survey context is inevitably fairly artificial and the responses can be partly conditioned by the way the questions are asked.
- Revealed-preference studies: it is sometimes possible to infer an environmental cost from actual changes in people's behaviour. For example, as people generally prefer not to live beside a busy road, there will be less demand for housing along the route and this will be reflected in lower property prices. The house price differential between an area seriously affected by traffic noise and pollution and another area comparatively free of these externalities can be used to

FIGURE 4.1 Impact Pathway Approach to valuing environmental effects



SOURCE: Adapted from Bickel and Friedrich (2005)

monetize their negative effects (using so-called 'hedonic pricing methods'). This method too can be problematic, however, as environmental quality is only one of several factors likely to influence house prices in an area.

One of the most contentious issues in the field of environmental economics is the monetary value to be placed on a human life lost as a result of an accident or pollution (Adams, 1981). Almost everyone would be likely to place an infinite value on their continued existence, but it is not possible to factor infinite values into the cost side of the internalization equation. Instead economists have derived ways of calculating the 'value of a statistical life', which is defined 'as the marginal willingness to pay to avoid the risk of a fatal accident aggregated over a large number of people' (Maddison *et al*, 1996). This value can be estimated by a mix of stated and revealed preference enquiries. A stated-preference survey can ask how much people are prepared to pay to reduce the risk of a fatal accident by a given percentage, while revealed preferences can be observed in the wage premium paid to workers in more dangerous jobs, and in insurance premiums.

Cost of avoiding environmental damage

Rather than assessing the cost of the environmental damage once inflicted, one can try to calculate what it would cost to avert it. Often the objective is not to eliminate the environmental effect completely but to reduce it to what, in public policy terms, is considered to be an acceptable minimum. This approach, for example, had been used by the UK government in estimating a 'shadow price' for carbon that assumes the concentration of CO_2 in the atmosphere will be limited to 550 ppm by 2050 (Defra, 2007). Account must be taken of the cost of the various measures that would have to be implemented to meet this target. A range of mitigation measures can also be applied at the local level to minimize the environmental impact of logistics, such as sound-proofing, locating distribution centres away from residential areas and switching to battery-powered vehicles. The additional cost of these measures can be used as a surrogate value for the environmental impact.

Summary of environmental costs

Different methods are used to attach monetary values to the various externalities. Table 4.1 summarizes the adverse effects of the range of externalities associated with logistical activity, identifies their key cost components, outlines the main methods used to value them and lists some of the major studies that have undertaken this valuation. Table 4.2 presents some of the monetary values that have been derived in the EU for key elements in the external cost calculation for transport (CE Delft, 2008).

In attaching monetary values to the future external effects of logistical activities performed today, economists must apply a discount rate to calculate their net present value. The choice of discount rate is discussed by Ricci and Friedrich (1999) and others, and has become a very contentious issue in the estimation of a social cost (or shadow price) for CO_2. Stern (2006), for example, has been criticized by Nordhaus (2006) and others for setting the discount rate too low in his analysis of the economics of climate change and thereby exaggerating its long-term social costs.

Two organizations have recently updated the valuation of the external costs of transport in Europe:

- In 2013, the European Environment Agency (EEA) published updated estimates of the external costs of air pollution for different categories of heavy goods vehicles (HGVs). The report provides tables for the external costs of air pollution for each EU country and HGV category (EEA, 2013).

TABLE 4.1 Nature, costs and valuations of logistics-related externalities

Externality	Adverse effects	Cost elements	Methods of valuation	Studies
Air pollution	Ill-health Discomfort Agricultural damage Other vegetative damage Physical damage to buildings	Medical treatment Value of statistical life/years lost Personal suffering Loss of agricultural output Loss of biodiversity Loss of amenity/landscape value Building value loss/repairs	Healthcare costs analysis Labour output analysis WTP/WTA assessments Agricultural surveys RP analysis or property prices Building repair costs	ExternE (EC, 2003) INFRAS (2004) UNITE (2003) COPERT (2009) TREMOVE (2009) Ricardo-AEA (2009)
Climate change	Sea-level rise Extreme weather events Animal extinctions Water shortages Agricultural damage Other vegetative damage Human health problems Ecosystem destruction	Medical treatment Value of statistical life/years lost Personal suffering Loss of agricultural output Loss of biodiversity Loss of amenity/landscape value Flood protection Population relocation Physical adaptation etc	Use of climatic models to predict temperature rise Assessment of future damage to human activity/ecosystems Costing of the damage Calculation of marginal abatement costs	Stern (2006) INFRAS (2004) COPERT (2009) TREMOVE (2009) Ricardo-AEA (2009)
Noise	Irritation Sleep disturbance Ill-health	Medical treatment Personal suffering Loss of amenity Building value loss/repairs Soundproofing	WTP/WTA assessments RP analysis or property prices Estimate of soundproofing cost	INFRAS (2004) UNITE (2003) COPERT (2009) TREMOVE (2009) Ricardo-AEA (2009)
Traffic accidents	Death and injury to humans and animals Damage to property	Medical treatment Value of statistical life/years lost Personal suffering Building value loss/repairs	Healthcare costs analysis Labour output analysis WTP/WTA assessments Costing of property damage	INFRAS (2004) UNITE (2003) COPERT (2009) TREMOVE (2009) Ricardo-AEA (2009)

TABLE 4.2 Mid-range valuations of external costs

Health-related costs of air pollution:	**Euros**
Mean value of a statistical life	2,000,000
Mean value of life year lost	120,000
Case of chronic bronchitis	190,000
Hospital admission with respiratory/cardiac problem	2,000
Loss of day's output through ill-health	83
Climate change (2010 central value):	
Per tonne of CO_2	25
Noise-related costs per person/annum (from road traffic – Germany):	
Noise level Lden dB(A) ≥70	175
Noise level Lden dB(A) ≥80	365
Traffic accident:	
Fatality	1,815,000
Severe injury	235,100
Slight injury	18,600

- In 2014, Ricardo–AEA prepared a report for the European Commission providing the most recent estimates of the external costs associated with accidents, congestion, noise, climate change and air pollution, infrastructure wear and tear and other upstream and downstream environmental impacts of passenger and freight transport (Ricardo-AEA, 2014).

Estimates presented in both reports are given in 2010 prices, and reflect scientific developments since the publication of the 2007 Handbook of external costs (CE Delft, 2008).

Cost of traffic congestion

Congestion is not, in the strict sense, an environmental externality, since its effect on transport cost is taken into account by carriers and reflected in their pricing (Beuthe *et al*, 2002). However, an extra vehicle entering the road system causes delays to the other vehicles on the network, imposing an additional cost upon them known as the marginal congestion cost (Sansom *et al*, 2001). Thus, road users should be required not only to absorb the direct cost of congestion which they experience themselves, but also the marginal cost they impose on other road users (Beuthe *et al*, 2002).

Traffic congestion also has an adverse effect on fuel consumption and the emissions of CO_2 and other noxious gases. When the traffic speed drops below 20 kmph, fuel consumption and CO_2 emitted per vehicle-km rise steeply (SMMT, 2005). It has also been estimated that, for a 40-tonne articulated lorry, making 'two stops per kilometre leads to an increase of fuel consumption by roughly a factor of 3' (International Road Union, 1997). The related environmental effects of traffic congestion are generally recorded separately under the air pollution heading.

Use of marginal or average/aggregated costs for externalities

Externalities can be valued on a marginal or average cost basis. The former should involve a 'bottom-up' analysis of the additional external costs imposed by an extra freight vehicle joining a traffic flow. External costs, on the other hand, can be averaged by vehicle, trip or freight consignment, by dividing a 'top-down' estimate of total environmental costs by the total number of units. In the case of those external costs whose relationship with traffic volumes is non-linear, such as congestion and noise, the marginal costs can be much higher than the average costs. The choice of costing method depends on the objectives of the exercise and 'nature of the policy question being addressed' (Ricci and Friedrich, 1999). The use of marginal costing is more appropriate in assessments of the cost-effectiveness of sustainability measures targeted on specific traffic flows. For example, the application procedure for Freight Facilities Grants in the UK, which, until their abolition in 2011, were designed to divert specific freight flows from road to rail, employed marginal costing to estimate the monetary value of the 'sensitive lorry miles' saved, namely 'the valuation of the environmental and other social benefits of removing one lorry mile of freight from road and transferring it to rail or water' (DfT, 2009). Where the objective is to compare, at a macro level, the total taxes paid by freight vehicles with the total infrastructural and external costs they impose, average or aggregated values are more applicable. This was the approach adopted in an internalization study of European road haulage for the European Federation of Transport and Environment (CE Delft, 2009) and in our research on the UK road freight sector (summarized in case study 1).

Goods vehicle external costs: Case studies

Case study 1: Internalization of the external costs imposed by road freight vehicles in the UK

(**SOURCE**: Piecyk *et al*, 2012)

This research focused on the extent to which the taxes paid in the UK by lorries (or heavy goods vehicles – HGVs), with gross weights of over 3.5 tonnes, and vans (or light goods vehicles – LGVs), with gross weights of up to and including 3.5 tonnes, covered their environmental, congestion and infrastructure costs, based on vehicle activity levels and costs in 2006.

It was calculated that in 2006 nearly £5.8 billion was collected in diesel fuel duty, vehicle excise duty (VED) and VAT paid by HGV operators and £4.12 billion by LGV operators. In the case of HGVs, 95 per cent of the revenue was from fuel-related taxes and only 5 per cent from VED. For LGVs, the corresponding proportions were 90 and 10 per cent. The full external costs of HGVs were estimated at £8.6 billion, £8.7 billion and £8.9 billion using, respectively low, medium and high values for emission costs (Table 4.3). The heaviest articulated vehicles (with gross weights of over 33 tonnes) carried 72 per cent of all road tonne-kms (DfT, 2007) but were responsible for only around 45 per cent of all the external costs of road freight transport. Conversely, rigid vehicles accounted for 49 per cent of the total external costs while carrying only 24 per cent of total tonne-kms. These differing proportions show how larger/heavier trucks have lower external costs per tonne-km, assuming loading factors and empty running figures at 2006 levels. The relationship between van activity and infrastructure, congestion and environmental costs was modelled in the same way as for HGVs. The full infrastructural, congestion and environmental costs of LGV traffic were estimated at £7.6 billion, £7.7 billion and £7.8 billion using, respectively, low, medium and high emission cost values (see Table 4.3).

TABLE 4.3 Total external costs of LGV and HGV operations in the UK in 2006

2006 (£ million)	LGVs	HGVs	Total
Low estimate	7,569	8,579	**16,148**
Medium estimate	7,690	8,744	**16,434**
High estimate	7,708	8,945	**16,653**

Overall, 42 per cent of the total external costs of HGVs were attributable to congestion, 22 per cent to infrastructure, 20 per cent to traffic accidents, 14 per cent to air pollution and greenhouse gas emissions and only 2 per cent to noise. By comparison, 73 per cent of the total external costs of LGVs were attributable to congestion, 17 per cent to traffic accidents, 8 per cent to air pollution and greenhouse gas emissions, 2 per cent to noise and only 1 per cent to infrastructure (Table 4.4). Climate change costs represented around 9 per cent of the total external costs of HGV operations, and 5 per cent of the total external costs of LGV operations.

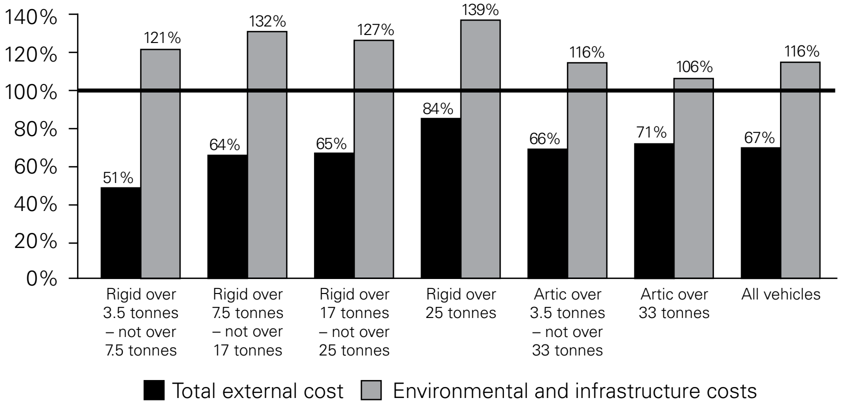
Figure 4.2 shows the extent to which the taxes and duties paid by different classes of HGV covered their allocated external costs using medium estimates of air pollution costs. The duties and taxes paid internalized on average 67 per cent of the total external costs (ie environmental, congestion and infrastructure costs) imposed by UK-registered HGVs in the UK in 2006. In the case of rigid HGVs, between 51 and 84 per cent of the costs were recovered by taxation, depending on the weight class of the vehicle. The taxes paid by articulated vehicles with gross weights in excess of 33 tonnes internalized roughly two-thirds of the externalities. Congestion costs constituted approximately 42 per cent of the full external costs of HGV traffic in the UK. If these congestion costs are excluded, it appears that taxes exceeded the value of the remaining externalities for all of the HGV weight classes. In 2006, the average truck in the UK paid 16 per cent more in duties and taxes than its allocated infrastructural and environmental costs (excluding congestion costs).

TABLE 4.4 Importance of external cost categories for LGV and HGV operations in the UK in 2006

2006 (proportion of total external cost)	LGVs	HGVs
Emissions	8%	14%
Infrastructure	1%	22%
Noise	2%	2%
Congestion	73%	42%
Accidents	17%	20%
Total	100%	100%

NOTE: Based on medium emissions cost values

FIGURE 4.2 Internalization of external costs by HGV category



The duties and taxes paid by LGV operators covered on average 54 per cent of the total external costs in 2006. If congestion costs were excluded, the taxes substantially exceeded the value of the remaining infrastructure and environmental costs for all categories of LGV, with the average LGV paying approximately twice its allocated infrastructural and environmental costs in duties and taxes. Congestion comprises a far greater proportion of total external costs for LGVs than for HGVs, reflecting the fact that LGV operations tend to be concentrated in and around urban areas, whereas HGVs run much of their annual mileage on less congested inter-urban trunk roads. Infrastructure costs, on the other hand, represent a much larger share of HGV costs because their heavier axle weights cause greater wear and tear on the road surface.

In the light of more recent reassessments of the impact of climate change, these estimates of the degree of internalization may turn out to be too optimistic. Stern (2006) suggests that this element of external costs may have a significantly higher value than previously assumed. If so, the tax-to-cost ratio would be lower than calculated, reinforcing the case for sustainability measures to reduce the environmental damage done by HGVs. The Stern review argued that the cost of CO_2 should be around £72 per tonne in 2006 prices – roughly three times higher than the medium value of the shadow price of carbon factored into the above calculations. The adoption of this value would reduce the overall degree of external cost internalization for HGV operations in the UK to 57 per cent.

Case study 2: Calculation of external costs of freight transport and development of a total cost tool for internalizing logistics and environmental externalities in Sweden

(**SOURCES**: Andersson *et al*, 2013; Fridell *et al*, 2011, 2013)

A tool was developed to calculate the emissions and external costs of freight transport options differing by route, vehicle type and mode. It calculates the number of vehicles/vessels that would be required based on the mass and volume of goods, as well as reporting logistics cost, external costs and environmental performance. The outputs comprise pollutant emissions, fuel consumption and the external costs of both emissions (CO_2, NOx, SO_2, CO, HC and PM) and other externalities (noise, congestion, accidents, upstream and downstream effects, nature, soil and water).

The tool can be used to analyse the potential effect on the overall performance of the logistics system of changing goods transport arrangements. It combines economic and environmental objectives and variables in assessing transport efficiency and effectiveness (expressed in terms of total logistics costs), and environmental and other external impacts (expressed in terms of external costs). The authors argue that such a model needs to take account of both logistics service deficiencies as well as external social and environmental impacts, so that companies and others can understand their size and importance, and factor them into the decision-making processes.

The model has numerous data inputs. The logistics cost module requires: direct transport cost; value of the goods; packaging cost; warehousing and inventory carrying costs; costs arising from loss of goods; the value of early delivery; delay costs; administrative costs and customs costs. The environmental cost module needs information about the goods; the distance they travel; transport mode; vehicle type; type of location; load factors; and the timing of the delivery. Where user data is not available, it can be substituted with default values built into the model. The emission factors for each mode and external cost values are drawn from different sources.

Several pilot studies have used this cost analysis tool to develop insights into the behaviour of different actors and assess the feasibility of the model. These studies have shown that the tool can be used by shippers to identify opportunities for efficiency improvements, and report logistics costs, external costs and environmental performance.

Case study 3: Internalization of external effects in European freight corridors

(**SOURCE**: Mellin *et al*, 2013)

This project was carried out by VTI at the request of the Swedish governmental Agency Trafikanalys (Transport Analysis), which must report annually on the extent to which the external costs of passenger and freight transport are internalized, ie to which the marginal external costs are covered by charges or taxes. The Agency wanted in its 2013 report to provide examples of how these marginal costs and the corresponding taxes and fees vary within and between European countries. For this purpose, VTI analysed 10 freight routes in Europe within the Narvik (Norway)–Naples (Italy) and Oslo (Norway)–Rotterdam (the Netherlands) corridors, comprising road, rail and seaborne services.

The results indicate that the internalization ratio varies considerably by mode, country and route. The internalization ratio was found to be highest for road and rail transport, and lowest for sea transport. For land based modes, the rates of internalization were higher in the Oslo–Rotterdam corridor than in the Narvik–Naples corridor.

The external costs of road transport differed between the countries, varying per vehicle-km by between 0.16 and 0.40 euro. This difference is attributed mainly to the share of truck movement on motorways and in urban areas. In terms of taxes and charges, whether a Eurovignette or road toll is levied is important as the countries with road tolls achieve a higher internalization ratio (eg Germany, Italy and Austria). Bridge toll fees also strongly affect the degree of internalization on the routes between Oslo and Rotterdam.

The results for rail freight also show differences between the countries. For example, rates of internalization in Sweden are below 50 per cent for both routes studied, suggesting that the level of taxes and charges is not sufficiently high to fully compensate for the negative externalities. Several countries have rail internalization ratios substantially above 100 per cent. A large proportion of the external costs incurred along the rail corridors studied was attributed to wear and tear. The ability of governments to recover these external costs through the charging system was also crucial in determining the degree of internalization for rail traffic.

The authors note that uncertainties in the valuation of external costs require a cautious interpretation of their results. However, even taking this uncertainty into account, the research quite accurately measured the impact of different transport policy decisions on internalization, both by mode of transport and by country.

Case study 4: The heavy vehicle fee (HVF) in Switzerland

(**SOURCE**: Swiss Federal Office for Spatial Development, 2012)

Concern among Swiss politicians about the growth in road-based transit traffic across the Alps culminated in the adoption of a constitutional article for the protection of the Alps in 1994. In 1998, a federal law introducing the LSVA (Leistungsabhängige Schwerverkehrsabgabe) or heavy vehicle fee (HVF) was approved by national referendum. The HVF started on 1 January 2001. Switzerland's desire to limit Alpine HGV traffic led to tensions with the EU which demands unhindered free movement of goods. Negotiations led to the 2002 Land Transport Agreement between Switzerland and the EU which oversaw the lifting of the 28-tonne weight limit on Swiss roads (which thereafter was gradually increased to 40 tonnes).

The HVF was introduced to encourage more sustainable freight transport and mode switch from road to rail. The HVF is charged per vehicle-km travelled by vehicle type, relating directly to vehicle use and differentiated according to EU Euro engine emission categories. It applies, on a non-discriminatory basis, to both domestic and foreign vehicles and to transit and domestic traffic. As a result, road freight traffic has become more efficient and environmentally friendly and the number of empty trips has decreased. At the same time, the inclusion of costs for accidents and environmental pollution has meant that the principle of true costs could be implemented, improving the relative competitiveness of rail. The rail network for transalpine crossings has been expanded with the construction of two new base tunnels at Lötschberg and Gotthard.

The HVF has increased progressively since it was introduced; from 1.6 Swiss cents per vehicle-km and tonne of total vehicle weight in 2001, to 2.44 Swiss cents in 2005 and 2.70 in 2008. This is the average fee for HGVs which is then adjusted plus and minus 15 per cent to calculate a lower, middle and higher fee for HGVs depending on their Euro engine emission standard. The increase in the HVF over time is intended to reflect the increase in external costs imposed by HGV activity in Switzerland.

The HVF is intended to internalize all road freight transport costs including the costs of external impacts such as environmental and health costs. To calculate the fee, the Swiss Transport Department carried out studies of the monetary costs of health impacts and damage to buildings caused by air pollution as well as the costs of noise and accidents associated with HGVs. The total external cost of goods transport by road was calculated to be approximately 1,000 million Swiss francs per annum. These calculations have been updated over time. New impacts have also been included in the calculations such as 'landscape fragmentation', damage due to climate change and traffic congestion. It is calculated that HGV traffic currently causes external costs of 1,554 million Swiss francs. Taking into account existing direct costs of 75 million Swiss francs, the HVF needs to collect 1,479 million

Swiss francs in order to achieve full internationalization. In 2008, the HVF revenue totalled 1,441 million Swiss francs.

A detailed study of the effects of the HVF in 2006 (together with the associated relaxation of truck weight limits) found that total vehicle-kms travelled by HGVs decreased by 6.4 per cent between 2001 and 2005, while the tonne-kms increased by 16.4 per cent. The HVF accounted for 28 per cent of the vehicle-kms saved while the increase in weight limits accounted for the remaining 72 per cent. However, since 2006 HGV vehicle-kms have significantly increased.

Case study 5: Effects of lorry charging in Germany, Austria and the Czech Republic

(**SOURCE**: Transport and Environment, 2010)

A project commissioned by Transport & Environment (T&E) investigated to what extent hauliers and shippers respond to changes in transport costs, and what happens to overall demand for freight transport by road if prices change (Transport & Environment, 2010; de Jong *et al*, 2010). Part of this study focused on HGV charging schemes in Germany, Austria and the Czech Republic. Unlike Switzerland which, as a non-EU country, could act unilaterally and set the truck tolls at a level which internalized a very high proportion of the environmental costs of road freight transport, Germany, Austria and the Czech Republic were bound by EU rules which prevented member states from including environmental costs in the calculation of the road tolls they imposed on trucks (McKinnon, 2006). Their governments could only take account of infrastructure and accident costs, though they are permitted to vary the tolls in relation to the Euro engine emission class of the vehicle.

In January 2005 Germany implemented a distance-based toll for all HGVs with gross vehicle weights over 12 tonnes using the motorway network. This toll system is referred to as the LKW-Maut (Lastkraftwagen-Maut) and the charging system is based on the route, distance driven, number of axles and the Euro engine emission standard of the vehicle. Using German transport statistics, analysis by de Jong *et al* (2010) indicates that nationally the average distance travelled by HGVs (using tonne-kms divided by tonnes as a proxy for average distance travelled) had been increasing by approximately 3 per cent annually between 1995 and 2005. Following the introduction of the LKW-Maut in Germany in 2005 there was a slowing of this growth rate and then overall reduction in the average distance travelled by HGVs (down by 0.5 per cent between 2005 and 2008). There is no direct evidence that this decline was due to the LKW-Maut, but as the toll scheme is based on distance travelled one would have expected vehicle operators to seek to reduce unnecessary travel in response (by actions such as improved routeing, raising load factors and consolidating goods in larger vehicles).

The Austrian LKW-Maut (also referred to as the GO toll system) was introduced in 2004 on motorways and express highways. All goods vehicles over 3.5 tonnes are included in this scheme. Using Austrian transport statistics, de Jong *et al* (2010) found that nationally the average distance travelled by goods vehicles had been rising since 1980 (again using tonne-kms divided by tonnes as a proxy for average distance travelled). However, between 2004 and 2006 there was a decrease in the average distance travelled nationally, with tonnes transported remaining stable but the average distance travelled falling. Again there is no direct evidence that this was due to the introduction of the LKW-Maut, but the timing suggests that there is a connection. Average distances travelled by goods vehicles rose substantially in 2007, though the Austrian Federal Agency of Transport attributed this mainly to the introduction of the Czech HGV charging system on motorways that year which led to a diversion of vehicles onto Austrian roads. This Czech Republic HGV motorway and expressway charging system is believed to have reduced HGV traffic on trunk roads within the country by 10 per cent, though some of this traffic was merely diverted onto the road networks of neighbouring countries or onto minor roads. The effect on HGV traffic overall is unknown.

Conclusions

This chapter has examined the case for internalizing the environmental costs of logistics operations, in particular freight transport. While recognizing that there are strong theoretical and practical objections to applying the polluter-pays principle, it nevertheless argues that, on balance, internalization is likely to achieve a series of desirable public policy goals. Obtaining accurate and credible cost estimates for logistics-related externalities is difficult, however, particularly as the valuation process is both data-intensive and requires a good deal of subjective judgement. Different valuation methods need to be used for different externalities and a decision made as to whether it is more appropriate to use marginal or average costs in the internalization calculation.

Case studies have been used to illustrate efforts, at a national and corridor level to calculate the extent to which taxes on road freight transport internalize its external costs and the use of road charging systems for trucks to achieve sustainability goals. For example, case study 1 indicated that, in 2006, these taxes covered only 67 per cent of these costs in the UK when congestion was included in the calculation. The heavy vehicle fee imposed in Switzerland, on the other hand, comes close to fully internalizing all the infrastructure, environmental and congestion costs associated with the movement of freight by truck.

There is a limit, however, to the extent to which any single country can unilaterally internalize the environmental costs of its freight transport. The resulting imposition of higher taxes on its transport operations can place its industry at a competitive disadvantage, particularly within an open market such as the EU. This is well illustrated in the case of the UK. Ironically, Britain's high fuel duty policy has promoted increased penetration of its road haulage market by foreign operators who internalize very little of the external cost they impose on the country's environment and infrastructure. This led the UK government to introduce a road user levy for HGVs in 2014, thereby ensuring that non-UK-registered vehicles make a contribution to wear and tear on the UK road network and at the same time establishing a more level competitive playing field between UK and non-UK-registered HGVs. Only the harmonization of internalization policies across Europe will completely rectify the conflict between efforts to apply the polluter-pays principle to road freight transport and the desire to make cross-border competition between hauliers fair.

The gradual upgrading of new freight vehicles to higher EU emission standards and steady improvements in their fuel efficiency are reducing the total value of emission-related externalities. Increases in official estimates of the social cost of carbon and in the level of traffic congestion, however, will tend to counteract this downward pressure on external costs. It is difficult to predict what the net effect of these conflicting cost pressures will be on the future degree of internalization. The issue would be further complicated by the inclusion of road freight operations in the European Emissions Trading Scheme, as has been discussed by Raux and Alligier (2007).

Awareness of the full costs of freight transport services should help businesses to plan and manage their logistics in a way that achieves longer-term sustainability. Also, if the higher freight costs associated with greater internalization are passed down the supply chain, the purchasing behaviour of final consumers should also become more sensitive to the environmental impact of the distribution operations that keep them supplied with goods and services.

Note

1 Cabotage is domestic haulage work undertaken by foreign-registered carriers.

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PART TWO

Strategic perspective

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05

Green logistics, sustainable development and corporate social responsibility

MAJA PIECYK and MARIA BJÖRKLUND

Introduction

In recent years, environmental and social considerations have become more prominent in corporate decision making. A well-implemented and strongly enforced Corporate Social Responsibility (CSR) policy is necessary to facilitate a company's contribution to sustainable development. Logistics, due to its cross-functional nature, is vital to every corporate strategy. This is particularly true for actions aimed at ensuring environmentally and socially responsible business operations. For instance, over 40 per cent of logistics professionals surveyed by Murphy and Poist (2002) indicated that logistics assumes a 'major role' in the implementation of social responsibility policies.

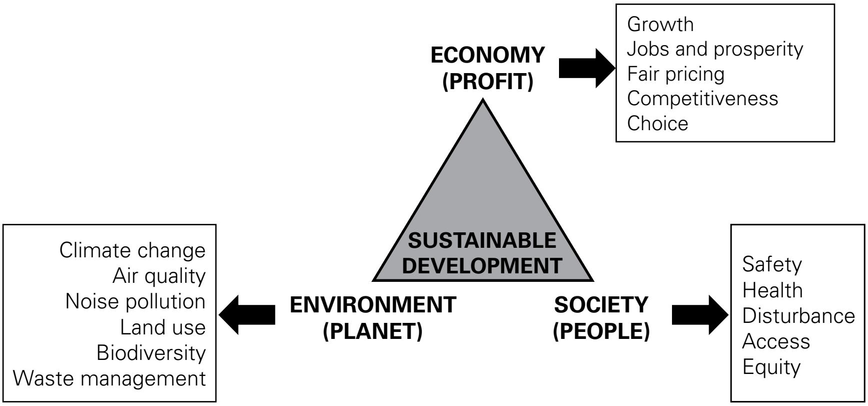
This chapter commences with an introduction to the concepts of sustainability and sustainable distribution.[1] This is followed by a discussion of issues related to CSR. Sustainable performance of any organization is influenced by a variety of internal and external stakeholders. The subsequent section presents their roles and responsibilities in the CSR agenda. The importance of a CSR performance measurement is highlighted next, along with a summary of the most popular CSR reporting guidelines and standards. The second part of the chapter focuses on CSR in relation to the logistics function. A summary of previous research is followed by a case study providing insight into the current CSR reporting practices in the third-party logistics industry.

Sustainable development and sustainable distribution

The concept of sustainable development first appeared in academic literature in the 1960s and 1970s. It was popularized in 1987 by a United Nations-funded report 'Our Common Future', also known as 'the Bruntland Report' (World Commission on Environment and Development (WCED), 1987). The report stated that 'humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs' (p 24). The concept of sustainable development is commonly interpreted as a balance of the interlinked social, ecological and economic dimensions (Figure 5.1).

At a company level, the concept of sustainable development is sometimes referred to as the 'triple bottom line' in the corporate decision-making process (see Chapter 1). The triple bottom line means expanding the traditional performance measurement criteria to include ecological and social performance in addition to financial results (Elkington, 1998). Sustainability requires organizations to take a holistic and integrated approach to managing their economic performance, human resources and environmental impacts. Wilkinson *et al* (2001) argue 'both human and ecological sustainability can shift the focus from short-term corporate survival to longer-term business success and ecological survival, with both requiring a shift in criteria from short-term financial profits to long-term returns' (p 1494). As, with the increase of income, people become more environmentally and socially/ethically aware, sustainable strategy is becoming an effective approach to seeking enduring competitive advantage and securing stakeholder approval (Markley and Davis, 2007). Hence, sustainability can become a key element in ensuring the long-term profitability and success of a business.

FIGURE 5.1 The concept of sustainable development



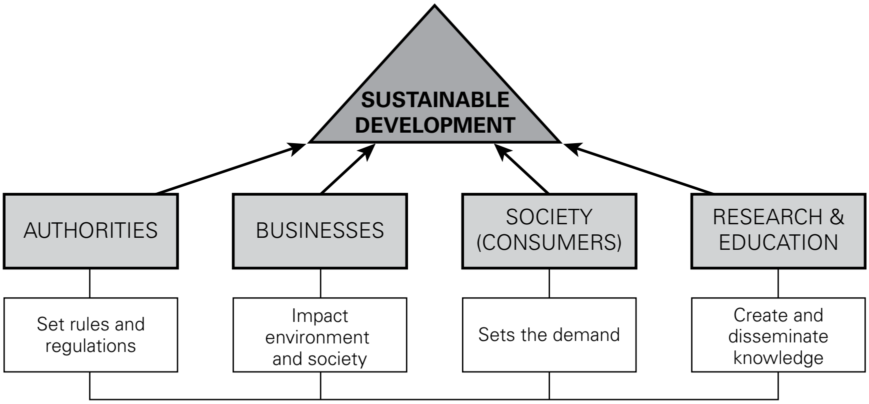
SOURCE: Adapted from www.greenlogistics.org and DETR, 1999

The responsibility for sustainable development is shared between a multitude of actors, such as international regulatory agencies, national governments, local authorities, businesses, consumers, and research and education institutions. The actors play different, supporting and interacting roles in the pursuit of sustainable development (Figure 5.2). In most countries, authorities are elected by the society in a democratic process, and their responsibility is to set rules and regulations the other actors must follow. Businesses influence the environment and society while performing their day-to-day operations. Consumers using products supplied by the businesses also impact the environment and society. They can alter business behaviour by generating demand for particular types of products and/or services. Also, the way they purchase, transport, store, use, and dispose of a product can be an important determinant of the overall impact of that product (see Chapter 3). The academic community plays an important role in the generation and dissemination of knowledge regarding for instance the economic, social, and environmental impact from business operations, sustainable management strategies, consumer behaviour, and the impact of laws and regulations.

Authorities, business, researchers and the wider public also share a responsibility to ensure a sustainable distribution and transport system. In April 2001, at the Council meeting in Luxembourg, the EU's transport ministers agreed on the demands that should be placed on a sustainable transport system. A sustainable transport system should:

- Allow the basic access and development needs of individuals, companies and societies to be met safely, in a manner consistent with human and ecosystem health, and promote equity within and between successive generations.
- Be affordable, operate fairly and efficiently, offer a choice of transport mode, and support a competitive economy, as well as balanced regional development.

FIGURE 5.2 Actors and their roles in sustainable development

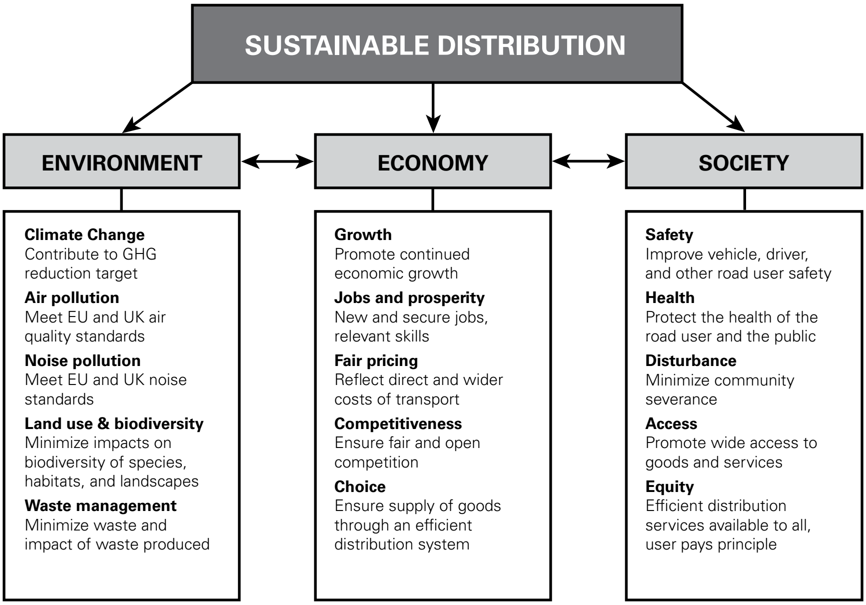


SOURCE: Adapted from Björklund, 2012

- Limit emissions and waste within the planet's ability to absorb them, use renewable resources at or below their rates of generation, and use non-renewable resources at or below the rates of development of renewable substitutes, while minimizing the impact on the use of land and the generation of noise.

In line with the above-mentioned demands, European governments have developed national strategies towards sustainable distribution and transport. In its Sustainable Distribution document (DETR, 1999) and subsequent policy statements (for example Department for Transport, 2008) the UK government adapted the concept of sustainable development to the distribution industry, and identified a series of policy measures designed to make logistical operations more sustainable in economic, social and environmental terms. The aim of the sustainable distribution strategy is to ensure that the development of the distribution industry does not compromise the future needs of the society, and environment, while facilitating economic growth. Sustainable distribution is concerned with achieving specific outcomes, which are presented in Figure 5.3. The interdependence of these outcomes needs to be clearly recognized, as the failure to address problems in one area will eventually inhibit progress and improvements in other areas. For example, a failure to address the problems of health, safety, noise or access would eventually threaten continued economic growth, which, in turn, would

FIGURE 5.3 The concept of sustainable distribution



SOURCE: Adapted from DETR, 1999

affect prosperity, competitiveness and the ability to tackle pollution, climate change and other environmental problems. The role of government in promoting green distribution systems is discussed in Chapter 18.

Corporate social responsibility (CSR)

Globalization of trade and the trend towards relocation of manufacturing to lower-cost countries make it very difficult to regulate corporate activities through a single country's legal and regulatory mechanisms. CSR has been long demanded by various stakeholders as a response to this challenge (United Nations, 2006). CSR often means different things to different people. Organizational leaders have varying views on what areas should be addressed, and what actions need to be taken as a part of socially responsible business operations. Bowen (1953) developed one of the first definitions of CSR, stressing the 'obligations of businessmen to pursue those policies, to make those decisions, or to follow those lines of action which are desirable in terms of the objectives and values of our society' (p 6). A widely cited definition of CSR, proposed by the European Commission (2001) in its green paper *Promoting a European Framework for Corporate Social Responsibility*, is 'a concept whereby companies decide voluntarily to contribute to a better society and a cleaner environment'.

CSR should be seen as a means by which business delivers its commitment to sustainable development. It refers to business activities guided by codes of conduct that exceed minimum legal standards relating to social conditions and environmental impacts. Furthermore, it can be argued that a holistic approach to CSR needs to address a wide range of issues related to CSR policy development, management and reporting.

As the concepts of sustainable development and CSR are closely related, the key dimensions of both are the same. Socially responsible companies need to include economic, social and environmental considerations in their corporate decision making:

- *Economic responsibility* concerns not only economic growth and shareholders' profits. Other important aspects include how the money is earned and divided between parties involved in a deal. Examples of economical responsibilities are fair pricing and purchasing policies, actions and policies against bribery and corruption, and contributions to the economic development of local communities.
- *Social responsibility* addresses the way people are treated both within and outside the organization. Companies can demonstrate social responsibility by, for example, the use of core labour standards set by the International Labour Organization. Other examples of social responsibilities include: respecting human rights, ensuring decent working and living conditions for employees (such as labour rights,

freedom of association, right to collective bargaining, no forced labour, maximum working hours, minimum age/child labour, fair treatment, and the advancement of gender, racial, and religious diversity in the workplace), health and safety policies, philanthropic contributions/donations and considerations, and involvement with local communities.

- *Environmental responsibility* focuses on how the business activities affect the planet. Examples of environmentally responsible practices are: precautionary approaches to prevent or minimize the adverse impact on the natural environment, or development and diffusion of environmentally friendly technologies.

According to Carroll (1979), the obligations businesses have to society can be categorized into four groups:

- *Economic responsibilities* to shareholders constitute base-level actions in the hierarchy of social responsibility. As basic economic units in the society, businesses have a responsibility to produce goods and services, and sell them at a profit.
- *Legal responsibilities* mean that businesses are expected to comply with legal obligations imposed by governments and regulatory agencies.
- *Ethical responsibilities* are behaviours and activities that are not necessarily codified into laws, but are expected as a part of social norms, for instance honesty in communication.
- *Discretionary responsibilities* are voluntary, philanthropic actions guided by an organization's discretion, rather than any legal requirements or ethical norms, ie it is not considered unethical per se, if a business does not engage in them. Examples of such activities include for instance provision of childcare centres for working mothers.

Common key dimensions can be identified in most descriptions and definitions of the CSR concept, such as the voluntariness of actions taken (not forced by legal demands), and the inclusion of the three sustainability dimensions: economy, environment and society. Another vital aspect is the interaction with stakeholders. The stakeholders can drive better CSR performance, but they can also hinder it, for example by placing demands that are not in line with the interests of the environment or society.

Based on the main drivers, the CSR involvement of organizations can be broadly categorized as follows (Maignan and Raiston, 2002):

1. Value-driven CSR: CSR is presented as being part of the company's culture, or as an extension of its core values.
2. Performance-driven CSR: CSR is introduced as part of the firm's economic mission, as an instrument to improve its financial performance and competitive posture.

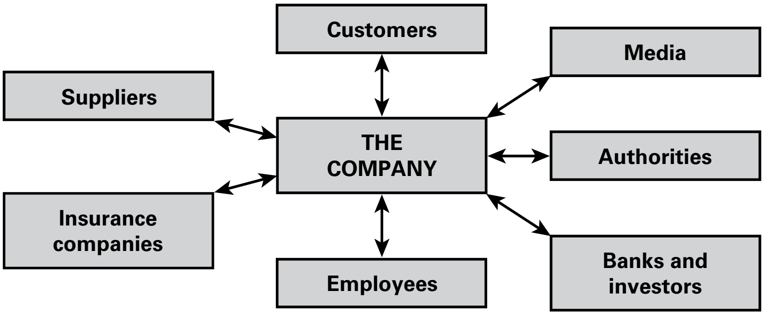
3 Stakeholder-driven CSR: CSR is presented as a response to the pressures and scrutiny of one or more stakeholder groups.

Stakeholders in CSR

The importance of inter-stakeholder relationships in CSR can be described with a stakeholder model. This model emphasizes a complex network of relationships, rather than just a series of dyadic connections between stakeholders and the company (Russo and Perrini, 2010). A company has relationships with multiple constituencies called stakeholders, which impact and are, in turn, affected by the corporation's decisions. Examples of CSR stakeholders are owners, trustees, employees, trade unions, customers, members, business partners, suppliers, competitors, government and regulators, non-profit organizations, local, national and international communities. A holistic approach with consideration given to all stakeholders and stakeholder dialogue are essential in CSR. To maintain a high level of confidence from their stakeholders, organizations need to express a commitment to CSR through their values and actions. Stakeholders' engagement ensures that businesses meet or exceed the expectations and regulations of communities they affect both locally and globally.

The focus on sustainability is a way to improve competitive advantage of a company (Markley and Davis, 2007). In an intensified business climate that strives towards increased profitability, products and services are increasingly purchased from low-wage countries in the developing parts of the world. The supply chains are becoming longer and more complex, involving a myriad of different actors and organizations. Many company's business involves organizations operating in countries with sometimes strongly diverging legislation, law obedience and business culture compared to the western world (Panapanaan *et al*, 2003). The associated external impacts of economic activity expand from local and regional to global.

FIGURE 5.4 Examples of stakeholders in CSR



SOURCE: Adapted from Björklund, 2012

As a result, companies have realized that they need to show concern about environmental impacts and social affairs in order to ensure their own long-term growth. CSR increasingly becomes 'an inescapable priority for business leaders in every country' (Porter and Kramer, 2006, p 78).

The rising pressure on companies to take extensive responsibility becomes evident in the increased scrutiny and *media* coverage regarding CSR issues. One important driver for an increasing number of companies to adopt CSR policies is a greater transparency of business activities due to the development of information and communication technology (European Commission, 2001). In recent years, several companies have actively focused on CSR management after reports, eg on substandard working conditions, had been published.

The CSR reputation of a company can influence decisions of governments and regulatory *authorities* in a process of granting and renewal of operating licenses. There is a growing tendency for governments towards stricter regulation of the CSR performance of companies. Some sectors are dependent on licences, such as for example energy development licences in the USA, in order to operate. Governments increasingly include CSR performance criteria in the allocation of such licences (Fossgard-Moser, 2005).

Customers often prefer brands and companies with a good reputation in CSR. Therefore, CSR can result in increased customer loyalty and revenues. Concerns and expectations from citizens and consumers are among the key drivers for companies to adopt CSR (European Commission, 2001). Active involvement in CSR can also improve the inter-company relationships and performance of *suppliers* (Carter and Jennings, 2004).

Investors, banks, public and private lenders increasingly take CSR into account when determining a company's access to capital. Several banks now include environmental and social risks as a part of their lending appraisal process. A growing number of investors, particularly those investing in 'socially responsible' funds, are also seeking to balance financial performance with social performance in their investment portfolios.

Insurance companies often present insurance quotas for companies facing an increased risk of serious environmental accidents or social scandals. A proactive CSR performance decreases the risk and can, therefore, lower insurance costs. CSR means proactive risk management and, thereby, a reduced vulnerability to misconduct (Schiebel and Pöchtrager, 2003). For example, ethical funds are often described as having lower risk compared to alternatives that disregard CSR.

CSR is also important from an internal company perspective. It can improve the productivity by, for example, increased *employees'* loyalty, better motivation and commitment to work, improved work environment, and a reduction in the number of injuries and lost workdays (Schiebel and Pöchtrager, 2003). Furthermore, CSR can also improve organizational learning. Businesses with a high level of responsible purchasing practices are for instance more commonly associated with organizational cultures with more free-flowing decision-making and entrepreneurial environments

(Carter, 2005). Last but not least, proactive management of CSR is likely to result in first-mover (-adopter) advantages.

CSR reporting standards

In order to support companies in measurement, verification and communicating of their CSR performance, a number of reporting guidelines and standards on how to record and report CSR-related information has been developed. The key environmental management standards were presented in Chapter 2 (Eco-Management and Audit Scheme EMAS, ISO 14000 and 14001 Environmental Management, BS8555: Environmental Management System). The standards presented below focus either on reporting all aspects of CSR, or specifically on its social dimension.

- The Global Reporting Initiative (GRI) (www.globalreporting.org) developed a widely accepted and comprehensive framework for accounting and reporting of corporate economic, environmental and social performance (Ciliberti *et al*, 2008). The GRI was started in 1997 by the Coalition for Environmentally Responsible Economies (CERES) and the United Nations Environment Program (UNEP). The current version of the GRI framework, the G4, was launched in May 2013. The guidelines are for voluntary use by companies, governmental and non-governmental organizations for CSR reporting with regard to their activities, products and services. Additionally, the GRI has developed supplements for several sectors to make reporting more relevant and tailored to the specific needs of diverse industries. A pilot version of the Logistics and Transport Supplement, intended to be used by logistics service providers (LSPs), is available.
- SA8000 is a voluntary certification standard for measuring social compliance in the workplace with regard to child labour, forced labour, health and safety, freedom of association and collective bargaining, discrimination, disciplinary practices, working hours and compensation. It was developed in 1997 by Social Accountability International (SAI), and it is based on the principles of international human rights norms.
- ISO 26000 Guidance on Social Responsibility provides guidance to assist organizations addressing their social responsibility. The standard is aimed at all types of organizations independent on their size, industry sector, location or type of activity. The standard offers guidance to organizations willing to improve impact on their workers and the society, but does not provide requirements. Hence, unlike some other well-known standards, for example ISO 14001, it is not certifiable.

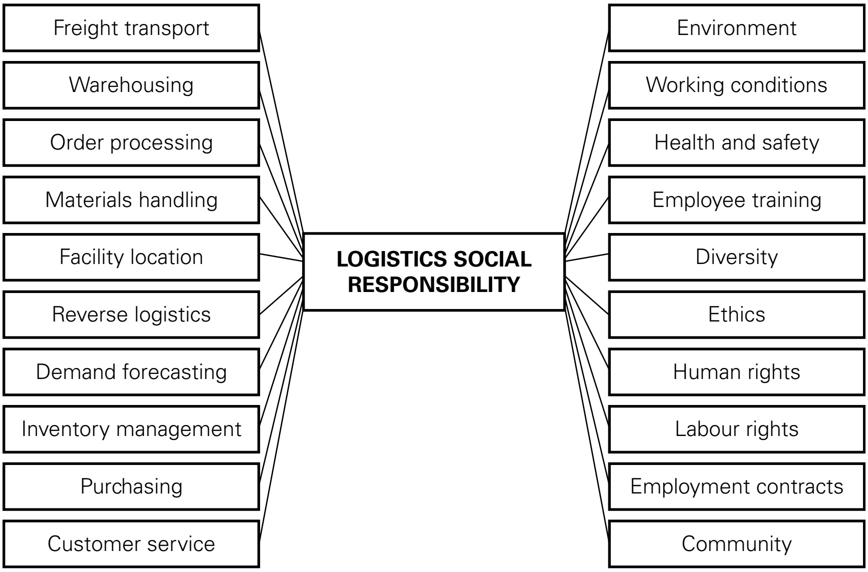
- The Dow Jones Sustainability Indices (DJSI) were launched in 1999, and are the longest-running sustainability benchmarks worldwide. DJSI assesses economic, environmental and social aspects of the largest 2,500 companies listed on the Dow Jones Global Total Stock Market Index. The assessment includes issues such as corporate governance, risk management, climate change mitigation, supply chain standards, branding and labour practices.

CSR and the logistics function

Logistics social responsibility (LSR) is a term often used by authors examining CSR issues in relation to logistics management. LSR typically comprises employee training, environment, health and safety, working conditions, workplace diversity, urban renewal, ethics, human rights, community issues and philanthropy (Figure 5.5).

Environmental issues, particularly reduction of GHG emissions from logistics activities, appear to be the most prominent aspects of CSR discussed in the recent academic literature. The rise in environmentally responsible logistics operations has been a result of governmental regulations, economic considerations and increasingly strong market signals from environment-conscious consumers (Goldsby and Stank, 2000). Environmental performance of logistics is often consistent with the bottom-line impacts: 'When a

FIGURE 5.5 Logistics social responsibility dimensions and logistics functions



firm's objectives are cost minimization and profit maximization, continuous improvement of the process to reduce end-of-pipe contamination and focusing on pollution prevention makes sense' (Wu and Dunn, 1994, p 22).

However, it is important to emphasize that the social element should not be ignored. 'For true corporate sustainability, an organization must recognize value and promote the capability of its people. For human resource sustainability to be achieved, therefore, the human resource policies and practices need to be integrated for sustained business performance and positive employee outcomes of equity, development and well-being' (Wilkinson *et al*, 2001, p 1497). The main social sustainability aspects covered recently in logistics research include:

- labour and human rights;
- employment, ie employment contracts, compensations and wages;
- working conditions, and occupational health and safety;
- job satisfaction, working hours, and the time workers stay away from home;
- ethics;
- workforce diversity.

Similarly to general CSR, a proactive involvement in LSR can be driven by different forces. Actions aimed at, for example, reduction of fuel consumption are examples of *performance-driven* LSR, where lower environmental impact will be in synergy with a better economic performance. *Stakeholder-driven* LSR will be actions undertaken in order to respond to consumer demand. González-Benito and González-Benito (2006) show that non-governmental stakeholder pressures exert a significant influence on the implementation of environmental logistics practices. LSR can also be *value-driven*, for example by taking steps to strengthen brand image and to be portrayed as a good corporate citizen. Some logistics providers expand their offering to include, for instance, carbon-free parcel deliveries. Overall, LSR can positively contribute to increased competitiveness, and lower costs, and thus generate long-term value to organizations.

Case Study: CSR reporting in the logistics industry

This case study, carried out in 2013–2014, focuses on CSR reporting practices of logistics service providers (LSPs). Despite research that clearly highlights the importance of CSR within logistics, only 45 out of 350 LSPs included in this study publish formal CSR reports, either as dedicated CSR reports (34), or as a CSR section in the annual reports (11). The CSR reports vary regarding their extent, reporting format and CSR aspects addressed. The extent of reporting varied from two pages on CSR in the annual report to a dedicated

165-page CSR report. Commonly the reports inform about the latest CSR initiatives undertaken, along with a number of environmental and social indicators discussed below.

Examples of CSR statements

Deutsche Post DHL:

> *We use our knowledge and global presence to make a positive contribution to society and the environment. Under the motto Living Responsibility we focus on protecting the environment (GoGreen), delivering help (GoHelp), and championing education (GoTeach), and support volunteering activities of our employees. (Global Volunteer Day, Living Responsibility Fund, www.dpdhl.com/en/responsibility.html)*

The NYK Group:

> *The NYK Group positions 'economic responsibility', 'environmental responsibility', and 'social responsibility' at the core of business activities because it takes an integrated approach to business management that focuses on maximizing benefits to the Group and society simultaneously. (http://www.nyk.com/english/Csr/nykcsr/concept/index.html)*

Lufthansa Cargo:

> *Employees of Lufthansa Cargo represent its goals and values on a daily basis. Their commitment, knowledge and attitude in dealing with customers, colleagues and partners are what make the company successful. Diversity is the key to success by bringing together knowledge and experience, expertise and skills. (https://lufthansa-cargo.com/en_de/meta/meta/company/responsibility/)*

Environmental indicators

The environmental aspects of CSR were particularly prominent in the reports published by LSPs. Environmentally friendly logistics solutions become a significant element in service offerings, as green performance is expected to increase in importance as a criterion in LSP selection (Björklund and Forslund, 2013). A better environmental performance is also likely to have a positive impact on a company's bottom line. (For example, as explained in Chapter 3, GHG emissions from freight transport are directly related to the amount of fuel used, thus can be easily translated into operating costs.)

The most common environmental indicators presented in the CSR reports are:

- actions and initiatives aimed at reducing the climate change impacts of the services offered, including certification to environmental standards (93 per cent of the CSR reports);
- greenhouse gas emissions (Scope 1 and 2)[2] (76 per cent);
- energy consumption (69 per cent);
- waste generated (56 per cent), and recycled (44 per cent of the CSR reports);
- water usage (51 per cent);
- emissions of air pollutants (31 per cent).

Social indicators

The GRI framework, used to structure the analysis in this case study, divides social indicators into four broad categories: labour practices and decent work; human rights performance; society performance; and product responsibility performance.

Indicators related to **employment practices and decent work** are the most commonly reported on in the logistics industry. LSPs frequently report on:

- training and education (87 per cent of the CSR reports);
- occupational health and safety (69 per cent);
- employment statistics (67 per cent);
- diversity and equal opportunity (58 per cent).

Human rights performance is a CSR aspect not adequately addressed in many of the reports studied. The aspects most commonly reported on are the investment and procurement practices, addressed by 49 per cent of the CSR reports. KPIs reflecting the **contribution to society** are present in most of the reports. However, the focus is very limited to indicators tracking community involvement (addressed in 78 per cent of reports) and anti-corruption measures (49 per cent). Customers do not usually have a direct contact or presence when a logistics service is carried out. Hence, the area of **product responsibility** does not feature prominently in CSR reports published by LSPs. Green-service labelling (eg carbon-free shipments) was the product responsibility indicator most often reported on (36 per cent of the reports).

Nearly half of the CSR reports included indicators related to initiatives aimed at employees' mental health and physical well-being; an indicator yet to be included in the GRI framework. Examples included actions to promote well-being, number of health trainers supporting employees, system of in-house health consultations, mental health training, stress management programmes or well-being workshops.

Humanitarian logistics

The area of humanitarian logistics has grown significantly in recent years. Due to the nature of their core activities, LSPs are particularly well positioned to offer physical support to relief agencies. The analysis of CSR reports published by LSPs shows that involvement in humanitarian logistics and emergency response operations features quite prominently in more than a half (59 per cent) of them. Examples of actions include donations of staff time, assets, storage and transport services and contributions of knowledge, skills and resources to humanitarian relief organizations.

Working with universities

The LSPs' involvement with academia is an important indicator of their social responsibility. This typically involved a contribution to academic research and/or funding of academic positions or institutions. Of those LSPs publishing CSR reports 20 per cent indicated having links with higher education institutions. LSPs' involvement with academia helps to advance research and ensure its practical applicability. It also provides the participating companies with better access to highly skilled graduates and latest developments in the field, thus contributing to the long-term sustainability of their operations.

Conclusions

While the remainder of this book focuses on the environmental aspects of sustainability, this chapter emphasizes the importance of maintaining a balance between all aspects of sustainable development. It provides an insight into a wide range of issues that should be considered by organizations looking to implement and execute an effective CSR programme. Special attention is given to CSR in relation to logistics operations. A review of CSR reporting practices in the third-party logistics sector shows that there is a significant room for improvement in the sector. The reporting rates are low, and where CSR reports are published, the content is often limited. This chapter provides guidance as what to report and how to derive the best value from presenting CSR to a wide range of stakeholders.

Notes

1. The term distribution encompasses activities related to physical flows of goods (ie transport, handling and storage), whereas logistics includes also planning and control activities, as well as management of information and capital flows.
2. Different scopes of greenhouse gas emissions are explained in Chapter 3.

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Restructuring road freight networks within supply chains

06

IRINA HARRIS, VASCO SANCHEZ-RODRIGUES, MOHAMED NAIM and CHRISTINE MUMFORD

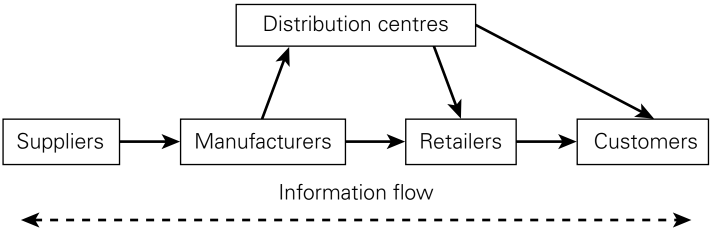
Introduction

This chapter aims to review the current state of knowledge on network design, focusing particularly on the facility location problem and on the impacts of uncertainty related to physical flows in logistics systems. We discuss the strategic design of networks and determine the extent to which environmental criteria are being utilized in supply chain design vis-à-vis traditional cost and customer service metrics. The impact of uncertainty in logistics and uncertainty mitigation approaches related to economic and environmental costs are also discussed in this chapter. We assess the current strengths and weaknesses of existing supply chain models, with the goal of highlighting future research challenges.

Traditional network design

Historically a supply chain has been defined as a system whose constituent parts include material suppliers, production facilities, distribution services and customers linked together by the feedforward flow of materials and the feedback flow of information (Stevens, 1989). The main features of a traditional supply chain (Beamon, 1999) are illustrated in Figure 6.1, where the black arrows represent material flows and the dotted arrow represents information flow.

FIGURE 6.1 Traditional supply chain



SOURCE: Based on Beamon (1999)

When designing a supply chain network, different levels of decisions need to be considered, from strategic through to operational. Strategic decisions typically have a planning period of many years, and involve choices related to the number, locations and capacities of facilities in a network. Tactical decisions involve a shorter planning horizon, and are usually revised monthly or quarterly. Tactical activities include the inventory planning, layout of facilities, and efficient allocation of resources. Finally, operational decisions, such as scheduling and routeing activities, consider day-to-day flows of products through the network, the amount of inventory in the system and so on. These decisions can be modified within a shorter period of time, for instance on a daily or weekly basis.

Strategic design of a logistics network focuses primarily on infrastructure. The facility location problem (FLP), also known as the location analysis problem, is a well-known problem in operations research. It consists of decisions concerned with determining the number of open facilities, their location, capacity, and type of service/product they provide. It can also consider which customers are assigned to which facilities to ensure that their demand is satisfied. FLP has wide application in both private and public sectors for a range of facilities as diverse as chemical plants, distribution centres, hospitals, retail outlets and fire stations. Depending on the application area, different objective functions and constraints are considered, varying from minimizing overall costs to maximizing the number of clients served. In a business environment and within a logistics context, minimizing the total cost is the most commonly used objective. The total cost consists of fixed and running costs of facilities, such as the costs for operating facilities, costs of production, storage, and picking activities and a transportation element to deliver goods to customers.

Facility location decisions are mostly strategic, if for example major long-term investment in new facilities is required. On the other hand, when businesses are able to acquire or hire a facility for a shorter term, decisions could be deemed tactical rather than strategic. Some of the early models in location analysis date back many years, and there is a rich literature of models and solution techniques. Daskin (1995), Owen and Daskin (1998), and Drezner and Hamacher (2002) present a comprehensive overview of different formulations and solution techniques in the field of facility location analysis. Klose and Drexl (2005) review contributions to the current state of the art in facility location models for distribution system design, and present the following classification of facility location models:

- *Discrete* vs *continuous* location models. In the continuous models it is feasible to locate the facilities anywhere, whereas discrete models have explicit sets of possible locations.
- The objective function in the problem formulation may be of the *minsum* or *minmax* type. Minsum models minimize the average distances while minmax models minimize maximum distance.
- *Uncapacitated* vs *capacitated* models. The uncapacitated facility location problem (UFLP) assumes that facilities have unlimited capacity, whereas the capacitated facility location problem (CFLP) imposes capacity constraints on each facility.
- *Single-source* vs *multiple-source*. Each customer will be assigned to just one facility in a single-source problem or to several facilities in a multiple-source problem.
- *Single* vs *multiple* objective models. Single objective formulations dominate location analysis research (eg Geoffrion and Graves, 1974; Barcelo and Casanovas, 1984; Beasley, 1988; Holmberg *et al*, 1999; Avella *et al*, 2009) and involve the optimization of a single objective, such as minimizing cost or maximizing profit. However, problems in the real world are frequently multi-objective in nature: for example it may be desirable to simultaneously minimize cost and maximize customer service. Despite its relevance in the real world, published research on multi-objective location problems seems to be rather limited.
- *Single-stage* vs *multi-stage* models. Multi-stage models consider the flow of goods through several hierarchical stages; whereas single-stage focuses on one stage explicitly, eg depot-customer.
- *Single* vs *multiple* product. If the nature of the products is homogeneous they could be considered as a single product, eg chilled product. On the other hand, if we have, for example, chilled, ambient and frozen product types, the problem becomes a multiple-product formulation.
- *Static* vs *dynamic* models. Static models consider a design over a single period of time, whereas dynamic models take account of variation over several time periods.
- *Deterministic* vs *probabilistic* models. Deterministic models use averaged data used on past history or future forecasts, which is assumed to be exact and correct, whereas probabilistic models consider data under uncertainty.
- *Location-routeing* problems combine location analysis with routeing aspects of the design.

As can be seen from the classification, the field of FLP formulation is large. It is, therefore, not surprising that the range of techniques is also large, varying from integer, dynamic, mixed-integer linear programming to heuristic methods and genetic algorithms. Coyle *et al* (2003) describe the principal modelling approaches such as mathematical optimization, simulation and heuristic methods. Mathematical optimization aims to find optimum solutions based on precise mathematical procedures, whereas a simulation approach allows a user to test the effect of alternative locations on costs and service levels. Heuristic approaches, on the other hand, do not guarantee optimal solutions but can produce an acceptable solution in a reasonable amount of time. Lagrangian relaxation techniques are leading heuristics methods for solving large CFLP problems (Barcelo and Casanovas, 1984; Beasley, 1988; Holmberg *et al*, 1999; Avella *et al*, 2009). Other techniques, such as approximation algorithms and metaheuristic approaches, are also applied to solving such model formulations.

The assignment of customers to serving facilities is carried out as an essential part of solving an FLP formulation. However, the serving facilities usually remain in place for many years, during which circumstances may change. It is common therefore, to regularly re-optimize the allocation of customers to serving facilities, to take account of changes in demand and/or supply patterns. This assignment problem is known as the generalized assignment problem (GAP) and was first introduced by Ross and Soland (1975). Since then many papers have been published on the GAP. It has a wide application, including assigning workers to jobs, staff scheduling, assigning stores to the serving facilities and project assignment. The GAP and solution techniques are discussed by Cattrysse and Van Wassenhove (1992) and Oncan (2007).

As discussed earlier, strategic modelling focuses mainly on a single objective function such as cost minimization or profit maximization, with all customer demands satisfied to a certain minimum level, and without exceeding the capacities of the facilities. With increasing environmental concerns and/or high levels of commercial competition, there is a need to deal with multiple objectives of minimizing the environmental impact and improving customer service simultaneously. Current *et al* (1990) classify the objectives for facility location into four categories: cost minimization, demand oriented, profit maximization and environmental concerns. Environmental objectives such as, for example, air quality, and health impact on local populations, are considered in their research. When multiple objectives are involved then, conventionally, companies will try to adjust the various parameters under their control in order to simultaneously maximize profit (or minimize costs) and optimize customer service. However, the two objectives are frequently in conflict and devising a single performance measure that weights the two objectives in a satisfactory way is difficult. An added complication arises when we wish to incorporate appropriate quantifying environmental measures into the model. This is discussed in the next section.

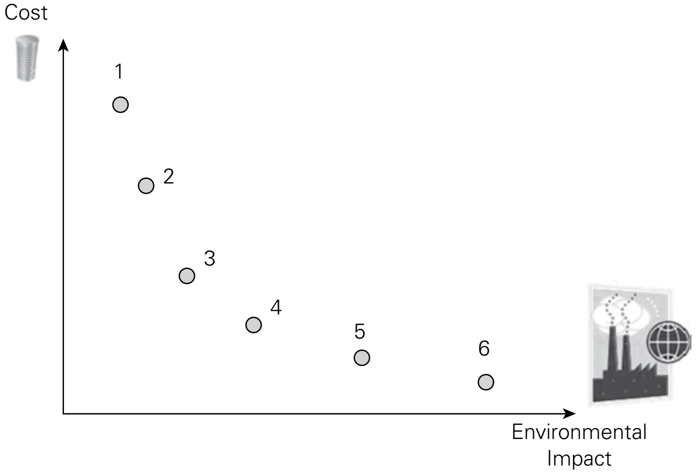
Green network design

There are two principal ways of considering green/environmentally friendly aspects as part of the network design:

1. Modelling a traditional network design with environmental aspects considered as constraints or objectives.
2. Modelling an extended supply chain (closed-loop supply chain or reverse logistics) which has extra facilities and processes such as collection and recycling with environmental objectives or constraints.

In this section we focus on the former approach where objectives are extended to include 'green' measures as part of the network design. An example of when economic and environmental objectives are considered simultaneously is illustrated in Figure 6.2. The Figure shows a trade-off 'frontier' often encountered when analysing a range of hypothetical designs for a distribution network. If the company is interested in obtaining the lowest possible cost solution, solution 6 would be chosen. On the other hand, if the emphasis is on minimizing the environmental impact, solution 1 would be chosen. In either case, a particular single objective has high priority for the logistics modeller. In reality, the question is likely to be: how can we design a network which simultaneously minimizes cost and the impact on the environment? In our example, solutions 3 and 4 have 50–60 per cent lower environmental impacts, yet the cost does not appear to be much higher than for solution 6. Thus, solutions 3 and 4 can be considered good compromise positions.

FIGURE 6.2 Trade-off options which balance economic and environmental objectives

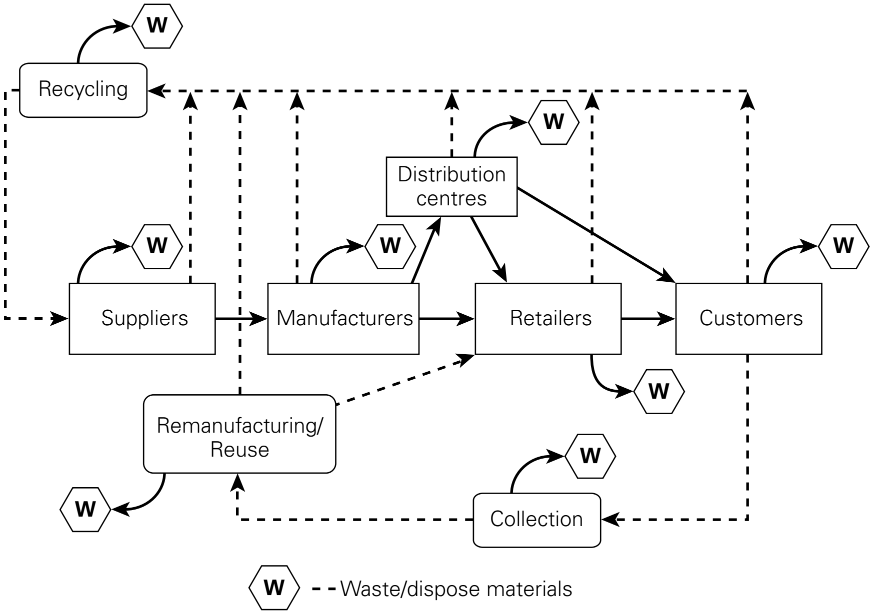


Beamon (1999) argues that the evaluation of the total direct and indirect environmental effects of all processes and all products should be an integral part of the planning of extended supply chains. A fully integrated supply chain (Figure 6.3) is described as a supply chain having all the elements of the traditional configuration (Figure 6.1), but also incorporating the recycling of products and packaging, as well as reuse and/or remanufacturing operations within a semi-closed loop. As such, it incorporates the elements of a reverse supply chain, reflecting the entire life cycle of the goods.

To help deal with the additional complexity of the extended supply chain, Beamon (1999) identified a set of potential strategic and operational considerations, including:

- the number and location of facilities for product/packaging collection and reuse;
- the effects of traditional supply chain strategies (eg decentralized vs centralized facility location) on environmental performance;
- simultaneous operational and environmental supply chain optimization;
- incorporating environmental and operational goals into traditional analysis;
- the level and location of buffer inventories to be considered on both sides of the extended supply chain (forward and reverse);

FIGURE 6.3 The extended supply chain



SOURCE: Based on Beamon (1999)

Beamon's work highlights the need to incorporate environmental metrics into the planning and design of supply networks. Other literature discusses the choice of metrics in greater detail. Hervani, Helms and Sarkis (2005), for example, review performance measurement systems and metrics used in the development of green supply chains. The proposed list of metrics includes a wide range of measures from atmospheric emissions to energy recovery. They include measures for onsite and offsite energy recovery, recycling and treatment, spill and leak prevention and pollution prevention. Additional general measures include total energy use, total electricity use, total fuel use, other energy use, total water use, habitat improvements and damages due to enterprise operations, cost associated with environmental compliance, and others. The authors point out that organizations may choose their environmental performance measurements specifically to meet new government regulations on emissions, energy consumption or the disposal of hazardous waste.

The scope of the analysis can also be extended beyond environmental variables to include the economic and social measures that one would normally expect to find in a broader assessment of sustainability. Singh *et al* (2009) provide an overview of various sustainability indices that can be adopted. In their paper, they consider sustainability in its broadest sense, covering aspects other than the environmental impacts, such as product-based sustainability and quality of life. In total, 70 indices were grouped under 12 categories, including the following environmental indices: eco-system-based indices (Eco-Index Methodology, Living Planet Index, Ecological Footprint); composite sustainability performance indices for industry (Composite Sustainable Development Index, ITT Flygt Sustainability Index, G Score method); product-based sustainability indices (Life Cycle Index, Ford of Europe's Product Sustainability Index); environmental indices for industries (Eco-Points, Eco-compass, Eco-Indicator 99); social and quality-of-life-based indices (eg Index for Sustainable Society) and others.

From a logistics perspective, Aronsson and Huge-Brodin (2006), in their comprehensive literature review, identified the measurement of emissions as one of the most popular ways of assessing environmental impact. They noted, however, that even though the direct environmental impact can be assessed in terms of emissions, it is the root causes of these emissions that need to be addressed. Exactly what action to take needs to be determined by an appropriate analysis of the supply chain as a whole. Determining which sustainable measures to use and the difficulty of calculating them has been discussed by several researchers (Aronsson and Huge-Brodin, 2006; Hervani, Helms and Sarkis, 2005; Beamon, 1999).

Some researchers have noted that an improved environmental impact sometimes follows a supply chain redesign exercise based on traditional performance measures such as cost or customer service. In such cases improvements in environmental performance can be viewed as ancillary benefits rather than resulting from the full integration of green principles into supply chain design. This can be illustrated by the application of the factory gate pricing (FGP) concept, where the retailer is responsible for transportation of the product from the supplier's premises. This has been analysed for the UK grocery (Potter *et al*, 2003) and the Dutch retail industry (Le Blanc *et al*, 2006). Both studies show that although FGP was primarily motivated by a desire to cut costs, it has also brought significant environmental benefits, such as reduced congestion and vehicle-kms. Potter *et al* (2003) analysed the Tesco supply chain and suggested that by implementing FGP with consolidation centres for inbound deliveries, a reduction of 28 per cent in vehicle-miles required to transport products to depots could be achieved, equating to over 400,000 miles per week.

Aronsson and Huge-Brodin (2006) also present three case studies in which distribution structures were modified in a way that had a positive effect both on costs and the environment (by reducing emissions). Among the typical changes made to distribution structures are a reduction in the number of nodes, the centralization of warehousing, the introduction of new information systems, the consolidation of flows, the standardization of vehicles and load carriers, and changes in transport mode.

Kohn and Huge-Brodin (2008) discuss two case studies that suggest improvements can be made from an environmental perspective without impeding the cost-efficient provision of customer service when changing decentralized to centralized distribution systems. They point out that although centralization often results in an increase of total tonne-kms for transport work, at the same time it opens up other opportunities that can have a positive impact on the environment, such as shipment consolidation, change of transportation mode (eg from road transport to rail) and a reduction in emergency deliveries. Obviously, there are constraints and difficulties that can prevent companies from fully exploiting these opportunities. For example, a switch from road to rail would be difficult for many companies, as in the case of ITT Flygt discussed by Kohn and Huge-Brodin, where limitations were imposed by the rail infrastructure of the European Union, but for other companies, modal change may be more realistic and beneficial.

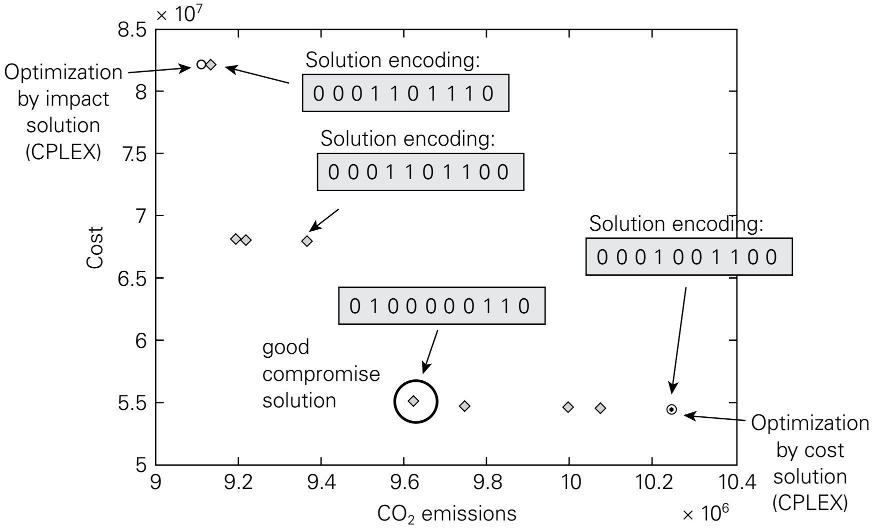
As we can see from the above, the current approach is to assess the environmental impact following a redesign based on the optimization of traditional objectives, such as minimizing cost. The present authors believe there is a need to consider environmental measures explicitly during the optimization process at the same time as traditional objectives, as discussed in an earlier publication (Harris *et al*, 2011a). Khoo *et al* (2001) use a simulation approach to select plant locations that balance low total market costs and low transport pollution with faster deliveries between plants, promotion of recycling of scrap metal and conservation of energy in a supply chain concerned with the distribution of aluminium metal. The simulation model was used to demonstrate the consequences of ignoring resource preservation and recycling activities as part of the network design. Other studies (Hugo and Pistikopoulos, 2005; Quariguasi Frota Neto *et al*, 2008) use multi-objective optimization techniques for evaluating the trade-offs between different objectives to make an informed choice that balances all important objectives. Recent publications by Farahani *et al* (2010) and Harris *et al* (2011a) demonstrate the need for multiple criteria location decision making with sustainable objectives (environmental and social) and consider this to be an important area for future research. Multi-objective optimization is discussed in more detail below.

Hugo and Pistikopoulos (2005) present a generic mathematical programming model for assisting the strategic long-range planning and design of a bulk chemical network. Their multi-objective mixed-integer programming problem is formulated to minimize the environmental impact resulting from the operations of the entire network whilst simultaneously maximizing the network's profitability. A method for impact assessment, the Eco-Indicator 99 method (Pré Consultants, 2000), is incorporated within the quantitative life cycle assessment model to formulate an appropriate environmental performance objective to guide strategic decision making. The Eco-Indicator 99 method attempts to model potential environmental impact on a European scale according to three categories: human health, ecosystem quality and resource depletion.

Another example involving the trading-off of cost against environmental impact is described in Quariguasi Frota Neto *et al* (2008), where the reorganization of a European pulp and paper logistic network is described. They use multi-objective programming to determine 'optimal' configurations of the network by solving the allocation problem. Environmental impact was assessed using an environmental index proposed in Bloemhof-Ruwaard *et al* (1996). This index uses life cycle analysis and considers a diverse range of emissions produced in the supply chain: namely global warming, human toxicity, ecotoxicity, photo-chemical oxidation, acidification, nitrification and solid waste. The technique provides a single weighted measure for environmental impact for each phase of the supply chain.

Harris *et al* (2011b) present a solution technique based on a multi-objective evolutionary algorithm (SEAMO2) (Valenzuela (2002) and Mumford (2004)) and Lagrangian Relaxation to solve the capacitated facility location problem (CFLP) and consider two objectives simultaneously: costs and CO_2 emissions from transport and running serving facilities. Their work is built on their previous work on uncapacitated FLP (Harris *et al* 2009). The solution technique for CFLP focuses on solving large data instances which can be obtained from Harrisdata (2011). These data sets have realistic characteristics of real-world transport and distribution depot networks and are published to encourage further research in the area of multi-objective optimization. Figure 6.4 illustrates the trade-off solutions for one of these data sets where each solution has a different combination and number of open depots. Good compromise solutions are located in the middle of the approximated Pareto curve. In the Figure, the solution encoding indicates for each of 10 depots, numbered 1 to 10, which ones are open (1) and which are closed (0).

FIGURE 6.4 Approximate Pareto frontier for FLP data instance



SOURCE: Based on Harris *et al* (2011b)

In the next section, we discuss the impacts of uncertainty on operational, tactical and strategic decisions as part of managing green supply chains. Pishvaee *et al* (2012) present a bi-objective credibility-based fuzzy mathematical programming model for designing a strategic green network under conditions of uncertainty and illustrate applicability of this model and the solution technique through an industrial case study. A CO_2 equivalent index is used to model environmental impact across the network.

As can be seen from the discussion above, to assess the environmental impact of supply chains, there is a pressing need for decision-making/support tools that incorporate green performance measurements. In addition, Hervani, Helms and Sarkis (2005) point out that although environmental performance measures are being incorporated into existing tools at an increasing rate, current availability is far from adequate. They discuss the various tools that are available, including analytical hierarchy process, balanced scorecard, activity-based costing, design for environmental analysis and life cycle analysis. Some of these tools could be directly applied to aspects of green supply chain management and performance, while others require adjustments and extensions. The authors point out that on the whole there is no perfect tool for traditional or green performance measurement systems, and that their usage is greatly dependent on acceptance by organizations. However, introducing new tools, or tools with an ‘unfamiliar feel’, into a busy commercial environment can be challenging, if their adoption involves large capital investment, significant staff retraining or an unacceptable element of risk.

Uncertainty in transport and supply chains

The complexity of any given supply chain is related to the number of echelons or cost centres present, where an echelon is identified as a place where inventory is kept (Tsiakis, Shah and Pantelides, 2001). There are clear interfaces between each echelon, namely, suppliers/manufacturers, manufacturers/distributors, distributors/retailers and retailers/customers. Material, cash and information flow across each interface. Typically, individual echelons embrace the following characteristics (Towill, 1991):

- perceived demand for products, which may be firm orders or simply forecasts;
- a production, or ‘value-added’, process;
- information on current performance (which may be high or low quality);
- ‘disturbances’, for example due to breakdowns, delays, absenteeism;
- decision points where information is brought together;
- transmission lags for both value-added and other activities;
- decision rules based on company procedures, for example, changing stock levels, placing new orders and production requirements.

Characteristics such as these can induce uncertainties within supply chains, which may not be due to any actual variations in marketplace demand. As far back as 1958 Forrester, in describing production–distribution systems, or what we now call supply chains, noted that demand in the marketplace can become delayed and distorted as it moves upstream in a supply chain, from customers through to raw material suppliers. At any one point in time, processes in various companies in the chain may be moving in different directions from each other and from the market, in response to order or production predictions.

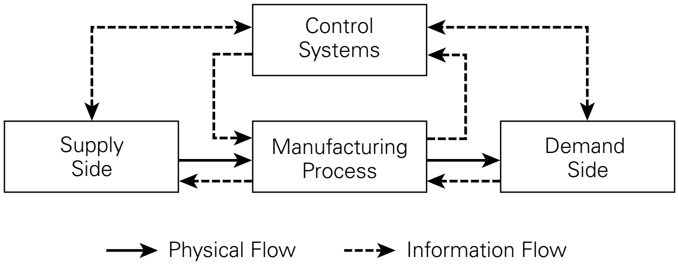
A considerable amount of research has been undertaken on uncertainty in supply chain management (Davis, 1993; Wilding, 1998; Mason-Jones and Towill, 1999; van der Vorst and Beulens, 2002; Geary *et al*, 2002; Peck *et al*, 2003, Walters, 2007; Sanchez-Rodrigues *et al*, 2008; Sanchez-Rodrigues *et al*, 2010), but in most of this work transport has typically been regarded as a marginal activity within supply chains (Stank and Goldsby, 2000) and has not been considered explicitly. To start to rectify these shortcomings, it is necessary to determine what forms of uncertainty affect transport operations. According to Van der Vorst and Beulens (2002), supply chain uncertainty refers to decision-making situations in which decision makers do not know what to decide. This indecision has many potential causes, including a shortage of one or more of the following: clear objectives, information processing capacity, or information about the supply chain or its environment. Such situations are hampered by an inability to accurately predict the impact of possible control actions on supply chain behaviour, or more simply, decision makers may lack effective control actions per se.

In response to uncertainties at a strategic level, supply chain agility is proposed by Prater, Biehl and Smith (2001). This may be achieved through flexibility and speed in the three key activities of sourcing, manufacturing and delivery. Naim *et al* (2006) developed a typology of transport flexibility to determine the level of customization required in the provision of transport services within supply chains as a result of different levels of transport flexibility. Furthermore, Naim, Aryee and Potter (2007) specifically address the issue of transport flexibility as a response to supply chain uncertainties, stating that various types and degrees of transport flexibility are required for different supply chain needs. For example, different solutions may be needed for routine activities (simply moving goods from A to B) than would be appropriate when customized or tailored solutions are required, involving multi-modality, warehousing provision or inventory management. Dimensions of transport flexibility might include mix, routeing, fleet and vehicle flexibility.

Davis (1993) was the first author to explicitly consider uncertainty as a strategic issue for supply chain performance when he stated: 'there are three distinct sources of uncertainty that plague supply chains: suppliers, manufacturing, and customers. To understand fully the impact on customer service and to be able to improve performance, it is essential that each of these be measured and addressed'. This work produced a framework that was initiated in Hewlett-Packard in the early 1990s.

Building on the work of Davis (1993), Mason-Jones and Towill (1999) developed the Uncertainty Circle Model (Figure 6.5) as a way of defining the different sources of uncertainty that can affect supply chain performance. They confirmed that uncertainty is a strategic issue in supply chains, and suggested that it originates from four main sources: the supply side, the manufacturing process, the control systems and the demand side. Hence they extended Davis's work by adding a further source of uncertainty, the control systems. Moreover, they emphasized that uncertainty initiated in the supply side and/or in the manufacturing process can be mitigated by the application of lean thinking principles. Uncertainty caused by control systems

FIGURE 6.5 Uncertainty Circle Model



SOURCE: Mason-Jones and Towill (1999) and/or on the demand side, on the other hand, requires an understanding of the dynamics of the whole system (Mason-Jones and Towill, 1999).

Another framework that takes uncertainty into account is the SCOR Model (Supply Chain Council, 2008). In a similar vein to Mason-Jones and Towill (1999), this model includes the supplier side as 'source', the manufacturing process as 'make' and the demand side as 'deliver'. It considers the logistics network concept by introducing the repetitive source–make–deliver sequences. Furthermore, the model extends the 'make' dimension by introducing the concept of 'value adding'. However, as with the Uncertainty Circle Model (Mason-Jones and Towill, 1999), it does not explicitly consider transport as a strategic supply chain process.

The Uncertainty Circle approach was further developed in research on the automotive industry by Geary *et al* (2002), where one of the main outcomes was an identification of the main issues associated with different types of uncertainty, examples of which are given in Figure 6.6. An attempt was also made to link the causes and effects of uncertainty or supply chain disruption. However, in neither Geary *et al* (2002) nor the work of van der Vorst and Beulens (2002) is transport considered as a strategic component of the supply chain or as a specific source of supply chain uncertainty. Instead a purely manufacturing perspective has been adopted.

The recent body of work on supply risk and vulnerability has added an important new dimension of exogenous events to the Uncertainty Circle (Peck *et al*, 2003). Examples of such events might include terrorism, industrial action, disease epidemics or severe weather conditions. Transport operations may be seriously affected either directly through such events, or more indirectly through government regulations and controls aimed at preventing

FIGURE 6.6 Examples of bad practices from the four sources of supply chain uncertainty

Process side
- No measures of process performance
- Reactive rather than proactive maintenance
- Random shop floor layout
- Interference between value streams

Supply side
- Short-notice amendments to suppliers
- Excessive supplier delivery lead time
- Adversarial supplier relationships
- No vendor measures of performance

Demand side
- No customer stock visibility
- No synchronization and poor visibility among adjacent processes
- Adversarial customer relationships
- Large, infrequent deliveries to customer

Control side
- Continuous product modification – high level of obsolescence
- Poor stock auditing
- Incorrect supplier lead time in MRP logic
- Infrequent MRP runs

SOURCE: Geary, Childerhouse and Towill (2002) their occurrence or minimizing their impact. Furthermore, businesses may decide to change their strategies, including their supply chain policies, to minimize the future impact of government interventions such as taxation changes or new regulations that may be looming on the horizon but whose shape is not yet known for certain.

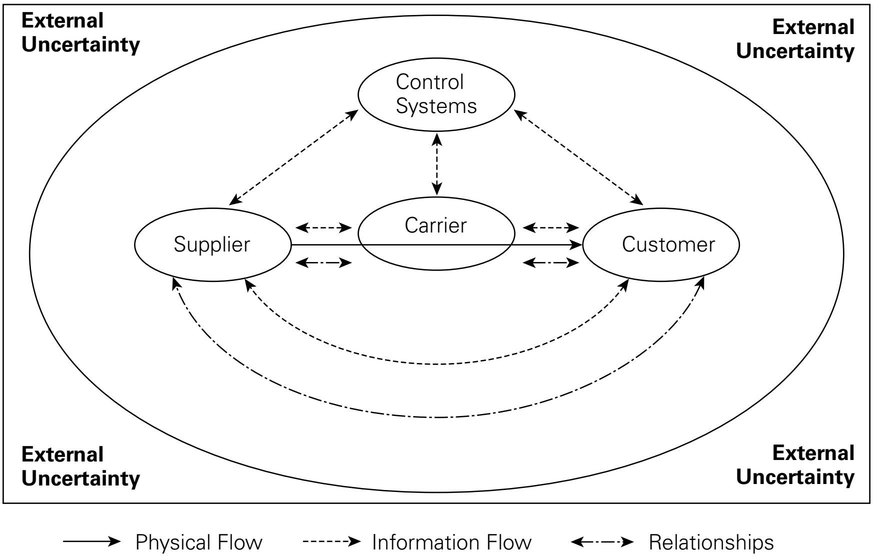
In the view of the present authors, work on the transport perspective of supply chain uncertainty is timely. Recently Prater (2005) developed an uncertainty framework that can be used to determine the causes of supply chain and transport uncertainty. This framework classifies uncertainty at both macro- and micro-levels. At the macro-level, uncertainty is typified in terms of general variation, foreseen uncertainty, unforeseen uncertainty and chaotic uncertainty. Getting down to the more micro-level, general variation consists of variable, multi-goal and constraint uncertainties. Foreseen uncertainty is caused by amplification of the demand from customers on inbound areas of the supply chain and by parallel interactions between members of the supply network that are at the same horizontal level such as carriers and/or suppliers. Unforeseen uncertainty is the consequence of deterministic chaos that disrupts long-term planning, such as that resulting from road congestion. Finally, chaotic uncertainty is general non-deterministic chaos that cannot be predicted by a mathematical function, for example natural disasters or political problems that disrupt the supply chain flow and cannot be predicted with any accuracy.

Uncertainty mitigation approaches in road freight transport networks

In an empirical case study, Sanchez-Rodrigues *et al* (2010) evaluate the impact of uncertainty on economic and environmental costs in the logistics triad. Their general Logistics Triad Uncertainty Model is shown in Figure 6.7. They found that uncertainty led to two main effects, which they term as 'extra distance' and 'extra time'. According to Sanchez-Rodrigues *et al* (2010), 'Extra distance/extra time' may be defined as any non-value-added or unnecessary distance/time within a distribution network due to supply chain uncertainty. It is the difference between the distance/time vehicles actually ran, and the distance/time they would have needed to have run if:

- the transport operation had received accurate and timely information on the volumes to be moved, and/or
- there had been no unexpected delays at loading or unloading points and/or
- there had been no operational failures within the distribution network and/or
- there had been no congestion on the journey that could not have been foreseen.

FIGURE 6.7 Logistics Triad Uncertainty Model



SOURCE: Sanchez-Rodrigues *et al* (2009)

'Extra distance' can increase fuel usage leading to increased costs and CO_2 emissions while 'extra time' leads to unnecessary slack time built into the transport schedules, hence not fully utilizing the vehicle resources available, and as a consequence, more vehicles are required to operate the road freight transport network.

Observations were undertaken of an FMCG secondary distribution operation based in the UK (Sanchez-Rodrigues *et al*, 2010). Observations included gathering data from the ICT transport system used to optimize, track and trace, and re-optimize transport movements. In addition, discussions with planners and managers were undertaken to corroborate and elaborate on the interpretation of data from the ICT transport system. As Table 6.1 shows, as a result of this research, Naim, Potter, Sanchez-Rodrigues and Marques (2011) developed an Uncertainty Mitigation Framework to classify the different actions that decision makers in road freight transport networks can take to mitigate uncertainty originated from both within and outside their networks.

They categorized the mitigation approaches as 'a priori' and 'a posteriori' and related them to 'base' and 'surge' tactics and strategies respectively. In the 'a priori' category, there is potentially sufficient information available before the event that causes the uncertainty. This occurs in the case of route diversion and what the planners believed could be done if the information was made available, enabled via communication flexibility (for the cases of load more than advised and products not loaded).

TABLE 6.1 Uncertainty Mitigation Framework

Extra distance/ time types	Uncertainty causes	Description	A posteriori 'surge' mitigation	A priori 'base' mitigation
Extra distance/time due to route diversion	Road restrictions Road Congestion not planned for	Extra distance needs to be run in an attempt to minimise the delay to the trip. But this may not always be possible and hence extra time is generated.	Routeing flexibility to accommodate re-routeing. Communication flexibility to utilise GPS and re-routeing software.	'Extra time' built into the plan when it is known that at certain times of the day there are likely to be delays eg rush hour, or evening roadworks
Extra distance/time due to delays	Store Suppliers Unplanned stops Road Congestion not planned for	Delays may occur, eg due to slow (un) loading at stores/ suppliers. This could incur the need for an additional vehicle, if the vehicle originally assigned to the trip is not able to reach its destination on time.	Capacity flexibility to accommodate variations or changes in traffic demand. Routeing flexibility to get around delays.	
Extra distance/time due to load more than advised	Late notification of extra volume from stores Late notification of extra volume from suppliers	The originally planned vehicle size is not appropriate and hence additional vehicles are needed to accommodate a higher volume.	Capacity flexibility to accommodate variations or changes in traffic demand. Link flexibility to allow vehicles to be sourced from other flows.	Advanced notice of changes in planned volume. Communication flexibility required to accommodate new sources of information.

TABLE 6.1 *continued*

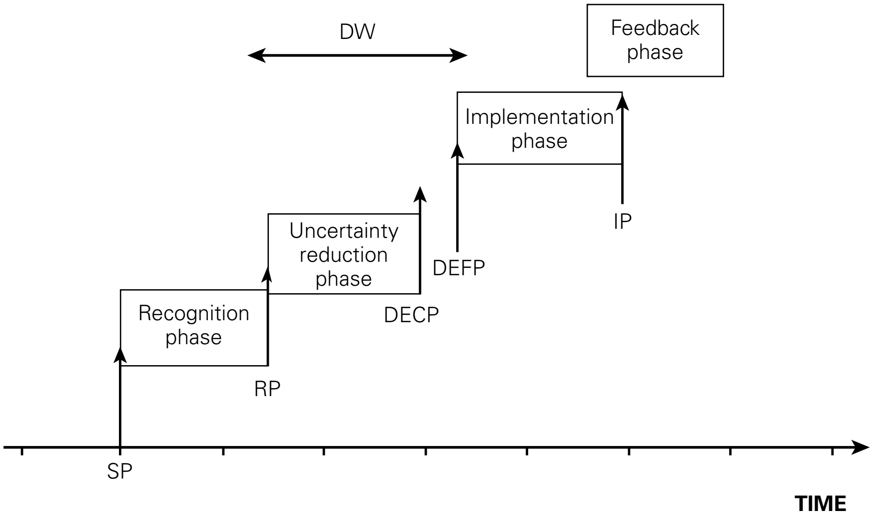
Extra distance/ time types	Uncertainty causes	Description	A posteriori 'surge' mitigation	A priori 'base' mitigation
Extra distance/time due to inappropriate vehicle size	Vehicle technical failure	Original vehicle not available for departure and may be substituted by a number of smaller sized vehicles.	Capacity flexibility and Fleet flexibility to provide different vehicle types.	
Other	Product not loaded at distribution centres Product not loaded at suppliers	The product ultimately needs to be moved, so volume accumulates for the next day which may lead to late notification of extra volume.	Capacity flexibility to accommodate variations or changes in traffic demand. Routeing flexibility to ensure full vehicle loads.	Earlier notice of missed additional products. Communication flexibility required to accommodate new sources of information.

SOURCE: Naim, Potter, Sanchez-Rodrigues and Marques (2011)

In the a posteriori case action can only be taken after the event happens and the transport planners take actions to add flexibility into their networks, particularly in the case of how they communicate within other decision makers within their network and how flexible is their fleet capacity and routeing. In terms of flexible fleet capacity, in the event of additional volume required to be moved, the transport planners outsource the movement to a sub-contracted carrier to avoid an increase in fixed cost within their network. In the case of routeing flexibility, transport planners have alternative routes in place if any of their better optimized routes become unavailable.

Decision making within road freight transport planning and execution is a temporal activity and is a consequence of a 'critical path' timeline. Naim *et al* (2011) draw a timeline (shown in Figure 6.8) to encapsulate the types of uncertainties and mitigations we have defined in Table 6.1. This timeline diagram is an adaptation of one used as part of the training guidelines developed for the United States of America military logisticians (Brecke and Garcia, 1995, 1998). In Figure 6.8, Start Point (SP) represents any event, or uncertainty cause, that disrupts road freight transport operations. The

FIGURE 6.8 The road freight planner's decision timeline



SOURCE: Naim *et al* (2011)

Recognition Phase is that time during which the transport planner is aware of the event occurring. The transport planner can be said to have 'sensed' the occurrence of the event by the Recognition Point (RP). The planner then has a Decision Window (DW) by which to seek alternative courses of action during the Uncertainty Reduction Phase, before they make a decision at the Decision Point (DECP), and start the Implementation Phase at the Default Point (DEFP).

From Naim *et al* (2011), it may be concluded that DW defines the time which it takes for the logistics operation to respond to the event and that by DEFP the logistics operations have recovered. How well and quickly that recovery is achieved is dependent on the inherent flexibilities of the logistics triad, or how prepared the road freight transport network is to respond to uncertainty. The approach also contains a feedback phase, where the lessons learnt from the actions undertaken are used by transport planners in preparing better for the next possible event. Approaches that detect and manage, or sense and respond, to unexpected events are well known in the literature (Haeckel and Nolan, 1993) with examples of implementation again coming from military logistics (Tripp *et al*, 2006). Moreover, Naim *et al* (2011) find analogy between such findings and supply chain resilience (for example, Peck *et al*, 2003; Sheffi and Rice, 2005). Ponomarov and Holcomb (2009) define supply chain resilience as 'the adaptive capability of the supply chain to prepare for unexpected events, respond to disruptions, and recover from them by maintaining continuity of operations'.

This work developed by Naim *et al* (2011) adds to the supply chain resilience literature by encapsulating the concepts of readiness, response, and recovery and sensing into an approach to road freight transport resilience. These concepts can be defined as follows:

- Readiness: before SP, the logistics triad is prepared for uncertainty or a disruptive event through the development of freight transport flexibility capabilities at a reasonable cost.
- Sensing: minimizing the lag between the event occurring and the logistics triad's recognition of the event, RP, ensures the number of options available to planners is maximized.
- Response: reaction to a specific event is given by DW. A quick and flexible response implies minimizing the time to react to the disruptions and begin the recovery phase.
- Recovery: a return to normal stable or steady-state conditions, by the implementation point, IP.

Gaps in our understanding and priorities for research

There has been little research into the impact of different supply chain practices on green logistics performance, and in particular, the impact of fundamental supply chain management principles still needs to be addressed. Whilst there is now a significant body of knowledge on uncertainty in supply chains in general, there has been a lack of explicit determination of the impact of uncertainties on transport performance, using either economic and/or environmental criteria. The impact of decision making, whether at strategic, planning or operational levels, needs to be considered with respect to balanced, or multi-objective, performance metrics that take environmental issues into account, in addition to economic costs and customer service levels.

Historically, most supply chain research considers the material producers, or 'suppliers', as the key players. However, recent research on the logistics triad sees the third-party logistics provider as a core constituent of the supply chain. Therefore, it is necessary to determine the impact of the relationships between all members of the triad and how various partnership arrangements may impact on green logistics performance. Again, historically, supply chain relationships have been considered from a vertical, forward material flow perspective. Other dimensions include reverse material flows and horizontal relationships, perhaps between carriers and their complementors and/or competitors. Alongside these relationship issues, there is a need to address how best to use information in the supply chain so as to mitigate against negative environmental impacts. For example, to what extent is information sharing vital between third logistics providers and other members of the triad?

Logistics flexibility, as a response to uncertainty, is still little understood in terms of its economic impact, let alone for its effect on green logistics. Therefore, the impact of interactions between transport providers and other members of the triad should be established, since these can represent a very significant source of transport uncertainty, and as a consequence have a considerable impact on green logistics performance.

It is important to take a holistic view in establishing the impact of supply chain practices on the environmental performance of transport, and to do this there needs to be a considerable degree of clarity about what aspects of uncertainty are relevant to green logistics. In order to determine this, future research should:

- determine and categorize all the sources of uncertainty that affect the supply chain and transport;
- consider the root causes and fundamental effects of each type of uncertainty;
- determine where each type of uncertainty originates from, whether in transport operations or other parts of the supply chain;
- determine the impact of the causes of uncertainty on green logistics performance;
- prioritize the causes of uncertainty and develop solutions, including flexibility strategies, to mitigate their implications;
- explore the full range of uncertainty, including that primarily related to the external environment, such as commodity availability, product prices, international trade regulations, taxes and duties.

With regard to environmental metrics and measures, Hervani, Helms and Sarkis (2005) identify the following issues for future research:

- The business and environmental outcomes of green supply chain management (GSCM) performance measurement systems and their impacts both within the organization and society at large need to be addressed. If as a result of such studies there is no immediate improvement, further research is needed to address when and if they will make the difference.
- There is a need for industry-specific research to address which performance measurement systems work best in which situations.
- There needs to be inter-organizational agreement on performance management and measurement.
- There is a need for tools to promote the development and improvement of green performance measures and supply chain management.
- Data and information issues relating to GSCM need to be addressed.
- The roles of new technologies including information technology in GSCM need to be better understood.

Singh *et al* (2009) point out that even though there is an international effort to measure sustainability, relatively few approaches consider environmental, economic and social aspects in an integrated way.

There is a lack of research into large-scale supply network problems, and such research would be conducive for multiple performance criteria assessment. Aronsson and Huge-Brodin (2006) have identified a general low level of interest in environmental issues in logistics. Their paper identified 'the lack of theories and models for connecting different logistics decisions on different hierarchical decision levels to each other and their environmental impact'. Hence, it is important to gain more insight into how companies can lower their costs and increase their competitiveness while at the same time reducing their environmental impact. In the cases where companies have undergone a strategic redesign of their supply chain or redesigned their distribution network, it appears that in many cases savings achieved in overall system costs also lead to environmental savings in terms of CO_2 emissions or energy savings.

Consequences and conclusions

In this chapter we have reviewed the current knowledge of supply chain modelling and identified a need to consider the environmental impact of business activities alongside the usual economic and customer service factors. We began with a survey of the current state of knowledge, discussing the strengths and limitations of some traditional supply chain models. We identified uncertainty – and its mitigation – as a key issue in supply chain management. Uncertainty can result in alternating periods that produce vast surpluses and shortages of inventory, wasting resources and impacting on customer service levels. Clearly, supply chains that perform poorly from an economic and customer service perspective are also likely to perform badly when considered from an environmental viewpoint. Thus, addressing the weaknesses should produce simultaneous benefits for all stakeholders.

We noted that traditional supply chain management focuses primarily on market and manufacturing issues, and transport has typically been considered as a rather marginal activity. However we can identify several reasons why this emphasis needs to change, not least increasing fuel costs. First of all, it is clear that the transport subsystem has a key role, and poor transport management will mean that goods are not delivered to where they are needed at the appropriate time, thus disrupting the operation of the whole supply chain. Second, transport activities have a high environmental impact, in terms of energy usage, carbon emissions, noise and pollution. Finally, the life-cycle approach to supply chains adds considerable complexity, and requires much additional transportation to deal with returns, recycling and remanufacturing. We have identified a need for a more holistic approach to transport, and more collaboration between logistics operators and those they serve.

Environmental performance measures have been discussed in some detail in this chapter. Plainly, we rely on appropriate methods and measurements to give accurate information to decision makers. However there are very many aspects to sustainability, and there appears to be no general agreement on how to trade-off the different components such as energy and raw material usage, greenhouse gas emissions and the generation of scrap and waste. Furthermore, there are few tools to support the measurement of environmental key performance indices.

It is clear to us that much more research is needed on how to quantify the impact of supply chain practices on green logistics performance, and the environmental impact of current supply chain management policies needs to be addressed as a matter of urgency. In particular, we need to look at how uncertainty in a supply chain impacts on transport performance, with respect to both economic and environmental criteria. Decision makers should consider environmental issues simultaneously with economic costs and customer service levels.

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Transferring freight to 'greener' transport modes

07

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> *The share of road transport in intra-EU long-distance freight transport is around 33 per cent, while rail and inland waterways jointly contribute less than 20 per cent. The poor environmental performance of the transport system is linked to the fact that the generally greener rail and inland waterways transport have failed to exploit their potential in medium to long distances.*
>
> **EUROPEAN COMMISSION, 2011**

Background

This chapter examines the division of freight traffic among the main transport modes, the so-called freight modal split. It discusses the ways in which freight can be transferred from road to alternative modes of transport with lower environmental impacts, particularly with respect to climate change. The main focus of the chapter is on efforts within the EU to promote greater use of rail and water – both inland waterway and short-sea shipping services – since these are the main alternatives to road for a broad range of commodity and flow types.

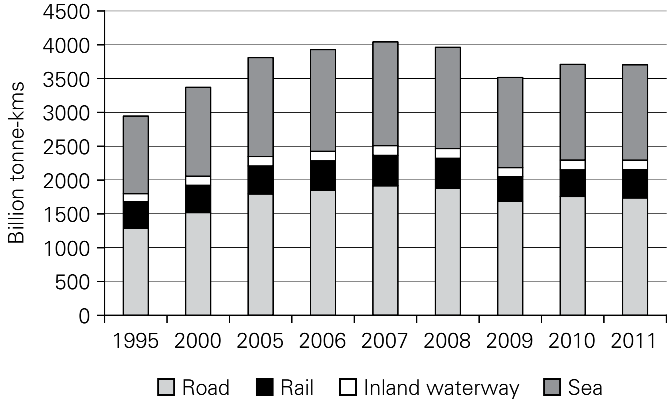
Little reference is made to pipelines and air freight because of the limited range of products they can reasonably carry. It is, nevertheless, acknowledged that specialized pipelines or underground conveyor systems can in particular circumstances offer an environmental alternative to road freight transport in sensitive areas, though often at very high cost (BBC News, 2014).

EU statistics show the changing distribution of freight activity across the transport modes under consideration. Road haulage has had the greatest share throughout the time period since 1995 (Figure 7.1), its share rising from 44 per cent in 1995 to 47 per cent in 2011. Sea freight is also a very important mode at the European level, although its share has marginally declined. It is evident that most of the growth in absolute volumes of road haulage and sea freight resulted from an increase in total freight activity, with the transfer of flows from other modes accounting for only a relatively small amount of road and sea growth.

The fortunes of the railways and inland waterways have been less positive, as can be seen from Table 7.1. Rail had been losing market share for a long time prior to 1995 and its share has continued to decline. Inland waterways have had a stable share of the European market but, at just 4 per cent, they cannot really be considered to be a major player other than in certain countries (eg Netherlands) or corridors (eg Rhine). Given the relatively limited extent of navigable inland waterways in the UK, waterborne freight is dominated by seagoing flows.

In the case of the UK, more than 95 per cent of trade by weight enters or leaves the country by sea (DfT, 2012), either short-sea to/from the rest of Europe or deep-sea to/from other continents, with most of the remainder travelling through the Channel Tunnel. Less than 0.5 per cent of the tonnage of international freight moves by air.

FIGURE 7.1 Freight transport performance (EU27) by mode 1995–2011



SOURCE: Based on European Commission (2013)

TABLE 7.1 Freight transport modal split (% of tonne-kms, EU27) 1995–2011

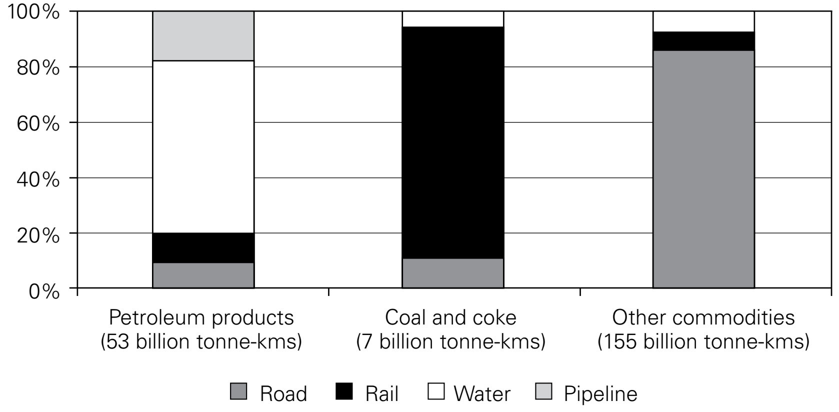
	1995	2000	2005	2010	2011
Road	44	45	47	47	47
Rail	13	12	11	11	11
Inland waterway	4	4	4	4	4
Sea	39	39	38	38	38
Total	**100**	**100**	**100**	**100**	**100**

SOURCE: Based on European Commission (2013)

Characteristics of the main freight transport modes

The main freight transport modes all have different characteristics, which lead them to play different roles in the movement of goods. Rail and waterborne freight have natural advantages in the movement of bulk products, resulting mainly from their ability to carry large quantities in a single train or vessel. By contrast, the flexibility and convenience of road haulage lends itself to the movement of manufactured goods. Typically, then, rail and water come into their own for commodity movements in the early stages of the supply chain, where flow volumes tend to be larger and of relatively low value compared to their weight. Road caters for the majority of the flows that distribute products, where consignment values per tonne are typically higher and flows are of smaller volumes. Rail finds it hard to compete for shorter distance flows, except when very large volumes are on offer. Hence there are well-established, large variations in the average distance that goods move by each mode, reflecting their different characteristics. The average road journey in Britain is 92 kilometres in length, while a rail movement averages 220 kilometres and for domestic waterborne freight the figure is 442 kilometres (DfT, 2011). Figure 7.2 demonstrates the dominance of waterborne freight in the movement of petroleum products, rail in the coal and coke market, and road in the carriage of other commodities. In recent times, the fastest growth has occurred in the movement of non-bulk commodities, favouring road haulage and strengthening its dominance of the UK freight market. Table 7.2 sets out an indicative mode suitability assessment for a range of commodity types.

FIGURE 7.2 Domestic freight transport moved (GB): mode share for selected commodities 2009



SOURCE: Based on DfT (2011)

The growth in the use of the freight container, and more recently the swap-body, has led to the development of intermodal transport, whereby more than one mode of transport is used for longer distance flows, with rail or water covering the majority of the distance and with road legs confined to the beginning and end of the journey. With intermodal transport, it is the unit in which the goods are conveyed that is handled at the point of modal transfer, rather than the goods themselves. This allows for greater standardization in terminal and transport equipment, reducing the cost and time of modal transfer. In the UK, domestic intermodal volumes by rail increased by 86 per cent in the 10 years to 2012/13, making this the fastest-growing sector of the rail freight market (ORR, 2013).

While the road haulage and waterborne modes have long been competitive markets, with considerable intra-modal competition for many commodities and flows, rail freight in Britain was part of the nationalized British Rail monopoly provider until the mid-1990s. Since privatization, the rail freight market has become increasingly competitive and this is regularly cited as one of the major reasons for the revival of rail freight activity.

As will be seen later, both European Union (EU) and UK government policies have favoured using competitive markets as a means of encouraging a more sustainable freight transport system, reflecting the inherent environmental advantages of certain non-road modes. While rail and water operations are almost exclusively in the private sector, government is involved in the provision of infrastructure for these modes. The British rail network is owned by Network Rail, nominally a private company but regulated by an independent regulatory authority and with no private shareholders. Many inland waterways are owned either by the Environment Agency (a government

TABLE 7.2 Mode suitability assessment for different commodity types

Commodity Type	Mode		
	Rail	Inland waterway	Short-sea shipping
Aggregates	/	/	/
Coal	/	–	/
Retail (non-food)	/	–	/
Retail (perishable food)	–	*	/
Container	/	–	/
Automotive	/	–	/
Parcels	/	*	/
Home delivery	*	*	*
Waste	/	/	/
Oil and petroleum	/	/	/
Steel/scrap metal	/	–	/
Forest products	/	–	/

KEY

/ Regular flows
– Trial/irregular flows
* Not suited

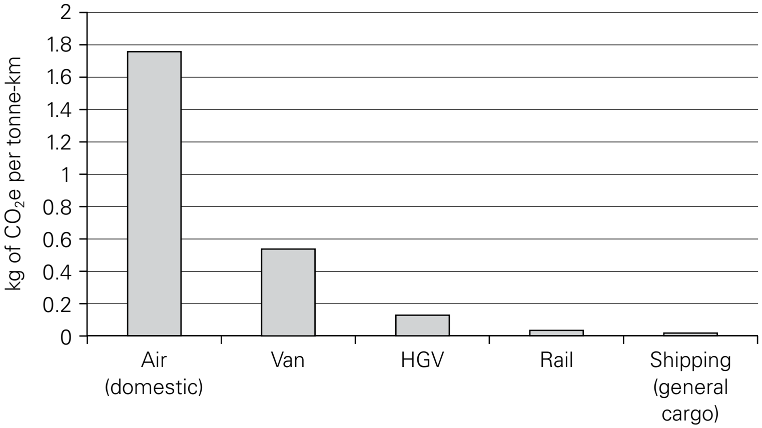
SOURCE: DfT (2008a)

agency) or by the Canal & River Trust, a registered charity organization which assumed control of the assets of the former British Waterways organization in 2012 (though arrangements differ in Scotland) – reflecting the low use of inland waterways for freight in the UK today and their greater focus on leisure and recreational use. By contrast, the majority of the biggest ports are now in the hands of private companies, though this is not necessarily the case elsewhere in Europe.

Environmental impacts of the main freight transport modes

In addition to each of the modes having different operational characteristics, their environmental impacts also differ significantly. Various attempts have been made to assess the relative environmental impacts of freight modes, and a relatively consistent picture emerges from these different studies despite some differences in absolute values. Figure 7.3 presents the direct greenhouse gas emissions per tonne-km for a range of transport modes using United Kingdom data (Defra/DECC, 2011). In general, rail and waterborne modes of transport are less damaging to the environment than road haulage, with typical emissions from the former two modes being several times less per tonne-km than for road. Air has significantly greater emissions at around 1.75 kg per tonne-km, so it is clearly undesirable from a sustainability perspective to encourage greater use of air freight.

FIGURE 7.3 Estimated average CO_2 intensity values for freight transport modes (United Kingdom)



SOURCE: Defra/DECC (2011)

While most of the concern about the environmental impacts of freight transport relates to the greenhouse gas emissions leading to climate change, the modes of transport also vary in terms of their local air pollution impacts. According to RSSB (2007), for example, rail freight performed significantly better than road haulage in terms of the emissions of nitrogen oxides and particulates on a tonne-km basis, but at that time was approximately three times worse than road for sulphur dioxide emissions. It is vital, therefore, to be clear on the environmental objectives to be achieved, in particular whether the mitigation of climate change impacts is the prime consideration or whether a trade-off between global and local emissions impacts is desirable. It should be borne in mind that these values are averages for each mode, which are helpful in identifying how each mode typically performs relative to the others but do not apply to every situation. The reality will be heavily influenced by the characteristics of the flow, not least the volume of goods to be moved, the efficiency and speed of the transport operation and the nature of the fuel consumed. For example, if a ship travels at 24 knots rather than 20 knots, it will typically use one-third more fuel (DfT, 2008b), worsening its environmental performance.

Case study: Container train load factors

The two pictures in Figure 7.4 demonstrate dramatically different load factors for container train services, clearly showing that environmental performance per unit of freight moved may be significantly influenced by the level of operational efficiency. In the example above, with a far higher train load factor, the amount of fuel used (and the associated pollutant emissions) will be slightly higher than in the poorly loaded example shown below, but the emissions per container or per tonne carried will be far lower in the example of the better loaded train. In fact, it may well be the case that in the case of the poorly loaded train, the environmental impact of using road haulage would be lower than it is for rail, given that only a small number of HGVs would be required to move the small number of containers being carried. By contrast, the example above is highly likely to be less polluting per unit carried than road since a large number of HGVs would be needed to move all the containers on the train.

A study of container train utilization, carried out as part of the EPSRC Green Logistics project (Woodburn, 2011), found considerable variability in load factors by port served, direction of travel (ie import or export), rail freight operator and specific corridor. Overall, a 72 per cent load factor was identified, with 75 per cent loading for imports and 69 per cent in the export direction. Load factors varied from a high of 80 per cent at Felixstowe to just 55 per cent at Tilbury, while across the four rail freight operators there was variability from 90 per cent down to only 54 per cent. For specific services in the sample of almost 600 trains, load factors ranging from 100 per cent full to completely empty were found. The average train carried 44 twenty-foot equivalent units (TEUs), which avoids the use of more than 20 HGVs for each rail service operated. If all of these trains were fully loaded, though, at least 30 HGV journeys per train would be avoided.

FIGURE 7.4 Examples of different load factors for container train services

SOURCE: Authors' collection

The policy framework

European Union

The momentum behind the promotion of policies designed to achieve a shift from road to 'greener' transport modes has grown since the late 1990s, at both the national and EU levels. In 1992, the European Commission published its first White Paper on Transport. This focused mainly on the liberalization of transport markets as part of the development of the Single European Market, but led to a strengthening of road's position in the freight market, at the expense of rail and inland waterways which both lost market share. The 2001 White Paper recognized this imbalance in the growth of the different transport modes and the consequent impacts on the environment, congestion and accidents. This second White Paper was published at a time when a consensus was forming within the scientific community as to the strong likelihood that human activities, of which transport is key, were responsible for the changing global climate. The subsequent 2011 White Paper continues with essentially the same emphasis on balancing economic development and environmental impacts. Specifically, targets have been set for 30 per cent of road freight travelling distances greater than 300 kilometres to transfer to rail or water by 2030 and 50 per cent by 2050 (European Commission, 2011). Reducing the dependence on oil-based fuel sources also favours a switch of traffic from road to rail, where the latter may have the opportunity to use electric traction, which raises the opportunity to use renewable or other non-fossil fuel power sources. At present, the waterborne freight sector is almost entirely dependent upon oil-based sources, so does not offer the same benefit over road, but of course is typically far more fuel efficient.

The EU has implemented its Integrated Maritime Policy, which is of particular significance for the UK given its reliance on shipping for international trade and the importance of coastal traffic. The policy aims to balance the often-conflicting challenges of globalization and economic competitiveness, climate change, marine environment damage, maritime safety and energy security and sustainability. One specific objective is the reduction of CO_2 emissions from shipping. Other EU policies and regulations influence both freight transport mode choice and the environmental impacts of the different modes. For example, increasingly stringent emissions regulations relating to the sulphur content of diesel fuel have been implemented for road vehicles, and are now being widened to cover most non-road diesel engines, such as those used in railway locomotives. This is causing significant concern in the European maritime sector at the time of writing, with ferry operators in particular concerned that the higher costs of purchasing cleaner fuel will make more marginal routes uneconomic to operate (Maritime UK, 2014).

UK government

In the UK, different levels of government have responsibilities that influence freight transport activity. The situation has become more complex in the last decade, with the introduction of devolved administrations in Scotland, Wales and Northern Ireland. A common theme in the freight transport policy documents published by the UK government and the devolved administrations is the strong desire to shift freight from road to rail and waterborne services (eg Scottish Government, 2006; Welsh Assembly Government, 2008; DfT, 2008a).

The evolution of freight transport policy aims to balance two of the main strategic objectives of the UK government, these being the generation of economic growth and enhanced productivity and a reduction in the environmental impacts (particularly relating to climate change) of transport activity. Switching freight to modes with lower carbon intensity levels is a key element of the strategy, which in itself will form an important part of the broader programme to reduce the UK's carbon emissions. More recently, the importance of tackling transport's impacts on the environment, with particular regard to meeting carbon reduction targets, has been highlighted in the Carbon Plan (DECC, 2011). A range of practical measures to encourage modal shift from road to rail and water is identified in the next section.

Initiatives to promote freight modal shift for environmental benefit

This section presents a selection of measures introduced by the European Union, UK government and the rail and water industries themselves to encourage the greater use of rail and waterborne modes. Finally, arguments are expounded that can be adopted to encourage freight users to consider switching from road. The aim is to show that a wide range of measures exists, rather than to provide a comprehensive review.

European Union

The EU has developed a Freight Action Plan (European Commission, 2007), in an attempt to coordinate policy initiatives relating to the performance of the freight sector. On modal shift, a number of initiatives are outlined, including the development of 'green' transport corridors for freight (including the establishment of a freight-oriented rail network), the removal of barriers that hinder the use of rail and water-based solutions, the promotion of best practice and the development of performance indicators measuring sustainability. Through its Greening Transport initiative, the EU aims to allow national governments to introduce user-charging schemes to internalize the external costs associated with freight movement, particularly relating to the road haulage sector. Traditionally, road tolls have been allowed only to recoup infrastructure costs, although differential tariffs based on vehicles' environmental characteristics have been allowed since 2006. Proposals have been developed to allow a more comprehensive charging regime that will better reflect the environmental impacts of freight traffic, leading to more efficient road haulage operations (eg by encouraging more fuel-efficient and less polluting vehicles), as well as shifting traffic to rail and water in situations where they become more cost-effective than road.

In conjunction with its programme to enhance transport interoperability and connectivity, the EU is using its Trans-European Network (TEN-T) programme to try to influence the modal split in favour of more sustainable transport. Many of the 30 priority projects are focused on removing obstacles to using rail and water, together with promoting intermodal operations that use the most appropriate mode for each stage of a freight flow. The EU anticipates that completion of the TEN-T priority network will slow down the rate of increase of CO_2 emissions from freight transport operations through a combination of modal shift and more efficient operations. The TEN-T initiative was formally refocused under the Connecting Europe Facility in early 2014 along the lines of core network corridors with a strong focus on non-road alternatives (European Commission, 2014). Nine long-distance corridors are being implemented to remove bottlenecks, provide missing cross-border links and promote integration and interoperability between transport modes. One focus of the TEN-T priority network investment is on major inland waterway improvements to facilitate waterborne freight movements, such as those planned for the Rhine/Meuse–Main–Danube system and also the proposed links between the Seine and the Scheldt. One specific TEN-T priority project is known as Motorways of the Sea. This concept attempts to develop maritime-based supply chains in Europe that will be more sustainable, and should also be more commercially efficient, than traditional road-only transport. A sea-based network is under development, primarily covering routes in the Baltic, western European and Mediterranean regions. The commercial viability of some such routes is however in doubt at the time of writing, with a route between France and Spain being withdrawn despite achieving high load factors because it is no longer economically viable without continued subsidy support (Todd, 2014).

UK government

Strategic measures that aim to reduce the dominance of road haulage include land-use planning policies, investment in transport infrastructure provision and capability, and infrastructure charging policies. An Infrastructure Planning Commission (IPC) has been established, which evaluates nationally significant infrastructure projects in an attempt to address concerns relating to the land-use planning process for the handling of strategic projects. Under the previous system, rail and water schemes that may offer broader environmental benefits were sometimes rejected due to local concerns.

For transport infrastructure, funding from the Transport Innovation Fund (TIF): Productivity and the Strategic Freight Network (SFN) Fund has been used to upgrade key links in the rail network to allow the more efficient movement of high-cube containers by rail between major ports and their hinterland. Regional development money has also been invested in some UK regions to ensure the movement of bulk freight by rail, as in the case of an enhanced rail connection to the port of Hull, but the demise of regional development agencies has ended such initiatives. Infrastructure charging policies are influenced by EU legislation but implemented by national governments, and mode choice can be influenced by decisions on road user charging and the level of rail track access charges, for example.

In addition, there are many practical initiatives supporting the transfer of freight to 'greener' modes. Two examples are identified here: freight mode shift grant support and the Freight Best Practice programme. The UK Department for Transport provides three different types of grant: freight facilities grants (FFG), mode shift revenue support (MSRS) and waterborne freight grants (WFG), although the schemes are not necessarily all in operation at any one time. These grants work on the premise of gaining environmental and social benefits that arise from the use of rail or water transport rather than road. The Freight Best Practice programme was traditionally focused on road freight transport but was broadened out to include guidance on multi-modal transport solutions that offer environmental and commercial benefits. One such product of this expansion in the scope of the Freight Best Practice scheme was a guide to *Choosing and Developing a Multi-modal Solution* (DfT, 2008a). However, the Freight Best Practice programme has since been suspended.

Rail and water industries

As has been seen, the rail and water industries typically have lower environmental impacts than road. It is important, therefore, not to make modal transfer from road more difficult through the introduction of policy measures, targets and regulations that make rail and water use more onerous. Equally, though, further improvements in environmental performance are desirable.

The privatized British rail freight operators have invested in more than 450 new Class 66 freight locomotives, replacing the vast majority of the older locomotive fleets inherited at the time of privatization. These new locomotives are more fuel efficient and less environmentally damaging than their predecessors. Indeed, the more recent batches of Class 66s to be delivered have significantly lower emissions of certain pollutants than those delivered earlier. According to Freightliner (2006), emissions of carbon monoxide are 95 per cent lower, hydrocarbons are reduced by 89 per cent and nitrous oxides are 38 per cent lower. The newer Class 70 PowerHaul locomotives are also claimed to provide significant environmental benefits relative to their power. Other measures that can be adopted to further reduce environmental impacts include shutting down locomotives between duties, which is more feasible with modern engines that readily restart, encouraging drivers to be more fuel efficient, and providing paths through the rail network that allow steady progress for freight trains rather than lots of acceleration, deceleration and idling in passing loops or yards. The Office of Rail Regulation has instructed Network Rail, the infrastructure manager, to accommodate a 30 per cent growth in freight services and a 25 per cent reduction in freight train delays caused by the infrastructure manager by 2014 (ORR, 2008). Freight operating companies estimate that they can reduce their CO_2 emissions by between 15 and 21 per cent through the implementation of a series of planned initiatives, including auxiliary power units, the relocation of fuel points, in-cab driver advice systems and the adoption of best practice for drivers and ground staff (DfT, 2008b). Steps are being taken to introduce sulphur-free diesel to replace the traditional gasoil used for rail freight operations. Biofuels are also under trial. In the longer term, greater use of electric traction may provide further environmental benefits, particularly if renewable sources are used for electricity generation, though a significant shift in this direction would require investment in additional railway electrification. Some European rail freight operators are investing in hybrid electric/diesel locomotives, which offer the benefits of electric traction for the trunk haul but low-power short-distance diesel capability in order to access freight terminals, thus ending the need for costly locomotive exchange. Such measures can assist with modal shift by improving the performance and reducing the cost of rail, and by projecting a more sustainable image for the industry in order to attract new custom. Organizations such as the Rail Freight Group and Freight on Rail also exist to lobby in favour of rail freight use and help to develop cost-effective and sustainable rail-based solutions.

The waterborne freight sector is more fragmented than the rail industry, but Freight by Water (FbW) has been established by the Freight Transport Association to promote short-sea, coastal and inland water freight as a commercially viable and sustainable mode of transport. FbW provides information about waterborne freight options to prospective users, hosts events to try to raise the profile of water freight and coordinates an industry response to public authorities.

Freight users

There are a number of arguments that can be used to encourage freight users to consider the use of 'greener' transport modes:

- It may be possible for companies to generate cost savings at the same time as reducing environmental impacts, particularly at times of high oil prices, since these affect overall road haulage costs proportionally more than those for the rail and water modes.
- Performance may be enhanced, leading to greater reliability and lower variability of freight operations. For example, the need for a

rail network path gives greater certainty of journey time (and arrival time at the destination) than the 'turn-up-and-go' arrangements for accessing the road network, which are prone to unpredictable congestion effects.

- Companies may benefit from marketing their use of 'greener' modes, for example as part of their corporate social responsibility (CSR) strategy. This may give them a competitive advantage and lead to additional sales revenue.
- Organizations are becoming increasingly concerned about business continuity and supply chain resilience, particularly in relation to their ability to deal with risks that arise from external sources and over which they may have little control or ability to respond in the short term. In the context of freight activities there may be risks associated with using road exclusively, such as major fluctuations in fuel prices or an interruption to the availability of fuel. As such, forward-looking companies are attempting to 'future-proof' their supply chains by ensuring that they have a choice of modes available to them.

In general, companies may find that they are able to make improvements to the performance of their supply chain operations if they consider the role for 'greener' modes when making strategic changes to their logistical activities. Forcing the use of different modes into an otherwise unchanged supply chain is unlikely to be successful.

Good practice in achieving modal shift to rail and water

The multi-modal guide referred to earlier in the chapter contains 35 case studies exemplifying the possibilities for using rail and water-based freight solutions (DfT, 2008a). These case studies feature logistics service providers, retailers, those involved in the movement of bulk products and container operators. More recently, the Freight Transport Association (FTA, 2012) published details of the use of rail freight by several major retailers. Some of the key features of these case studies are highlighted below, using quantified benefits where possible.

Freight grants have been a fundamental ingredient in the success of a number of the flows that have shifted from road to 'greener' modes. In the retail sector, Asda uses shipping services to deliver products directly to its Import Deconsolidation Centre at Teesport in north-east England. The company uses rail for general merchandise and clothing products moving between the Midlands and central Scotland and also within Scotland. These initiatives have been key to supporting Asda's carbon reduction targets. Similarly, Tesco uses rail between the Midlands and central Scotland, saving more than 7 million road-kms per annum and leading to around 6,000 fewer tonnes of CO_2 being emitted each year, and has recently switched flows to rail between the Midlands and both south-east England and South Wales. It has also begun to use the inland waterway system to move containerized wine that is imported through Liverpool and bottled in Manchester. The 60-kilometre barge transfer along the Manchester Ship Canal removes 50 lorry journeys each week. A similar barge operation moves grain between the terminal in the Port of Liverpool and flour mills in Manchester, saving more than 125 lorry movements per week.

Modal transfer has also occurred in the bulk sectors that traditionally make great use of rail and water, highlighting the fact that there is often scope for still greater use of 'greener' modes even where they already have significant market share. For example, significantly greater volumes of coal can now be handled at the port of Immingham as a result of investment in new equipment that can load 1,500 tonnes of coal into a train in 23 minutes. Investment in new equipment is fundamental to the success of many of these initiatives, and again grant funding is often available. Days Aggregates received grant funding to assist with the purchase of mobile handling equipment to unload aggregates at terminals in the London area. More strategically, as part of the expansion of the Haven ports, covering Felixstowe and Bathside Bay, Hutchison Ports has committed to investing in the rail network to enable more container trains to operate and to carry high-cube containers more efficiently. In this case, private finance is being used alongside government funding for the rail network, with the aim of increasing rail freight volumes from Felixstowe by 3 per cent each year. In addition, the Haven Gateway Partnership has secured European funding for a Low Carbon Freight Dividend project to support SMEs (small and medium-sized enterprises) to shift freight from road to rail.

Shipping lines have become increasingly involved in contracting train space on container services, in some cases even committing to regular full trainloads. Kuehne & Nagel uses a mix of dedicated trains, contracted space on multi-customer trains and spot hire of capacity, and is on record as stating that its container flows by rail are now more punctual than by road. Similarly, the development of rail services sponsored by logistics service providers has been one of the most successful developments in the past decade in attracting consumer products to rail. Logistics companies such as The Malcolm Group, Eddie Stobart Ltd and John G Russell (Transport) Ltd have become established players in the rail freight market, acting as consolidators to make up viable trainloads from their customer base and bridging the gap between the rail operators and freight customers. The Tesco rail freight example referred to earlier is an interesting example of supply chain cooperation, since Tesco provides 100 per cent of the northbound volume and 90 per cent of the southbound volume, with freight for other Eddie Stobart customers helping to fill the remaining southbound capacity. In the shipping sector, a number of container shipping lines such as Feederlink BV, OOCL and K-Line have developed short-sea and coastal services that move containers to ports that are closer to their ultimate destination, rather than relying on land-based onward movement from the major ports.

Conclusions

This chapter has outlined the reasons behind the desire for an increase in the share of freight being moved by rail and water, given that these modes are typically 'greener' than road haulage. The policy framework has developed over the last decade to reflect the growing concern about the environmental impacts of freight transport activity, primarily relating to climate change but also with respect to local air quality issues. There are some signs of success in encouraging the use of alternatives to road, particularly with the resurgent rail freight sector but also with new waterborne flows. There is potential for considerably greater transfer of freight from road, but progress is likely to be limited until many of the new EU and UK policy initiatives under discussion are implemented. It seems unlikely that CO_2 emissions targets will be met without more concerted action to achieve modal shift, given the ongoing reliance on fossil fuels in the road haulage sector.

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08

Development of greener vehicles, aircraft and ships

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Introduction

Many of the technical improvements that have been made to freight vehicles and vessels over the past few decades have reduced their environmental impact. Some of these improvements have been required to meet tightening environmental legislation, particularly on air pollution and noise. Others have been motivated mainly by commercial pressures to improve energy efficiency and vehicle loading, though they have indirectly yielded environmental benefits.

Reports by various international organizations stress the importance of new technology in efforts to make freight transport more environmentally sustainable. For example, the World Economic Forum and Accenture (2009) rated the application of 'clean vehicle technologies' as the most promising of 13 methods of decarbonizing global supply chains. The International Energy Agency (2009: 30) argued that 'Current and emerging technologies have the potential to deliver substantial reductions in CO_2 emissions from transport. But they need to be introduced rapidly, at a rate and on a scale that is unprecedented in the last 40 years of transport evolution'. The latest Assessment Report of the IPCC (2014: 6) notes that 'In OECD countries, advanced vehicle technologies could play a bigger role than structural and behavioural change' in the decarbonization of transport.

In this chapter, we examine the extent to which new technology will contribute to the greening of companies' freight transport operations. It adopts a cross-modal perspective, considering the opportunities for technologically improving the environmental performance of trucks, vans, freight trains, ships and planes. While there is a strong commitment to make freight transport more environmentally sustainable across all modes, individual modes can have particular environmental priorities. The shipping industry, for example, is under strong pressure to reduce sulphur emissions, while the use of ultra-low-sulphur fuels is now the norm in the trucking systems of developed countries. Research and development efforts can therefore have a different focus in particular sectors of the freight market.

Generally speaking, advances in vehicle technology can reduce the environmental impact of freight transport in three ways:

- increasing vehicle carrying capacity;
- improving energy efficiency;
- reducing externalities.

These advances are not always mutually reinforcing in environmental terms. For example, redesigning engines to reduce NOx emissions usually impairs fuel efficiency and increases emissions of CO_2. The potential for exploiting these advances also varies between modes. Regulations governing the size and weight of road vehicles, for example, tightly limit the scope for enlarging trucks, whereas in the maritime sector the maximum size of container ship has more than doubled since the year 2000. The duration of the vehicle/vessel replacement cycle also varies widely between freight modes, from a few years in the case of vans to tens of years in the case of ships, aircraft and locomotives. The economics and practicality of retrofitting new technology is similarly variable. As a result, technical innovations are adopted more rapidly in some freight modes than in others. Over a 20- to 30-year time horizon, however, the development and diffusion of clean vehicle technology is likely to reduce substantially the externalities of all the main modes of freight transport.

Road freight

Trucks

Carrying capacity

Governments impose limits on the maximum gross weight and dimensions of vehicles. When these limits are relaxed, vehicles can be redesigned to maximize the resulting gain in carrying capacity. There has been much discussion in Europe and North America in recent years about the costs and benefits of allowing trucks to get longer and heavier, possibly raising the limits to those prevailing in Scandinavia, Australia, South Africa and some US states. There are many variants of longer and heavier vehicles (LHVs) currently in operation in these countries and states. Liberalization of vehicle size and weight limits elsewhere would simply open other road haulage markets to existing types of LHV, probably with some customization of the equipment to local regulatory, infrastructural and business requirements. A comprehensive review of research on LHVs undertaken by the OECD/International Transport Forum (2010: 9) concluded that 'Case study results (Alberta and Saskatchewan in Canada, Sweden and Australia) suggest that the use of higher capacity vehicles has reduced the amount of truck traffic on the road, with benefits for safety and the environment, including reducing the growth of fuel consumption and CO_2 emissions'. This issue is more fully discussed in Chapters 11 and 18.

In those countries with sufficient height clearances at bridges and tunnels, it is possible to gain additional carrying capacity vertically by making the vehicles taller. In the UK, for instance, where road infrastructure can accommodate trailers up to 5 metres high, there has been a proliferation of double-deck trailers. It was estimated, in 2010, that around 6,500–7,500 such trailers were running on UK roads (McKinnon, 2010). Until recently, most of the double-decks had on-board powered lifts which permit the loading and unloading of the upper deck anywhere. These hydraulic lifts add a 2–4-tonne weight penalty and substantially increase the capital, operating and maintenance costs of the trailer. Many major users of double-deck trailers are now opting for fixed-deck models and investing in external lifting equipment at reception bays. Removing lifting gear from the trailers improves fuel efficiency and increases available carrying capacity. The weight-carrying capacity of a truck can also be increased by reducing its tare (or empty) weight. The use of less dense materials in truck chasses can significantly cut the tare weight. According to the European Aluminium Association (2006), switching from steel to aluminium could cut around 3,000 kg from the weight of an articulated lorry. This would permit an 11.5 per cent increase in the payload of a vehicle registered at a gross weight of 40 tonnes. Research in the United States, however, suggests that the direct fuel savings from reducing tare weight are relatively modest, at roughly 0.5 per cent per 1,000 lbs (0.45 tonnes) (Southwest Research Institute, 2008; Greszler, 2009). As discussed in Chapter 12, the main environmental benefit of lightweighting accrues from increases in the effective carrying capacity of trucks moving dense, weight-constrained loads and hence freight consolidation in fewer trips.

One of the major challenges for designers will be to maintain or even increase vehicle carrying capacity while improving the aerodynamic profiling of the truck. There is a trade-off between the degree of streamlining and the cubic capacity of the vehicle. Enlarging the vehicle generally increases wind resistance and reduces fuel efficiency. To maintain carrying capacity within a new generation of low-drag vehicles it will be necessary to extend the legal length limit. The European Parliament has recently approved a relaxation of truck length and weight limits to permit greater aerodynamic profiling of trucks but no net increase in carrying capacity. It is estimated that this regulatory change may cut CO_2 emissions from the trucks affected by 7–10 per cent (European Commission, 2014). The issue of aerodynamic profiling is discussed below and in Chapter 12.

Energy efficiency

Numerous studies have been conducted in North America and Europe on the potential for improving the energy efficiency of trucks. It was estimated in the US in 2006 that the average thermal efficiency of engines in the heaviest categories of US trucks (Class 7 and 8) was around 42 per cent. The 21st Century Truck Partnership declared an objective of raising this thermal efficiency in prototype truck engines by 50 per cent by 2010 with a 'stretch' goal of 55 per cent achievable by 2013 (National Academies of Science, 2007). A review of the Partnership's efforts to achieve this goal can be found in a recent report (National Research Council, 2012)

In 2010 the US government launched a joint programme with industry called 'Supertruck' with the aim of cutting energy use per tonne-km by 50 per cent. It was announced in 2014 that the Supertruck partners had 'demonstrated a 20 percent increase in engine efficiency and a 70 percent increase in freight efficiency, reaching over 10 miles per gallon under real world driving conditions on a Class 8 tractor-trailer' (US White House, 2014). It was estimated that if the entire US truck fleet could attain the efficiency of the prototype Supertruck, the country would save approximately 300 million barrels of fuel annually, currently valued at $30 billion. The challenge is now to roll out the range of technologies embodied in the Supertruck across the next generation of US trucks. This would not only bring economic and environmental benefits to the US, but also to those countries to which it exports freight vehicles, such as Mexico, South Africa, Chile and China.

Similar efforts have been underway in Europe to improve the energy efficiency of trucks (AEA Technology/Ricardo, 2011). EU research has identified 'powertrain efficiency improvement' as offering the greatest potential for reducing GHG emissions. 'Powertrain' is the collective term for the engine, transmission system and drive-shafts, which together generate the power and convert it into vehicle motion. The energy savings from particular technologies vary with the 'vehicle duty cycle', that is, the nature of the delivery operation. This is well exemplified by hybridization, combining diesel and battery power, which can cut by around 20–30 per cent the fuel consumption of a rigid vehicle undertaking multiple-drop/collection deliveries in urban areas (AEA Technology/Ricardo, 2010: 118), but which will have very limited application in long-haul trucking.

To maximize the combined impact of new truck technologies it is necessary to adopt a holistic approach to future vehicle design. The Supertruck project in the United States, for example, has helped to break down the 'silos' that have traditionally existed among truck, trailer and equipment engineers. Application of this 'whole vehicle' approach is improving the energy efficiency of auxiliary equipment on the vehicle, such as pumps, fans, air compressor, heating, air conditioning and power steering. The installation of separate power systems for this equipment saves energy by decoupling their operation from that of the main vehicle engine. Separate batteries can be used for this purpose. The US Department for Energy has estimated that fuel efficiency gains of up to 50 per cent can be achieved by overhauling these auxiliary systems.

Aerodynamic profiling will also be a major source of future energy savings in the road freight sector. For the foreseeable future, most of the savings from improved streamlining of vehicles are likely to come from wider diffusion of existing technology. This technology is reviewed in Chapter 12. In the longer term, however, vehicle manufacturers will adopt radically new truck designs that will yield step-change improvements in energy efficiency. One feature of these designs will be the integration of the tractor and trailer to permit optimal profiling of the complete vehicle and largely eliminate the turbulence created in the gap behind the tractor unit. It is predicted that it will be possible to reduce the coefficient of drag (CD) on articulated trucks from the current average of around 0.57 to the 0.30 achieved by some types of car. This was achieved by a ‘concept vehicle’ developed by truck manufacturer MAN called the ‘Dolphin’ (*Commercial Motor*, 8 January 2009).

The so-called ‘next generation’ tyres should also be able to raise fuel efficiency by 3.5–8 per cent by reducing rolling-resistance. The UK government’s Carbon Plan identifies the equipping of trucks with low rolling-resistance tyres as a relatively cost-effective means of cutting carbon emissions and envisages it saving around 700,000 tonnes of CO_{2e} annually by 2022 (Department of Energy and Climate Change, 2011). Automatic pressure monitoring and inflation of tyres will also yield significant fuel savings and improve tyre wear.

In Japan, truck manufacturers are now required to meet tightening fuel economy standards for new vehicles. The Japanese government’s Energy Conservation Law made provision for the adoption of a ‘top runner’ fuel efficiency standard for trucks. The ‘top runner’ concept aims to make the best-in-class performance the average by a target date. For trucks this will entail improving the average fuel efficiency from 6.30 km/litre in 2002 to 7.09 km/litre in 2015 (Ministry of Economy, Trade and Industry, 2008). Different target improvements have been specified for different vehicle weight classes. Tax incentives are being used to promote this move to higher efficiency standards. The purchase tax is being reduced by 1–2 per cent for new vehicles meeting the target fuel efficiency standards. Fuel economy standards for new trucks were introduced in the US and China in 2014, while the EU is planning a similar policy intervention. The diversity of vehicle types and the combination of different types of auxiliary equipment on a single vehicle make it difficult to define fuel economy standards in this sector. Individual truck manufacturers have much less control over the fuel performance of the final lorry than their counterparts in the car sector.

Reducing externalities

A distinction can be made between externalities that are fuel-related (mainly air pollution and GHG emissions) and those with little or no relationship to energy use (accidents, noise, vibration etc). Improving fuel efficiency reduces the former but not the latter. These fuel-related externalities can also be reduced independently of fuel consumption in three ways:

- *Altering the nature of the fuel/energy source*: switching from conventional diesel to alternative fuels such as biodiesel mixes, compressed natural gas or biomethane can significantly reduce emissions of particular pollutants per litre of fuel consumed, though allowance must be made for the lower calorific content of some fuels. The use of alternative fuels is discussed in Chapter 13. Existing trucks can be run on low percentage mixes of biodiesel with conventional diesel, though high mixes or full substitution of biodiesel generally requires engine modification.

  The 'electrification' of trucks through the use of batteries, either as the sole or a supplementary power source, can cut diesel fuel consumption and reduce externalities per unit of energy consumed. By eliminating exhaust emissions it improves local air quality, but often at the expense of higher emissions at the point where the electricity is generated. The net effect of electrification on the carbon intensity of road freight transport largely depends on the mix of primary energy sources used to generate the electricity. In a country like the UK, for example, which is currently dependent on fossil fuels for roughly three-quarters of its electricity (DECC, 2011), the net carbon benefits from switching to battery-powered freight delivery vehicles are very small. For countries with a plentiful supply of low-carbon electricity from renewable sources (eg Sweden and Switzerland) or nuclear power (eg France), the environmental case for electrifying the road freight sector is much stronger. In modelling future trends in transport energy use and CO_2 emissions, the International Energy Agency (2009) anticipates (in its so-called 'Blue Map' scenario) a reduction in the average carbon intensity of electricity generation worldwide from 550 g CO_2/kWh in 2005 to 160 g by 2030 and a figure 'close to zero by 2050' (p 81). If it proves possible within this time frame to decarbonize electricity supply to this extent, the challenge will be to find cost-effective means of transferring the low- or zero-carbon electricity into road freight operations. It is generally agreed that the use of batteries for this purpose will be confined to smaller rigid trucks and vans with a drive cycle characterized by frequent stops and starts and a limited delivery range. The prospects of heavy, long-haul trucks being completely battery-powered or even hybridized are rather slim. It is possible, in an era of low-carbon electricity, that heavily trafficked highways will be electrified, with 'trolley trucks' powered by electricity drawn from overhead cables. Studies in Sweden (eg Ranch, 2010), France, Germany and the US have already investigated the technical, economic and environmental aspects of this concept. Siemens, with financial support from the German government, has constructed a 2-kilometre e-Highway on a former airfield near Berlin to trial the use of prototype trucks that can draw electrical power from overhead cables or run on conventional fossil or renewable fuel.

- *Engine redesign*: tightening emission standards have forced vehicle manufacturers to radically redesign truck engines over the past 20 years. Future 'cleaning' of diesel engines is likely to be marginal by comparison with what has so far been achieved, particularly if increased priority is given to minimizing fuel consumption and CO_2 emissions. As discussed in Chapter 12, alternative approaches to emission reduction have been adopted by vehicle manufacturers in recent years: exhaust gas recirculation (EGR) and selective catalytic reduction (SCR). Views differ on which of these systems will offer the more cost-effective means of meeting future emission standards. Proponents of EGR argue that, in the SCR system, downward pressure on NOx levels requires the addition of greater quantities of the AdBlue chemical at higher economic and environmental cost. To comply with the Euro 6 emission standard by 2013, however, it has been necessary to combine the EGR and SCR technologies, particularly in an effort to minimize any associated fuel and CO_2 penalties (AEA Technology/Ricardo, 2010).
- *Exhaust system*: particulate traps are currently used in diesel exhausts to remove PM10s. The amount of particulate matter emitted by the engine depends on the temperature and completeness of the combustion process. In the EGR system, combustion temperatures are lower, more particulate matter is emitted and, as a consequence, particulate filters must be installed to reduce PM10 emissions to the regulated levels. Such filters are not required by SCR systems. The future development of truck exhausts will partly depend, therefore, on the evolution of EGR and SCR systems, independently or in combination.

Other non-fuel-related improvements to the environmental performance of trucks are likely to be incremental. For example, the combination of quieter engines, air brake silencers, internal load restraint systems, low rolling-resistance tyres, quieter refrigeration units and cab soundproofing offers the potential for further noise reduction.

Vans

Carrying capacity

Unlike trucks, the maximum permissible weight of vans does not change over time as a result of governments relaxing restrictions on vehicle weights. Instead the weight limit for vans (also referred to as light goods vehicles or light commercial vehicles) is fixed, as it defines whether the vehicle is a van or truck, and thereby the regulations to which the vehicle and its owner and driver are subject. In many countries the maximum permissible gross weight for vans is 3.5 tonnes (it is important to note that some vehicles are manufactured with van bodies with a gross weight of over 3.5 tonnes but these vehicles are treated as trucks in terms of driving and operational regulations).

Vehicle manufacturers produce a wide range of styles, weights and sizes of vans. These can be categorized by gross weight as small (car-derived/micro), medium and heavy vans. Table 8.1 provides a summary of the typical attributes of these three categories of van.

TABLE 8.1 Summary of the typical size, weight and fuel efficiency attributes of vans

	Small vans	Medium vans	Heavy vans
Typical gross weight (tonnes)	Up to 1.8	1.8–2.6	2.6–3.5
Typical payload (tonnes)	0.4–0.8	0.8–1.2	1.2–2.0
Typical load space (m^3)	1–3	4–8	7–17
Typical fuel consumption (mpg) (Litres per 100 km)	40–55 (7.1–5.1)	30–40 (9.4–7.1)	20–35 (14.1–8.1)
Example models	Vauxhall Corsa Citroen Berlingo Renault Kangoo	Ford Transit VW Transporter Renault Trafic	Ford Transit Mercedes Sprinter Iveco Daily

SOURCE: Authors' estimates

Vans have a far wider range of uses than trucks. In fact, only around one van trip in five actually carries freight. Survey work in Britain suggested that in the period 2002–03 commuting accounted for 39 per cent of all van journeys, servicing for 23 per cent, goods collection and delivery for 22 per cent, and personal journeys for 16 per cent (Allen and Browne, 2008).

This wide range of journey purposes means that van operators have extremely varying requirements in terms of load space, payload, vehicle length, vehicle height and vehicle body requirements, and put the load area of the vehicle to differing uses. For example, in the case of service activities often only tools, equipment and parts are transported (which may not be particularly heavy) and vans may be equipped with sophisticated racking systems for these purposes. In some operations drivers will require space to work inside the vehicle (for example, an electrician having to carry out preparatory work inside the vehicle, or a delivery driver sorting goods in a parcel delivery operation). As a result, the average lading factor (in terms of weight and volume) for the van population is likely to be lower than for trucks. In Britain, the Company Van Survey that was conducted between 2003 and 2005 showed that, overall, vans were more than half full (by volume) for only 34 per cent of total vehicle-kms travelled (DfT, 2008).

Even though vans have a maximum gross weight of 3.5 tonnes, the average gross weight and payload of vans can increase if operators purchase a greater proportion of heavier vans over time. This has been happening in the van sector. Analysis of the vans sold in Britain between 1990 and 2007 suggests that the average gross weight and payload of vans has increased by 10–20 per cent over this period.[1]

Regulations have not prevented manufacturers from increasing the length of vans. A growing proportion of the medium and heavy vans are being produced with long wheel bases (the wheel base is the distance between the front and rear wheels). The longer the wheel base, the bigger the load space in the vehicle. Vans with long wheel bases are often between 0.5 and 1.5 metres longer than their medium wheel base equivalents. Assuming that the width and height of these vehicles are the same, the long wheel base varieties have approximately an additional 20 per cent load space for every extra 0.5 metre of length compared with shorter vans, with little or no difference in gross weight.[2]

As with trucks, van manufacturers try to use lighter materials (for the chassis, body and internal racking systems) where possible to reduce the tare weight of the vehicle and hence maximize payload.

Energy efficiency

Up until the 1990s the majority of vans in Europe were powered by petrol. However, diesel engines became increasingly popular among van operators as manufacturers overcame the problems of vehicle speed and noise associated with early diesel vans. Diesel engines also have greater fuel efficiency, are hardwearing and, owing to technological advances such as fuel injection and turbocharging, can now produce much greater power and torque (Momenta, 2006). It is estimated that diesel vehicles have a fuel economy advantage of approximately 20 to 40 per cent over petrol vehicles (EIA, 2009). In Britain, for example, 69 per cent of all vans were diesel-powered in 1998, but by 2012 this had risen to 95 per cent (DfT, 2013). By contrast, in the USA, diesel-powered vans have accounted for, on average, only about 4 per cent of new van sales each year for the past 20 years (EIA, 2009). The greater penetration of diesel vans in Europe is likely to be due to factors such as higher average fuel prices, more favourable tax policies for diesel and less stringent emissions standards (which permit higher levels of NOx and PM in Europe than in the USA) (EIA, 2009).

As concern grows about fossil fuel consumption and emissions, leading to new regulations and tax regimes, it is likely that greater use will be made of new technologies that help to improve the fuel efficiency of vans such as hybridization, devices to reduce engine idling and speed limiters. Hybrid vehicles and anti-idling technologies have particular relevance to vans owing to the high proportion of operations carried out in urban areas, involving stop–start traffic conditions and, in some cases, multi-drop delivery rounds.

It is also likely that further significant improvements in the fuel efficiency of diesel engines are possible through advanced turbocharging with direct fuel injection. A senior director of a major van manufacturer was quoted as saying that they expected 'that small, highly efficient diesels capable of 100 miles per gallon will become commonplace' (Anon, 2008a).

A sizeable number of vans make use of auxiliary equipment, including refrigeration, air conditioning, heating, pumps, fans and power steering. As with trucks, the use of power sources other than the vehicle engine to run this equipment has the potential to reduce total fossil fuel consumption.

The use of tyre-pressure monitoring systems and low rolling-resistance tyres has the potential to improve van energy efficiency (AEA, 2010). Aerodynamic profiling is generally less important for vans than trucks owing to their smaller sizes and because a greater proportion of van activity takes place in urban areas at lower average speeds. It has, nevertheless, been improving, as demonstrated by the streamlining of the Ford Transit van (Storey and Boyes, 2003).

Externalities

Euro emission standards for local air pollutants apply to newly manufactured vans as well as trucks and are gradually tightening. In addition, as part of its strategy to cut CO_2 emissions from vans, the EU passed legislation in 2011 similar to that adopted for cars in 2009. This legislation will reduce van emissions to an average of 175 g CO_2/km by 2017 (with the reduction phased in from 2014) and to 147 g CO_2/km by 2020. This will represent a reduction of 14 per cent by 2017 and 28 per cent by 2020 compared with the 2007 average (European Commission, 2011). In the UK, vehicle manufacturers have been required to test the fuel consumption and CO_2 emissions of their vans since the start of 2008 (Anon, 2008b). Since June 2009 the CO_2 emissions and fuel consumption data for new van models on the UK market has been made available via an online database compiled by the Vehicle Certification Agency, Society of Motor Manufacturers and Traders, and Department for Transport (DfT, 2009; VCA, 2014). Producing this data is complicated by the number of van variants manufactured, the range of body types and the effect of vehicle lading, but this data is intended to help operators include fuel efficiency and CO_2 considerations in their vehicle purchasing decisions. Data suggests that typical CO_2 emissions from vans fell from approximately 320 g/km in 1980 to 220 g/km in 2008 (based on data supplied by Ford) (VDA, 2008).

In the USA, new vans are subject to engine emissions standards for air pollutants that have become tighter over time. All new vans (and cars) have to display a fuel economy label (a window sticker) that provides details of the vehicle's miles per gallon which is independently tested by the United States Environmental Protection Agency (EPA). Since 2013 this label also provides details of the vehicle's greenhouse gas emissions, and other air pollutant emissions (EPA, 2014). This data for all cars and vans is also made available in an annual Fuel Economy Guide (US DoE and EPA, 2014a).

Exhaust emission limits for air pollutants from vans were first introduced in Japan in the 1970s and have been progressively tightened. Van manufacturers are also required to meet fuel economy standards for new vehicles operated in Japan using the 'top runner' approach in the same way as already explained for trucks (ie by basing future targets on the most energy efficient vehicle available on the market). Targets are set for a wide range of van weight classes. The 2015 fuel efficiency regulation will introduce targets for an even greater range of van weight classes up to 3.5 tonnes gross weight. When the 2015 targets are met for vans, it is estimated that the average van fuel economy in Japan will be 15.2 km/litre, which represents a 12.6 per cent improvement on 2004 performance (Dieselnet, 2014).

On a 'well-to-wheel' basis, diesel vans emit 15 per cent less GHG than petrol vans (EIA, 2009). A further 20–25 per cent GHG reduction can be achieved by switching to petrol- or diesel-powered hybrid electric vehicles. It is important to note that diesel engines emit less CO and HC but relatively more NOx and PM than petrol engines.

A wide range of alternatively fuelled vans is available (including liquefied petroleum gas, compressed natural gas, biofuels, electric and hybrid vehicles). As well as the emissions benefits of these alternative fuels, electric vehicles also cut noise levels. However, the use of these alternative fuel vans is discouraged by their higher purchase price, higher operating costs, limited range and lack of refuelling infrastructure (Commission for Integrated Transport, 2010). The use of batteries can also reduce payloads by 200–700 kg (Element Energy, 2012). Consequently, the market penetration of these vans has remained low; for example, fewer than 1 per cent of vans in Britain are currently alternatively fuelled (DfT, 2013). Forecasting work carried out in the UK suggests that this situation is unlikely to change in the short term, with high battery costs and other technologies restricting widespread deployment. However, the work suggests a strong potential for alternatively fuelled vans in the medium term (to 2030), owing to rising diesel fuel costs and falling battery and fuel cell costs (Element Energy, 2012).

Proximity sensors and additional mirrors are being offered by manufacturers to enhance van safety and reduce collisions, especially in urban environments. Other equipment such as rear-view cameras are also being developed to aid driver awareness. The Electronic Stability Program (ESP), a computerized technology that detects and prevents skids, is also available from some van manufacturers. At the same time, tyre grip is being enhanced, especially for wet weather conditions, thereby reducing accident risk (Banner, 2008).

These improvements to the design of new vans make them safer and more environmentally sustainable, but some of these benefits are eroded by poor maintenance and inefficient operation. Official data in Britain, for example, shows that a significant proportion of vans are not well maintained by operators (proportionately more vans failed their annual vehicle test than any other vehicle type in 2012/13) and are regularly overloaded (proportionately more often than trucks) (VOSA, 2013). These can be important factors in vehicle accident involvement.

Rail freight

Carrying capacity

The key variables influencing train carrying capacity are weight and length. For heavy flows, such as coal and steel, weight tends to be the constraining factor, while for lighter weight flows, such as intermodal, train length is more likely to constrain the carrying capacity. The EU is developing policies to improve rail infrastructure capability, in terms of train length, axle loads, loading gauge (ie maximum vehicle dimensions) and maximum speed, to allow greater carrying capacity (European Commission, 2007).

Across Europe, traditional two-axle wagons have gradually been replaced by bogie wagons, which tend to offer a higher payload for a given train length, as well as being less damaging to the rail infrastructure. These new bogie wagons are far larger than those that they have replaced. The bogie wagons now widely used for coal flows in Britain also offer a slightly greater payload-to-tare-weight ratio per wagon and have led to greater train payloads overall. On a selective basis, additional wagons have been added to increase train payloads where route conditions allow. British rail freight operators have been introducing new PowerHaul locomotives which are more powerful than the existing Class 66 design. This means it is possible to operate longer, heavier trains in situations where locomotive power has constrained the maximum train weight. In North America, double stacking of containers is an efficient means of carrying a greater volume for a given train length, but this is not a realistic option in Europe owing to the more restricted loading gauge. Instead, measures to increase train lengths are being examined, often requiring changes to signalling systems, passing loops and terminals. In the Freight Route Utilization Strategy for the British rail network, measures to allow 775- or 900-metre-long trains are identified (Network Rail, 2007). In many cases, though, trains are currently loaded to neither their maximum weight nor length owing to flow characteristics or operational inefficiencies, so the potential often exists to make improvements within the existing weight and length limits.

Energy efficiency

The rail industry has gradually been improving its knowledge of energy use, both of electricity and diesel fuel, but has generally lagged behind the road haulage sector in achieving significant improvements. It is likely that there will be a greater focus on the energy efficiency of rail freight in the future, partly in response to increasing energy costs but also to preserve, and if possible reinforce, rail's environmental advantage over road in the movement of goods. According to *The Case for Rail* (RSSB, 2007), a range of initiatives to improve energy efficiency has been adopted by the British rail freight industry. For example, diesel engine shutdown when stationary for 15 minutes or more has reduced fuel consumption by 3–5 per cent. Fuel conservation may also result from better network operations management (eg optimization of train paths to reduce stop–start and acceleration–deceleration procedures) or reduced operating speeds, though this may result in longer journey times. Fuel consumption is affected by aerodynamic drag, particularly at speeds of around 60 mph (100 kmph) or more. For intermodal trains in particular, drag can be reduced considerably by optimizing train loading to reduce the number and size of gaps between containers (Stehly, 2009).

For diesel operation, further improvements to engine design are achievable. Ricardo (2012) has identified considerable potential to adopt non-rail technologies to improve diesel locomotive fuel efficiency, as well as possible savings through better collaboration within the rail sector. Regenerative braking is increasingly being adopted for electric traction, where electricity can either be fed back into the power supply system for use by other trains or returned to the National Grid to be used elsewhere. In addition, human factors are recognized as being important, with increasing attention being devoted to driver training and monitoring. It is likely that increased use will be made of computer simulators to train staff to drive locomotives more energy efficiently and safely (Ward *et al*, 2004).

Reducing externalities

In sharp contrast to several other European countries, the overwhelming majority of rail freight in Britain (around 90 per cent) is hauled by diesel locomotive. Per tonne-km, diesel-powered rail engines typically generate far fewer externalities than road goods vehicles (RSSB, 2007). The exception, until recently, where road was far outperforming rail, was in sulphur dioxide. Rail is also considerably safer than road. As discussed in Chapter 7, freight transport externalities can therefore be reduced by effecting modal shift from road to rail. That said, as with energy efficiency, the road haulage sector has tended to implement measures to reduce externalities per tonne-km at a faster rate than rail (largely in response to tightening regulatory controls on exhaust emissions). Considerable potential still exists to raise environmental standards in the rail freight industry. Potential measures to reduce rail freight externalities include:

- Maximizing the use of electric traction: this makes zero-carbon-emission freight possible if electricity production is from non-fossil fuel sources. Currently, though, only around a quarter of electricity production in Britain is from these sources (DECC, 2011). Electric traction also has the benefit of removing air pollution at the point of use, and any pollutants arising from electricity generation may more easily be tackled at source.

- Continuing to invest in low-emission diesel locomotives where electric traction is not viable: almost the entire British diesel rail freight fleet has been replaced since privatization in the mid-1990s, leading to considerable reductions in externalities. The EU has introduced Non-Road Mobile Machinery (NRMM) legislation covering many gaseous and particulate pollutants (European Commission, 2013), although the increasingly stringent regulations threaten to cause a shortage of diesel locomotives due to the non-compliance of most locomotive types with the regulations coming into force at the end of 2014 for new locos. Perversely, this may constrain the shift of freight from road due to a shortage of rail equipment or lead to older, less efficient locomotives remaining in service for longer than would otherwise have been the case. A similar tightening of emission standards in the rail sector has been occurring in the United States (EPA, 2014b).
- Low-sulphur fuel: EU legislation under the Fuel Quality Directive is tackling rail's sulphur dioxide emissions, with standards for the sulphur content of fuel having been implemented in 2008. Legislation took effect in 2012 dramatically reducing the sulphur content of rail fuel, though at the expense of fuel efficiency and CO_2 emissions. The taxation system does not always favour the use of less polluting fuels by rail freight operators, so operators could be further incentivized to switch to cleaner fuels through taxation changes.
- Noise and vibration problems can be ameliorated through quieter engine technology, track lubrication, new braking systems and other improvements. The EU is implementing noise abatement regulations for rail freight with, for example, Deutsche Bahn taking the lead in fitting low-noise brake blocks to its freight wagon fleet (DB, 2013).

Across Europe, market liberalization has increased the number of organizations involved in rail infrastructure and service provision. The resulting fragmentation of responsibilities and actions makes it more challenging to implement large-scale initiatives to reduce externalities, creating a need for industry leadership. It is hoped that the Sustainable Rail Programme (RSSB, 2007) being developed for the British rail network will succeed in adopting a holistic approach, at least at the national level. For example, recent decisions to electrify more of the rail network may lead in time to more use of electric traction, countering the recent emphasis by individual freight operators on diesel engines owing to their ability to be used network-wide.

Air freight

Air cargo trends

The movement of freight by air is more damaging to the environment, on a tonne-km basis, than by any of the surface freight modes (see Chapter 2). One might, therefore, expect that if companies were serious about greening their logistics systems, future demand for air cargo services would be likely to drop. On the contrary, it is predicted by both Boeing (2013) and Airbus (2013) that the volume of air freight traffic will grow, respectively, by 5.2 per cent and 4.8 per cent per annum over the next 20 years. To accommodate the forecast tripling of air freight traffic over this period, the global fleet of air-freighters will have to expand by around 77 per cent (Airbus, 2013) to 'over 80 per cent' (Boeing, 2013).

To mitigate the environmental effects of this huge future increase in air freight volumes there will need to be substantial reductions in externalities per tonne-km. IATA, the international trade body representing 140 airlines worldwide, has set a target of capping CO_2 emissions from aviation (both passenger and freight) by 2020 and ensuring that further air traffic growth would be carbon neutral. It believes that this can be achieved by a combination of fleet renewal, advances in engine and airframe technology, improved operational practices, more efficient air traffic control and a switch to biofuels (IATA, 2009). By 2050 IATA aims to have reduced total CO_2 emissions from aviation by 50 per cent against a 2005 baseline, despite the huge predicted growth in air transport over the next 40 years. In addition to the measures listed above, substantial carbon offsetting will be required after 2025 to 'close the gap'. The credibility of these very ambitious targets is questionable, however. Macintosh and Wallace (2009), for example, argue that the future reductions in emissions per tonne- or passenger-km will be more than offset by the predicted growth in air traffic volumes.

On the other hand, past environmental trends in aviation provide some grounds for optimism. The International Civil Aviation Organization (ICAO) (2013:11) claims that 'over the past 50 years, aircraft have become 80 per cent more energy efficient and 75 per cent quieter'. Looking forward, the 'Flightpath 2050' vision of the European Commission (2011) for European aviation includes goals to cut CO_2 and NO_x emissions per passenger-km by, respectively 75 per cent and 90 per cent by 2050. Although no explicit reference is made to air freight, it can be assumed that its emission-intensity could be reduced by a similar magnitude.

Most of the past energy-efficiency gains have come from improved engine technology, in particular the use of high bypass ratio turbofans and low-emission annular combustion systems. The Advisory Council for Aeronautics Research in Europe asserts, however, that 'although there is scope for further improvement by evolving existing technologies, further substantial improvement will require the introduction of breakthrough technologies and concepts into everyday service' (ACARE, 2008: 61). The development, implementation and diffusion of these new technologies will in all likelihood be relatively slow as aviation is essentially ‘a long life cycle industry’ (ICAO, 2007). It can take 10 years to design a new aircraft, which will then be manufactured for around 20–30 years, with each aircraft having a typical lifespan of 25–40 years. The investment cycle can be as long as 55 years (Committee on Climate Change, 2008). The uptake of new, more environmentally friendly technology is even slower in those sectors of the air freight market that use former passenger aircraft converted into freighters at a later stage in their life. In 2013 only 26 per cent of the global air cargo fleet was less than 15 years old (Airbus, 2013). Airbus also predicts that 68 per cent of the 2,730 additional air-freighters required over the next 20 years will be converted from older passenger aircraft.

According to IATA, roughly 50 per cent of air cargo tonne-kms are moved in the belly holds of passenger aircraft. This means that, to a substantial extent, environmental improvements in aviation are shared between passengers and freight and progress at a similar rate. It also has implications for the allocation of responsibility for externalities between people and goods travelling on the same aircraft. Freight typically accounts for 15–30 per cent of carbon emissions in wide-body passenger aircraft and 0–10 per cent in narrow-body planes (Jardine, 2009).

Increases in capacity

As with other transport modes, load consolidation in aviation reduces energy consumption and externalities per tonne-km. As passenger aircraft have increased in size, their belly-hold capacity has also grown, particularly on long-haul routes, increasing the average air cargo payload. The development of new freighter versions of these aircraft and the conversion of these larger aircraft to cargo operations also expand carrying capacity. An Airbus 380 freighter, for example, will carry a maximum payload of 150 tonnes by comparison with a maximum of 124 tonnes on a 747-400. The belly-hold capacity of new passenger aircraft is also expanding. The Boeing 787 Dreamliner, for instance, will have 47 per cent more revenue-earning cargo space than previous aircraft of its type.

Future air cargo payloads will not only be a function of the carrying capacity of the aircraft, however. As this mode provides a rapid and reliable service for time-sensitive products, future capacity utilization will partly depend on the prevalence and rigidity of JIT scheduling. The fastest-growing sector of the air freight market has been that held by the integrated express carriers that cater mainly for time-critical consignments and often have to sacrifice load efficiency for service quality.

Improvements in fuel efficiency

Scenario modelling by ICAO (2013) suggests that the average fuel efficiency of aviation will increase at a rate of 0.57–1.50 per cent per annum up to

2050, depending on assumptions about aircraft technology and operational improvements.

The three main sources of fuel efficiency gains in aviation are the airframe, the engine and the air traffic management (ATM) system:

- *Airframe*: this determines the weight and aerodynamic efficiency (or streamlining) of the aircraft. Aircraft with a given carrying capacity can be made lighter by increased use of special alloys and composites. The A320, which entered commercial service in 1988, comprised roughly 12 per cent composites, while the A380 introduced in 2008 had just over twice this percentage. Half of the primary structure of the new Boeing 787 Dreamliner is made of composite materials. The switch to 'fly-by-wire', involving the replacement of hydraulic controls by wiring, has also reduced aircraft weight. Advances in aerodynamic profiling are also improving fuel efficiency, as well exemplified by the Dreamliner, which overall is 20 per cent more fuel efficient than current aircraft of its type and capacity. Retrofitting 'winglets' to the ends of aircraft wings can also improve fuel efficiency by an average of 4–6 per cent (*Flight International*, 27 June 2008). Research for the Committee on Climate Change (2008: 316) suggests that 'evolutionary changes in airframe technology could conceivably deliver 20–30 per cent improvement in the efficiency of new aircraft' in 2025 as compared to 2006.
- *Engine technology*: ACARE (2008) estimated that the application of a series of engine-related technologies could cut the specific fuel consumption (SFC) of new aircraft by 15–20 per cent per cent between 2000 and 2020, figures broadly in line with estimates quoted by the Committee on Climate Change (2008: 316), which indicate that 'evolutionary changes in engine technology could deliver another 15–20 per cent improvement' in fuel efficiency between 2006 and 2025.
- *Air traffic management*: this includes the airborne routeing of the aircraft as well as its taxiing on the ground. For example, following an IATA (2004) initiative, improvements were made to 350 air routes worldwide, saving a total of 6 million tonnes of CO_2 in 2006 (ICAO, 2007). Routeings through congested European airspace still carry a significant environmental, as well as economic, penalty, however. In 2007, such congestion added an average of approximately 50 kilometres to the length of each flight (EuroControl, 2008). An influential report by the IPCC (Penner *et al*, 1999) on the links between aviation and climate change indicated that an overhaul of the air traffic control (ATC) system could cut CO_2 emissions from aviation by up to 18 per cent. Thomas (2008: 68), however, argues that as much of the world 'languishes under a mountain of bureaucracy' this forecast for fuel savings 'in a perfect ATC world is a distant goal'. ACARE (2008: 64) estimates that 'between 13 per cent

> and 15 per cent of fuel is consumed through excessive holding either on-ground or in-flight and through indirect routeing and non-optimal flight profiles'. It has set a target of 5–10 per cent fuel savings from 'radical changes to the air traffic management system'. These changes will be at least as dependent on international collaboration as on technological upgrading of ATM systems. By far the most important initiative in Europe to improve air traffic management is 'SESAR'. This is the European ATM modernization programme, which runs through to 2020 and aims to create a Single European Sky. It is estimated that between 2011 and 2014, air navigation improvements in Europe would cut flying distances by approximately 12 million nautical miles and CO_2 emissions by 240,000 tons annually (EuroControl, 2012). Globally, the routeing of commercial aircraft has become less efficient because of the need to make detours around war zones, particularly following a missile strike on a Malaysian Airlines plane flying over eastern Ukraine in July 2014.

Looking beyond 2020, ACARE (2011) foresees the 'next generation of radically new technologies', including blended-wing-body aircraft, offering further fuel efficiency improvements of 20 per cent, though given the long development and implementation lead times it is unlikely that these technologies will be widely deployed in the air freight sector before 2050.

Reduction in externalities

The main environmental impacts of aviation are GHG emissions (mainly CO_2 and water vapour), nitrogen oxides (NOx) and noise. Per passenger-km and per tonne-km, these externalities have been declining. Efforts are being made to maintain, and if possible accelerate, this rate of improvement.

Some of the environmental goals for aviation are in conflict, however. For example, NOx emissions can be reduced by lowering thrust levels at take-off, but this can make it more difficult to comply with local noise regulations (Somerville, 2003). The high engine temperatures required to minimize fuel consumption and hence CO_2, CO and hydrocarbon emissions promote the formation of NOx. One technical challenge, in aviation as in other modes, is therefore to minimize the fuel penalty associated with NOx reductions (Janix, 2007).

Electrification, using renewal or nuclear power, which offers large potential for the decarbonization of land-based freight modes will not be a feasible option for aviation. The main requirement of an aviation power source is a very high ratio of energy to weight (ie energy density). There is no prospect, however, of the energy density of batteries coming anywhere close to that of kerosene in the foreseeable future (Committee on Climate Change, 2008).

Net emissions, measured on a life-cycle basis, can be reduced by switching from kerosene to alternative fuels. To date, several airlines have made trial flights with one or more engines powered by biofuel/kerosene blends. While this has been shown to be feasible, 'no game-changing alternative to burning kerosene is foreseen in the short to medium term' (Airbus, 2008: 18). This is supported by Somerville (2003: 227) who argues that 'kerosene is likely to remain the fuel for aviation for at least the next few decades'. On the other hand, IATA has set a target for its member airlines of 10 per cent alternative fuel use by 2017. This is contingent, however, on sufficient quantities of aviation biofuel being supplied by that date. IATA recognizes that this may require an investment of around $100 billion in new refining capacity. Moreover, as discussed in Chapter 13, doubts have also been raised about the net life-cycle carbon savings and wider environmental effects of a major switch to biofuels. Overall, the commercialization of biofuel use in aviation is being constrained by 'high production costs, limited availability of suitable feedstocks, uncertainty surrounding the definition of the sustainability criteria, and a perceived lack of both national and international political and policy support for aviation biofuel' (Gegg *et al*, 2014).

Shipping

Shipping has traditionally been regarded as 'the most environmentally sound mode of transport' (Bode *et al*, 2002). Its relative environmental advantage stems from its low energy consumption per unit of freight movement: a 3,700-TEU[3] container ship, for example, uses only 0.026 kW to move one ton one kilometre as opposed to 0.067 kW for diesel-powered rail freight, 0.18 kW for a heavy truck and 2 kW for air freight moved in a Boeing 747-400 (Network for Transport and the Environment quoted by CSIS, 2009). However, emissions of pollutants, such as SOx, NOx and particulate matter (PM), per unit of energy consumed are much higher than for these other modes and have been declining at a much slower rate.

Sulphur is the environmental Achilles heel of the shipping industry. Ships burn extremely dirty 'bunker fuel' rich in sulphur, which is left as a residual fraction in the refining process when cleaner 'distillate' fuels, mainly petrol and diesel used in surface transport, have been extracted. On average this bunker fuel contains around 27,000 parts per million (ppm) of sulphur, by comparison with 10–15 ppm in the fuels consumed by road vehicles in Europe and the United States (ICCT, 2007). This leads Kassel (2008) to describe ocean-going ships as the 'last bastion of dirty diesel engines'.

Ocean-going vessels are also responsible for around 17 per cent of total global emissions of NOx, and much higher percentages in the vicinity of ports and coastal channels (ICCT, 2007). It is sometimes argued that emissions from ships have attracted little public attention because they are much less visible than those from land-based transport. Roughly three-quarters of their output of noxious gases, however, are emitted within 400 kilometres of land (ICCT quoted by Kassel, 2008) and can thus adversely affect coastal populations and ecosystems. The effects can be severe. Corbett *et al* (2007), for example, have estimated that around the world there are approximately

60,000 'premature mortalities' each year primarily as a result of the inhalation of ship-related PM emissions.

In recent years, several developments have turned the environmental 'spotlight' on shipping. Much more research has been done on the subject to improve our understanding of the nature and scale of the problem. Globalization has been driving the growth of international shipping. Between 1990 and 2008, 'global container throughput rose by an annual average rate of more than 10 per cent' (Deutsche Bank Research, 2011). In 2012, global container traffic was 12 per cent above its 2008 pre-recession peak (Unctad, 2013), while global seaborne trade is projected to grow by 6 per cent per annum at least until 2016 (DNV, 2012). Although international shipping was excluded from the Kyoto system of GHG accounting, its 2.5 per cent share of global emissions[4] is roughly equivalent to that of aviation and likely to be covered by future national and international GHG reduction targets. Impressive reductions in emissions per tonne-km by other transport modes have also eroded shipping's relative environmental advantage. Indeed the European Commission has predicted that total emissions of SOx and NOx from international shipping will exceed those of land-based sources of these gases by around 2015–20.

The International Maritime Organization (IMO) has responded to environmental pressures by establishing future limits for SOx and NOx emissions from ships both globally and for particular maritime zones. Individual shipping lines are also setting targets for cutting emissions, in many cases maintaining recent improvements in environmental performance. The 80 per cent of container shipping lines belonging to the Clean Cargo Working Group (2013) collectively reduced the average carbon intensity of their operations by 16 per cent between 2009 and 2012 (expressed as gCO_2 per TEU-km). Recent reductions in emissions have been due mainly to the commissioning of new, cleaner and more fuel-efficient vessels and the adoption of more fuel-efficient operating practices, such as reducing speeds (known as 'slow steaming'). What are the prospects for achieving more substantial greening of maritime operations in the longer term? These will be briefly assessed for deep-sea container shipping.

Carrying capacity

There has been a huge expansion in container ship capacity over the past 50 years, from the 58 TEUs handled by the *Ideal X* in 1956 to the 18,000 TEUs carried by Maersk's Triple E vessels introduced in 2013. This increase in ship size has been driven by economies of scale, a component of which is the reduction in average fuel consumption per TEU and per tonne-km. Tozer (2004) also notes that in the future 'the scale economies associated with the largest ships may make it economically viable to install additional and more sophisticated equipment to improve environmental performance'. For example, as larger ships tend to be more stable they require less ballast water and hence consume less fuel transporting this additional weight.

The Triple E vessels offer a 50 per cent reduction in CO_2 emissions relative to the 'industry average on the Asia–Europe trade lane' (Maersk, 2013). This is not only achieved through increased vessel size, but also by altering the shape of the hull, improved engine performance and the design of the vessel to sail at a slower optimal speed (20 as opposed to 23 knots).

In the longer term vessel size is likely to be constrained more by port and channel capacity than the exhaustion of technical scale economies in the ship itself. Relatively few ports would have the draught, dock and handling capacity to accommodate 'ultra-large' container ships, limiting their routeing options and revenue potential. The average size of container ships is, nevertheless, likely to continue to rise and, if matched by a growth in traffic volumes on the major deep-sea routes, will maintain the downward trend in energy consumption and emissions per tonne-km.

Energy efficiency

The energy and CO_2 efficiency of container ships has also been increasing independently of the growth in carrying capacity. It has been claimed that 'a container ship now typically emits about a quarter of the CO_2 it did in the 1970s as well as carrying up to 10 times as many containers' (CSIS, 2009). A seminal report by the IMO in 2009 examined a broad range of technological and operational options for achieving future large-scale reductions in the carbon intensity of shipping (Buhaug *et al*, 2009). Around the same time, the Japanese shipping line NYK released an 'exploratory design' for a 'Super Eco Ship' which it believed could be launched by 2030 and offer a 69 per cent reduction in CO_2 per container handled (relative to the 2008 average) (NYK, 2009). This vessel's environmental credentials would be enhanced by further lightweighting and streamlining of the hull and use of alternative power sources such as LNG-based fuel cells, solar cells and wind power. The use of sails as a supplementary power source has been trialled and shown to yield significant carbon savings. The company that tested this technology, SkySails (2009), claimed that 'Depending on the prevailing wind conditions, a ship's average annual fuel costs can be reduced by 10 to 35 per cent' by using this system. UNCTAD (2013) notes that 'many experimental designs and concepts for eco-friendly ships (for example, wind and solar power) are being reported' but concludes that 'their application in the near future remains doubtful'.

In an effort to cut carbon emissions from shipping, the IMO launched in 2011 a global standard for CO_2 emissions from new vessels. All new ships will now be assigned an Energy Efficiency Design Index (EEDI) based on energy use and CO_2 emissions per capacity-km. New vessels entering service in 2015 will have to be 10 per cent more energy-efficient than the average vessel built between 1999 and 2009. This threshold will rise to 20 per cent for post-2020 ships and 30 per cent for post-2025 ships.[5] This is 'intended to stimulate innovation and technical development of all elements influencing the energy efficiency of a ship from its design phase' (IMO, 2011: 35). It has been estimated that this measure could save around 263 million tonnes of CO_2 by 2030 (ICCT, 2011). The IMO has also introduced a Ship Energy Efficiency Management Plan (SEEMP) for the operation of existing vessels. Shipping lines can volunteer to calculate energy efficiency operational indicators (EEOI) for their vessels and try to raise their EEOI scores by applying a range of 'best-practice measures for fuel-efficient ship operation' (IMO, 2011: 36).

The main source of energy and CO_2 savings in the maritime supply chains in recent years has been the slow steaming of deep-sea container vessels. This is an example of what the World Economic Forum/Accenture (2009) call 'despeeding' and rates as the second most important way of decarbonizing global supply chains. There is a quadratic relationship between vessel speed and fuel consumption. As a rule of thumb, Faber *et al* (2012) suggest that a 10 per cent decrease in vessel speed reduces engine power by 19 per cent. Cariou (2011) has estimated that slow steaming by deep-sea container vessels, *ceteris paribus*, reduced CO_2 emissions by 11.1 per cent between 2008 and 2010. This practice was primarily motivated by a desire to economize on fuel during a period of high oil prices and global economic recession. It has nevertheless indirectly yielded significant environmental benefit. Although the strategy was largely imposed by the carriers, most shippers appear to have been able to accommodate the longer transit times in their logistical schedules without too much difficulty. Simulation modelling by Maloni *et al* (2013) on the Asia–North America trade lane found that so-called 'extra-slow steaming' (ie 18 as opposed to 24 knots) was the optimal speed at which the overall net gains across stakeholders are maximized, cutting total costs by 20 per cent and CO_2 emissions by 43 per cent.

Externalities

SOx emissions are reduced by removing sulphur from the fuel burned in ships. The IMO now limits the sulphur content in bunker fuel to 4.5 per cent and this maximum will drop to 1.5 per cent by 2020. In several maritime zones (Sulphur Emission Control Areas or SECAs), such as the Baltic Sea, North Sea/English Channel and West Coast of the United States, the tighter limits are being introduced more rapidly. The International Council on Clean Transportation (2007: 9) recommended that 'a uniform global fuel sulphur standard of 0.5 per cent be introduced in the medium term', which 'relative to the 2.7 per cent average sulphur content of current marine fuel... will reduce SO_x emissions by approximately 80 per cent and PM emissions by approximately 20 per cent'. Imposing a 'global cap on sulphur content of marine fuels of 0.5 per cent by 2020' would present a formidable challenge to the oil industry and require massive investment in new refining capacity (Kanter, 2008). The American Petroleum Institute has estimated that an investment of $126 billion would be required, inflating the cost of a barrel of marine fuel by an average of $13–14. Bringing sulphur emissions from shipping down to the levels now prevalent in overland freight transport will, therefore, be costly.

The 'desulphurization' of marine fuel would also indirectly help to cut NOx levels. It would permit the installation of SCR in marine engines to remove more NOx from exhaust emissions. Overall, the ICCT believes that new ship engines should be able 'to achieve NOx limits that are 40 per cent lower than the current standard in the near term'. Further deployment of 'additional emission control technologies' would allow NOx levels to fall by 95 per cent in the medium term. As in the case of the other freight transport modes examined in this chapter, the NOx reduction is likely to entail some loss of fuel efficiency and hence an increase in CO_2 emissions per tonne-km, forcing designers and operators of ships and regulatory authorities to balance environmental priorities. In the case of shipping, the trade-off between pollutants is complicated by the regional effect that sulphur aerosols can have in reducing 'radiative forcing' and hence countering global warming (Eyring *et al*, 2007).

Technical developments can also help to reduce the externalities of shipping at the points where they are concentrated: that is, in the vicinity of ports. This can be done by stopping the ship's diesel-powered auxiliary engine from running while in port (so-called 'hotelling') and plugging the vessel into the local electricity grid using a system called 'cold-ironing'. By offering suitably equipped vessels this alternative power source, ports such as Gothenburg, Zeebrugge and Long Beach in California are managing to reduce local concentrations of SOx, NOx and PMs. Widespread application of this practice, however, will require the adoption of international standards of shore-side electricity supply to ensure compatibility of voltage and frequency between ship and port 'plug-in'.

Summary

Mainly because of intense market pressures and a lax regulatory regime, the rate of environmental improvement in the shipping sector has been slow. The rather complacent view that shipping is inherently 'green' has now been challenged, forcing regulators, shipping lines, ship designers, port operators and oil companies to place much greater emphasis on environmental performance. The rate of environmental improvement will be partly constrained by the relatively long lifespan and replacement cycle of the vessels. The International Council on Clean Transportation (2007: 10) acknowledges that 'a low fleet turnover rate means that the largely uncontrolled vessels that make up the majority of the international shipping fleet today will continue to pollute for several decades before they are retired'. The potential exists to retrofit ships with devices that improve fuel efficiency and cut emissions. The IMO estimated that retrofitting and maintenance measures could improve fuel efficiency by between 4 and 10 per cent (Buhaug *et al*, 2009). In response to the surge in demand for global shipping services since 2000, a large amount of new capacity that meets higher standards of fuel efficiency and emissions has entered service in recent years.

The new EEDI regulations introduced by the IMO will enforce higher energy- and CO_2-efficiency standards for new ships. The adoption of 'market-based measures' currently being considered by the IMO and the possible inclusion of shipping in the European Emissions Trading Scheme would further incentivize the decarbonization of the maritime sector.

Conclusions

The redesign of vehicles and application of new technology offer the potential to reduce the environmental impact of all transport modes by a significant margin. In environmental terms, the rate of technological improvement has been faster in road freight transport than across the rail and waterborne sectors. This is partly because regulatory pressures to cut emissions have been stronger in this sector, but also because it has a higher energy intensity than rail and shipping and is thus more sensitive to rising oil prices. The 'electrification' of rigid trucks and vans over the next 20 years and their powering by low-carbon electricity will offer a quantum reduction in their environmental impact. The electrification of rail freight services should help them maintain their environmental advantage. While maritime and air freight services will remain heavily dependent on fossil fuels, major opportunities exist to cut their environmental costs per tonne-km.

To meet the environmental targets that have been set by governments and international organizations, efforts to design and commercialize greener vehicles are likely to intensify. Designers' environmental priorities are also likely to change. The overriding emphasis on minimizing noxious gases is likely to give way to a more holistic view of the 'green vehicle' that achieves a better balance of clean air, climate change, noise and safety objectives.

While vehicle design and technology have a key role to play in the greening of logistics, at least as much environmental benefit will accrue from more effective use of vehicles and a rationalization of the underlying demand for freight transport.

Notes

1 This estimate is based on the authors' own analysis of annual van licensing data provided by the Society of Motor Manufacturers and Traders.

2 This estimate is based on the authors' own analysis of the effect of van length on load space.

3 Twenty-foot equivalent unit.

4 Some reports suggest that it may be as high as 4.5 per cent (Vidal, 2008).

5 A concession has been made to some less developed countries, granting them an extra four years to meet each of the EEDI thresholds for new ships.

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Reducing the environmental impact of warehousing

09

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Introduction

When considering issues of energy intensity, carbon footprints or sustainability within the supply chain, most attention has been given to understanding and mitigating the impact of transportation. By comparison, little attention appears to have been given to evaluating the consequences of warehousing within the supply chain. However, like many other areas of business, the opportunity to place a 'green wash' on an activity by prefacing that activity with the accolade of 'green', 'eco' or 'carbon neutral' has not been missed and is indeed an increasing feature of headlines in supply chain practitioner publications – but what can we understand from the use of such terms? What actions can and should the warehouse sector be adopting today or anticipate undertaking to meet those environmental aspirations? This chapter addresses these questions by reviewing the changing nature of warehouse activity, and the factors affecting and mitigating energy use and consequential emission, and so through this wider assessment places terms such as the green or carbon neutral or eco warehouse into a wider reference framework.

This chapter explores approaches to reducing the environmental impact of warehousing at a level that an individual firm or warehouse manager could reasonably take. However, the discussion does go beyond considering just the micro-level actions of a firm and considers wider macro-level impacts of emissions, land use, environment and ecology. Technical aspects of building design, the assessment of the thermal qualities of different materials and descriptions of building energy mass balances are left to others (eg Treloar *et al*, 2001), as are operational efficiency measures and wider supply chain decisions that may affect a warehouse's environmental impact, such as inventory decisions (eg Arikan, Fichtinger and Ries, 2013).

The first section sets out the changing scale and energy use of warehousing relative to other commercial property activity, primarily in the UK. For the reader not familiar with an understanding of the role performed by today's warehouse, a short review of recent trends is included. From this a three-stage warehouse sustainability model that addresses the business, economic, environmental and social aspects is put forward.

Once a baseline of impact and scope has been established, the next section identifies those actions that businesses can take and are taking to reduce the energy intensity within their current operations. This is a 'business-as-usual' approach focusing on reducing demand and becoming energy efficient. From that position the next section moves on to consider to what extent warehouse operators can incorporate low-emission and new forms of sustainable energy generation and resource management into their activities. The final section considers a deeper and wider range of measures and actions where companies are seeking to achieve minimal impact over the widest breadth of economic, resource, environmental and ecological features.

Scale of the environmental impact

The term warehousing in today's supply chain is a portmanteau one that includes a wide range of functions and activities, from cross-dock, consolidation centre, regional distribution centre (RDC) and composite warehouse to national distribution centre. While the large and often anonymous grey buildings that cluster around our motorway intersections, primary ports and the outskirts of most large towns are easily visible, the activities within remain hidden. A warehouse may imply a point where goods are stored for a long period of time, and while this remains an important function the warehouse is more associated today with terms of flow, movement, the rapid fulfilment of customer orders, and the provision of customizing and value-adding services (Baker and Canessa, 2009; Frazelle, 2002). The term warehouse, whenever it is used in this chapter, refers to this wider intensive role, which is more often associated with the term distribution centre.

First, it is necessary to quickly establish the scale of the sector in terms of area occupied and overall use of energy. By considering these trends in association with the main operational and business changes, the drivers to achieving energy and resource efficiency will become clearer.

In assessing the overall impact of warehousing, consideration has to be given to the relative scale and trends in the extent of the land occupied, the direct energy used, the emissions produced (primarily carbon dioxide, CO_2), water consumed and embedded energy contained in building materials. The area under occupation is usually reported in terms of the internal floor area of the buildings in square metres and not the total land area of a location. The measure for energy used, regardless of the source (oil, gas, fossil-generated electricity) or method of generation, is kWh, which is again related to area and is generally expressed as kWh/m^2. Emissions for direct and embedded energy are normally measured as CO_2/m^2.

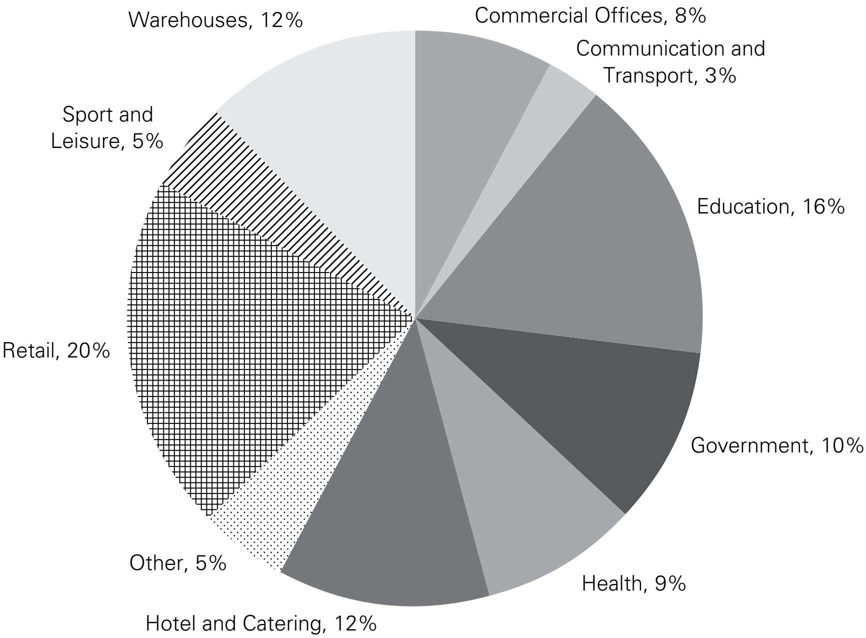
The range of official statistics that capture the breadth of information identified above is very limited. This is a consequence of sector and sub-sector definitions being constructed around broad industrial classifications rather than building activity, and of a high level of data aggregation (UK GBC, 2007). Warehousing for most statistical purposes is subsumed within larger industrial classifications or absorbed within broad commercial headings such as office, shops and factories. In addition, there are relatively few and infrequent surveys of warehouse operations. However, some major features can be identified:

- Buildings account for a substantial proportion of global energy use, estimated at 32 per cent by the Intergovernmental Panel on Climate Change (IPCC, 2014a) and 40 per cent by the World Business Council for Sustainable Development (2008). This figure increases to about 50 per cent if construction, including embodied energy within the materials, is taken into account. In advanced economies commercial property can account for a substantial proportion of the energy consumed in buildings – for example, in the United States, commercial property accounts for about 40 per cent of energy consumed and residential property 60 per cent (World Business Council for Sustainable Development, 2008 and 2009). Over the global economy as a whole, greenhouse gas emissions from buildings exceed those from transport (IPCC, 2014b).In the United Kingdom, the Department of Energy and Climate Change (2013a) estimates that warehouses account for 2.1 million tonnes of oil equivalent energy usage (which equates to 4.0 million tonnes of primary energy, due to loss in electricity transmission, etc), compared to 7.7 million for heavy goods vehicles and 5.0 million for light goods vehicles.
- In terms of logistics activities, it is estimated that 3 per cent of total UK emissions are from warehousing (UKWA, 2010). This compares to about 4 per cent from heavy goods vehicles and 2 per cent from vans (DfT, 2009). However, national figures such as these do not include international transport. A global supply chain study of greenhouse gas (GHG) emissions has found that 13 per cent of supply chain emissions emanate from logistics buildings compared to 87 per cent from transport (World Economic Forum, 2009). Thus, while transport is the most important logistics contributor to GHG emissions, particularly if international transport is added to domestic figures, warehousing is significant and therefore must be taken fully into account in supply chain studies. In addition, warehousing is viewed as a supply chain activity in which there is significant potential for cutting carbon emissions (World Economic Forum, 2009).
- Studies from the UK and United States suggest that the growth in electricity consumption and energy for all commercial property is closely coupled to the rate of increase in total floor space (Green Buildings.com, 2008). The warehouse sector in England and Wales totalled just under 159 million m^2 in 2008, which constituted 27.6 per cent of commercial properties. Between 2000 and 2008,

> while factory space declined by 10 per cent, retail space remained almost constant, office space grew by 8 per cent and warehouse space increased by 15 per cent (Department of Communities and Local Government, 2012). Since the recent recession, overall industrial floor space declined by 4.4 per cent in the period 2008 to 2012 (Valuation Office Agency, 2012), but no separate figures are available for warehousing. Figures maintained by Jones Lang LaSalle indicate that the take-up of new large warehouses since the recession has been patchy but with 2013 take-up exceeding that of 2007, prior to the recession (Jones Lang LaSalle, 2014). The figures thus suggest that warehousing is continuing to be very important to modern supply chains. This importance is exemplified by the appearance of new types of warehousing in recent years such as e-fulfilment centres (eg the grocery 'dark stores'), consolidation warehouses for shopping centre deliveries and port-centric import warehouses.

The picture that emerges is that warehouse activity has a significant impact through the scale of its activities. While its energy consumption and total CO_2 emissions are lower than for transport and some other non-domestic building sectors, such as retail (see Figure 9.1), its impact is substantial and increasing. The next section will identify those changes in warehouse activity that have led to this increased resource and carbon intensity.

FIGURE 9.1 Energy consumption in the UK service sector (split by thousands of tonnes of oil equivalent)



SOURCE: Adapted from Department of Energy and Climate Change (2013a) – 2012 figures shown

Increasing resource intensity

The warehouse or distribution centre is often one of the largest fixed and long-lived assets within any organization's supply chain. Investment decisions in warehouses are therefore of strategic importance, with the focus of decision making being on cost reduction and return on investment as well as improved customer service and operational performance. However, it should be remembered that logistics as a percentage of cost of sales in the fast-moving consumer goods sector averages around 6–8 per cent. Within overall logistical costs, European warehouse activity contributes approximately 24 per cent of total logistics costs compared with 40 per cent for transportation (ELA, 2004), with comparable figures of 24 and 44 per cent respectively for the United States (Establish, 2013). As a consequence, while warehousing has significant impact within a firm it is not surprising that more opportunity and management focus has been directed towards reducing transportation spend and emissions.

Significant growth in the total area occupied by warehousing has already been identified, but what has been of greater significance has been the increase in size, scale of throughput and duration of activity. In the late 1990s (ie 1996–1999) the average size of a newly built large distribution centre was 20,000 m^2 and this has increased more recently (ie 2010–2013) to 28,000 m^2 (Jones Lang LaSalle, 2014). In addition the height, and so the cubic capacity, of the buildings has increased as greater use is being made of high-bay automated storage and retrieval systems (AS/RS) or narrow-aisle racking systems (Baker and Perotti, 2008) in order to accommodate ever-larger product ranges. Minimizing the visual impact on the wider environment of these buildings, which can now often reach over 20 metres in height, has become a further issue as a consequence. Some warehouses now have gradated horizontal colour schemes so as to blend in with the sky. At the local level a new generation of transhipment or cross-dock centres has emerged that place a premium on buildings of much lower heights but with large floor area, with banks of doors on opposite sides of a building to facilitate the rapid transhipment of orders. Both warehouse types are often being located in proximity to centres of population rather than points of supply. Consequently warehouses tend to cluster along the major arterial routes in what were often former green fields rather than brownfield land located within urban areas (Hesse, 2004).

Increasing the size of warehouses has also meant that capital invested in these buildings has risen. This has resulted in a substantial increase in the intensity with which these assets are operated in order to achieve faster investment paybacks and to reduce unit fixed costs. This intensification is also reinforced by retailer moves towards longer trading periods across the week and by industry adopting continuous replenishment and JIT production methods. Many warehouses now expect to work two or three shifts on five or more days per week, increasing to three shifts on six or seven days per week at peak times (Baker and Perotti, 2008). A typical grocery RDC will today operate 24 × 7 for 364 days per year. Sweating the asset in this way reduces unit fixed costs and defers the need for further capital investment but increases the operational consumption of energy per square metre for power, light and heat.

Concentration into larger warehouses has additionally meant that the numbers of inbound supplier vehicles and outbound customer deliveries serving these warehouses through a 24-hour period has increased. The road congestion effects around distribution parks are further compounded by an increasing proportion of those commercial vehicles being made up of articulated maximum-weight or maximum-capacity trucks. At the same time the number of staff employed within these warehouses has also increased. Again, a grocery RDC can now employ over 1,000 employees per eight-hour shift. This places pressure on increasing the size of onsite service areas, employee car parking and local road infrastructure. While good connectivity to the trunk road network is a priority for new warehouse developments, connectivity to public transport service networks for staff is often very poor.

To cope with increased product ranges, reduced order lead times, greater customization, and health and safety regulation, greater use is being made of powered mechanical equipment in the form of forklift trucks, conveyors and automated order-picking or sortation systems (Baker, 2006). This is in addition to other value-adding activities such as labelling or product assembly operations, which have been transferred from manufacturing as companies have adopted postponement strategies. To cope with this the warehouse has had to rapidly extend the use of IT support systems deployed at operator level, using wireless communications to support bar code readers, voice and light picking, and more recently radio frequency identification (RFID) technologies. Against the accrued benefits of a ‘paperless warehouse’ has to be set the overall increase in power needs to support additional IT infrastructure.

The final feature to be considered is the emergence of a multiplicity of market intermediaries and a separation between those who occupy, design, finance and manage buildings (Scrase, 2000; Hesse, 2004; Reed and Wilkinson, 2005). In this business environment it can be difficult to establish a consensus of how to balance long-term capital investment decisions against short-term operational savings in energy or resource consumption for a third party. ‘Market capitalization and returns on investments are now becoming preferred in land-use decisions, whereas public institutions – obligated by environmental, transport or community needs – are losing influence’ (Hesse, 2004: 167).

Framework for assessing the environmental impact of warehouses

The previous review of major trends in warehouse activity has shown how diverse are the areas affected by warehousing and suggests that any mitigating actions require a systems-wide approach. On the one side there are the micro-level firm-based direct inputs associated with meeting operational needs that consume resources: these include energy, water and land, and building materials. However, there are also wider external macro-level outputs that go beyond the boundary of a single firm and affect the environment and society. These externalities are associated with the impact of land use, atmospheric emissions, waste management, traffic and congestion, public transport, visual intrusion and ecology. The systems approach clearly draws upon the life cycle analysis now widely used throughout supply chain analysis (Carbon Trust, 2006b; Tsoulfas and Pappis, 2005; Padgett *et al*, 2008).

The main elements of this framework are shown in Figure 9.2. The suggested framework is separated into a micro-level perspective, which emphasizes the individual firm and economic features, and a macro-level perspective where broader externalities related to the environment and society are considered. The scope of these two perspectives can be further classified by type of resource and related activities. Finally three developmental stages can be envisaged from a baseline of being energy efficient before seeking to adopt low-emission technologies and then achieving full sustainability.

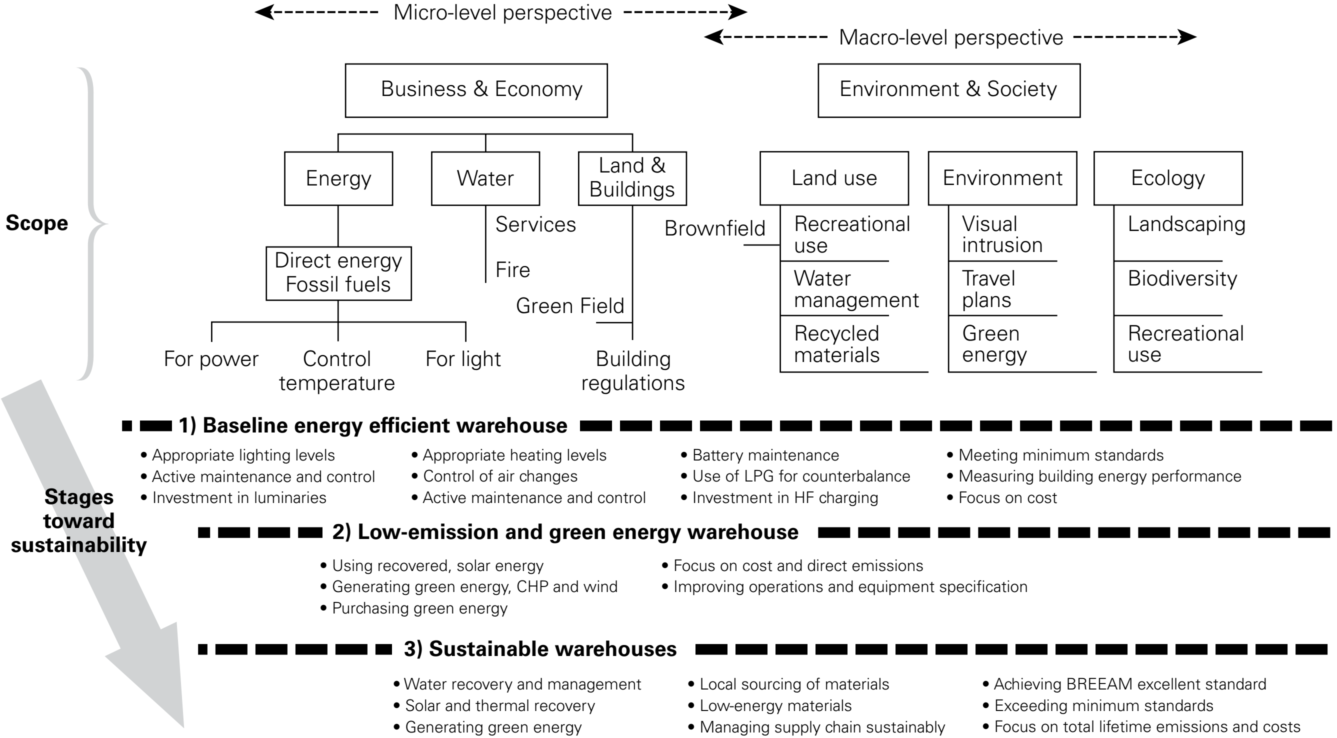
For a firm, the immediate and business-as-usual objective is the efficient and economic use of energy inputs, typically fossil based, that provide power for equipment (forklift trucks, conveyors etc); and regulation of temperature (cooling or heating), light (internal and external) and water for personal hygiene and processes. This is a baseline that all warehouses should achieve as a minimum. The next section maps out the range of actions that can be taken for a warehouse to become energy efficient.

Ways of reducing the environmental impact

Stage 1: Improve energy efficiency

There is little published information on the actual cost structure of warehouse operations, and even less on direct spend on energy costs or energy consumption rates. The range of building types, and the range of use and operating conditions, makes producing benchmarks or standards particularly challenging. This is further compounded by inconsistency in the building energy models (UK GBC, 2007), variation in boundary definitions for activities (Johnson, 2008; Padgett *et al*, 2008) and little or no central collation of energy data (Perez-Lombard, Ortiz and Pout, 2007). The Royal Institute of Chartered Surveyors (RICS) estimated that direct energy costs in warehouses account for 1 per cent of operational expenses, while property costs contribute around 10 per cent and labour up to 85 per cent (RICS Green Value Report, 2005, cited in KingSturge, 2007). Other sources suggest that energy costs of between 5 and 10 per cent may be more representative of general-ambient warehouses, while temperature-controlled warehouses operating at –26°C may well have costs closer to 15–20 per cent. Regardless of actual level,

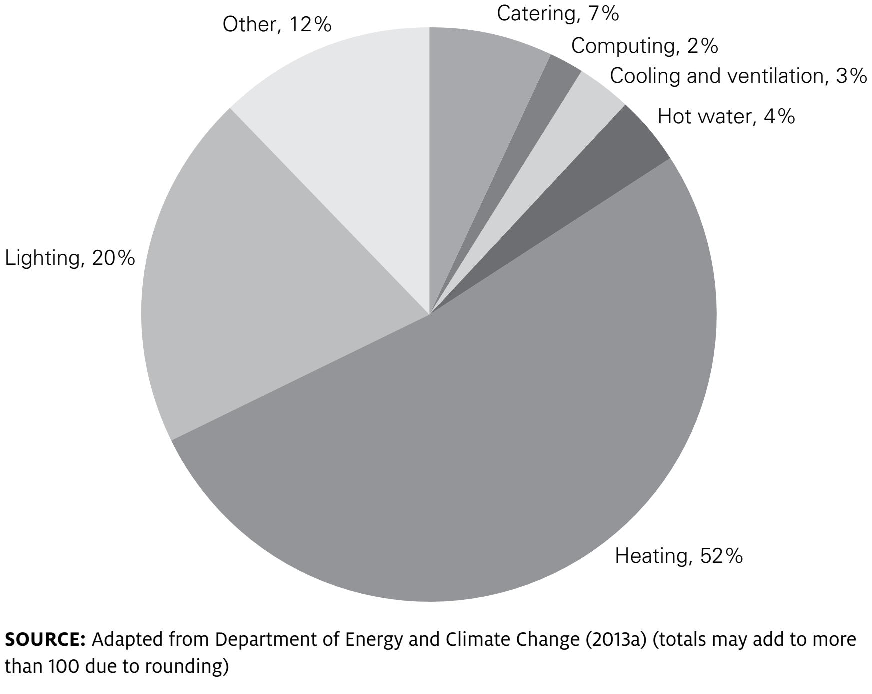
FIGURE 9.2 Framework of assessment for developing sustainability in warehousing



surveys undertaken by the UK government's Energy Efficiency Best Practice Programme suggest that 50 per cent of all direct energy used for heat, light and powered equipment could be saved by simple housekeeping measures (Carbon Trust, 2002a).

There is a lack of consistent and comprehensive data that shows exactly where energy is used in warehouses. For example, in the UK, some sources show that heating is the main use of energy (DECC, 2013a) whilst others indicate that lighting is the predominant use (UKWA, 2010; Prologis, 2013). Even individual warehouse managers often do not have accurate information on energy use and, of course, the relative balance is highly variable depending on factors such as the required product environment, building insulation properties, airtightness, extent of rooflights and degree of equipment automation. The emphasis of surveys on particular types of warehouses has probably led to the apparent differences in opinion on energy usage. The figures issued by the UK Department of Energy and Climate Change (DECC) are shown in Figure 9.3, with heating representing 52 per cent of energy used, and lighting being second in importance at 20 per cent. Obviously, these figures reflect climatic conditions in the UK. In warmer climates, less energy is used for heating but more for cooling and ventilation.

FIGURE 9.3 UK warehouse energy consumption



SOURCE: Adapted from Department of Energy and Climate Change (2013a) (totals may add to more than 100 due to rounding)

Each of these major areas of energy use and emissions are reviewed in the following sub-sections.

Warehouse temperature

Fuel oil or gas is the primary source of energy for heating a warehouse, and electricity is used for cooling. The extent of the energy consumed is primarily determined by:

- The temperature required to maintain the stored products in a satisfactory condition. This may require intervention to maintain a maximum or minimum temperature level, as well as to control relative humidity.
- The background temperature of the internal space required for operatives to perform their work in comfort (known as the dry resultant temperature) in relation to the extent of their physical exertion and the location of the task being undertaken.

Further structural factors influencing the energy required will be the overall thermal mass of the building: the nature of the materials used in the construction of the building as well as levels of insulation; the orientation of the building relative to local prevailing wind and sun, and the heating or cooling degree days; the overall volume of the building; and thermal gain from internal processes and equipment such as forklift trucks or lights. Owing to their greater overall thermal mass, larger buildings tend to require less energy per m^2, with heat loss through walls being relatively small. Reducing the internal target temperature has the largest effect on energy consumed, with a 1°C reduction typically producing a saving of 10 per cent. Setting local temperatures by zone in a way that is appropriate to the activity being carried out is therefore important. In areas where there is a high level of physical activity, such as loading bays, 13°C should be adequate, while for order picking or inspection 19°C would be required. In bulk storage areas for dry ambient products 10°C may be satisfactory (Carbon Trust, 2002a).

Once the building achieves its required temperature, the maintenance of that level is affected by the ventilation. This is expressed as the number of air changes per hour. All buildings require ventilation to maintain a satisfactory working and storage environment. High air-exchange rates are associated with high energy cost, as buildings or zones within a building have to recover heat loss or reduce gain in the case of temperature-controlled warehouses (Carbon Trust, 2002b, 2006a). Air changes are directly affected by the level of draughts, often the consequence of poor construction or maintenance but often more significantly affected by the number and type of doors and the time that the doors are left open. In addition, the location of the doors around the building is important. For example, doors on two opposite sides, as in flow-through warehouse designs, may encourage a draught through the building whereas a U-shape design may reduce this effect. Stratification through convection as a result of warm air rising and cold air sinking is an additional feature in all buildings (Aynsley, 2011), and again is most prevalent in buildings with high air-exchange rates and not only taller buildings.

Significant savings can be achieved by (Carbon Trust, 2002a):

- opening doors only in periods of vehicle activity;
- incorporating barriers such as close-fitting door locks, plastic strip barriers or fast-acting doors in areas frequented by forklift trucks;
- segregating intake or dispatch areas from other areas of activity;
- using zoned or time-controlled thermostats.

The source of heating used in the warehouse depends upon the size of areas to be controlled and the extent that local zone conditions have to be maintained. For large areas, or where there are high air-exchange rates across a building and where an overall minimum temperature is required, ducted warm-air systems are most efficient. These systems are usually powered by fuel oil or gas, although new biomass and combined heat and power systems are further options. For smaller areas local heating is usually provided by either suspended warm air heaters or radiant heaters, powered preferably by gas or fuel oil. Suspended heaters that are unflued have a high thermal efficiency of 100 per cent but are only suitable for large-volume buildings owing to the build-up of by-products of combustion. Flued heaters should still achieve thermal efficiencies of 90 per cent and are best suited to large buildings with low air-change rates. Radiant heaters that emit infrared radiation from hot surfaces have a lower net thermal value of 50 per cent, but they are effective at providing localized heat in areas of high air-exchange rates, typically close to doors where operators require higher levels of comfort or are mainly engaged in low-activity tasks or sedentary activities (Carbon Trust, 2002b).

Warehouse lighting

Managing lighting efficiently in terms of its functional performance, cost, energy use and resultant emissions is the most straightforward area within the warehouse to manage. A combination of simple housekeeping measures, use of known and available technologies, simple control methods, clear performance standards and methods of calculating comparative installed circuit demand in terms of watts per m^2 all assist. Annual energy consumption is itself easily measured by multiplying the installed load by the floor area and hours of operation. A single 400W high-pressure sodium light bulb operated continuously for a year has been calculated to produce the equivalent of 1.69 tonnes of CO_2 according to Powerboss Eluma (Wyatt, 2007), so taking lighting seriously has considerable environmental and energy consequences as it is dependent upon electricity.

The term used to measure the amount of light in an area is 'lux' and the required luminescence and colour-rendering level is set by the nature of the task being undertaken. The extent to which natural light needs to be complemented by additional light sources (known as luminaires) is affected by the extent and orientation of rooflights, the duration of daylight hours, height of buildings and aisle widths. Guidance lux values and target installed circuit loads are reproduced in Table 9.1 from the Carbon Trust's *Good Practice Guide 319* (Carbon Trust, 2002a). Providing too much light is as disadvantageous as too little as it can cause glare and operator discomfort.

TABLE 9.1 Recommended light levels in open and racked warehouse areas

General warehouse lighting conditions		Target installed circuit W/m^2	
		300 Lux	500 Lux
General lighting in 'open' area		5–6	8–10
Constrained by aisle and height			
Aisle width (metres)	Mounting height (metres)	150 Lux	300 Lux
1.2	4.5	8	14
2.4	6.5	8	16
3.0	8.0	9	17

SOURCE: Carbon Trust (2002a)

Simple cleaning of both rooflights and luminaires should be a regular feature of any energy efficiency strategy, as light levels can be reduced by 50 per cent in two years through the accumulation of dust and so increase operating costs by 15 per cent (ie energy consumed) (Carbon Trust, 2007). Regardless of type of lamps fitted, a replacement strategy based on average usage and not on failure is recommended. With buildings increasing in height, difficulties in accessibility can be more easily managed within a prescribed programme of replacement using access towers, which can also be linked to full cleaning of all luminaires.

The choice of lamp type and the control gear to switch lights on and off needs to take into account the activity to be undertaken, the likely frequency of switching, the lamps' run-up (time to reach optimum light from start or restart) and restrike (time for lamp to cool down before switching on again) rates and the average life of the lamp in relation to the ease of access for replacement. Replacing old mercury discharge lamps with high-pressure sodium lamps (SON) should produce a 15 per cent saving in energy costs;

replacing old-style 38m (T12) tubular triphosphor-coated fluorescent lamps with 26m (T8) tubes will bring an 8 per cent saving; and if a high-frequency control gear is used, 20 per cent savings in energy consumed can be expected. Fitting high-performance lamps without adequate maintenance or placing them in luminaires without efficient optics or prismatic glass to direct the light falling into an area will considerably reduce these savings, as lamp power ratings or numbers or both would need to be increased (Carbon Trust, 2002a, 2007). Table 9.2 indicates the appropriate types of lighting for different activity areas around the warehouse, taking account of colour rendering and lighting efficiency measured in lumens per watt.

TABLE 9.2 Appropriate lamps by activity area

Site location	Space use	Recommended lamp type
Internal	Offices	Triphosphor tubular fluorescent, compact fluorescent, low voltage tungsten halogen
	Factories	Triphosphor tubular fluorescent, high pressure sodium, metal halide, inductive, emergency directional LED
External	Car parks	High pressure sodium, metal halide, compact fluorescent
	Floodlighting	Metal halide and high pressure sodium

SOURCE: Adapted from Carbon Trust (2007)

The effectiveness of light-emitting diodes (LEDs) has increased dramatically in recent years and these are now becoming viable for industrial use. The Carbon Trust (2014a) indicate that LED lights may provide savings of 65–85 per cent compared to halogen and 20 per cent compared to compact fluorescent and high intensity discharge lights, as well as offering a long product life. However, they have warned that research has shown that some individual units may fall below specification. This type of lighting is particularly suited to refrigerated warehouses owing to their low heat output (Rogers, 2012) but is also now being used increasingly in normal temperature facilities. Where operations are continuous (ie 24 hours), payback may be as fast as one year (Carbon Trust, 2014b). There is an increasing number of examples where LEDs are being employed both internally, such as at Sainsbury's Daventry distribution centre (*SHD Magazine*, 2013a), and externally, such as at NCP car parks (Building4Change, 2013). In the future, organic light-emitting diodes (OLEDs), which are flat panels giving even, diffuse light, may also offer energy-efficient lighting (Carbon Trust, 2011).

Mechanical handling equipment

To achieve the rapid and intensive movement of goods, all warehouses will use a range of mechanical handling systems for the transit and lifting of goods. A simple manual warehouse will use counterbalance forklift trucks to unload vehicles and to move and lift pallets of products into block stacks. Further types of forklift truck, such as reach trucks, are required to achieve higher storage densities through the use of pallet racking. Higher labour efficiencies for case or item picking require the use of ride-on trucks, low-level order pickers or simple conveyors. Higher throughputs, wider product ranges and more intensive operations add further specialist electro-mechanical systems in the form of high-bay stacker cranes, sorting and collation conveyors, layer pickers, A-frames and robotics (Baker, 2006). To consider such a range of equipment is not possible here and so only the largest single category, forklift trucks, will be reviewed.

While the category of forklift trucks covers a very wide variety of types of truck, the choice of type of power unit and consequential fuel type is a simple one. The choice lies between those trucks that use an internal-combustion engine as their primary power source and those that use lead-acid electric-storage batteries. For combustion engine units, the main power alternatives are diesel fuel or liquefied petroleum gas (LPG). The power unit provides propulsion to the truck while secondary motors power hydraulic pumps for lifting.

The starting point for the choice of equipment lies not in considering the energy source to be used but rather in wider equipment characteristics related to: the type of access to products (aisle width and lift height); whether the work is done in an open or closed environment (operating outside a building, on uneven surfaces or where fumes can affect personnel or goods); weight distribution (for stability of trucks, all require a heavy counterweight). Counterbalance trucks, while offering more energy options, are limited in the areas of the warehouse they can operate in, owing to their lower lift heights and wider turning radius. They are used predominantly in receiving and dispatch bays, where surfaces are uneven or open to the elements. Where counterbalance trucks are used externally, LPG and diesel are alternatives, while for internal use the choice is between LPG and electric-storage batteries. For flexibility of function across the entire warehouse, electric-storage battery trucks predominate and are incorporated into a wider variety of reach trucks, narrow-aisle trucks and order-picking trucks.

Within this apparently narrow choice of alternatives there is a range of options that companies can take to reduce the levels of direct energy consumed, emissions produced and wider environmental impacts associated with manufacture and disposal, especially of batteries, and these will be reviewed next.

As with all comparative analysis of energy consumed and emission balances, the issue is not with energy efficiency conversion factors or CO_2 emission rates but the definition of system boundaries. The difficulties in providing a straightforward answer to this are highlighted by Johnson in his review of carbon footprints for electric and LPG forklifts (Johnson, 2008). Studies have failed to agree on relative energy efficiencies as there is no standard industry test cycle and no consistency in the system boundaries. CO_2 per kWh output boundaries can be defined as 'well-to-pump', 'well-to-wheel', 'outlet-to-battery', 'battery-to-wheel' or 'wheel-to-exhaust', all producing different relative performance values for each fuel type. So while LPG has the highest energy efficiency at 89.3 per cent and lowest CO_2 emissions, one study showed it used six times more energy per operating cycle than electricity, but on a well-to-battery basis electric-storage batteries were less efficient. Overall Johnson concludes that 'fuel carbon footprints of electric and LPG forklifts are, in principle, about equal, while in actual practice, LPG's footprint is smaller than that of electricity' (Johnson, 2008: 1572). In a business-as-usual scenario where the choice is between LPG, diesel fuel and electric battery, this tends to reinforce a cost-of-ownership approach based around capital purchase and disposal values, fuel cost, fuel consumed and maintenance rather than a wider evaluation of total emissions.

Looking to the future, there are new counterbalance design options starting to come onto the market built around alternative engine technologies used also in the automotive industry. Internal-combustion power units using biodiesel or hybrid fuel combinations and hydrogen fuel cell technologies are all coming onto the market. In 2009 the American Recovery and Reinvestment Act subsidized the introduction of hydrogen fuel cells in trucks at a number of companies, including BMW, Coca-Cola, FedEx and Walmart, and unsubsidized repeat orders have been continuing. BMW Manufacturing in South Carolina now operates over 275 fuel cell forklift trucks. Hydrogen for this fleet is currently brought in from external sources but may be produced onsite in the near future from methane collected from a nearby landfill site, which currently supplies 50 per cent of the facility's energy needs (*Fuel Cell Today*, 2013). Examples of fuel cell trucks being used in Europe include DB Schenker in Austria, Ikea in France, Marks & Spencer in the United Kingdom (*Logistics Manager*, 2012; *Fuel Cell Today*, 2013).

The efficiency of lead-acid electric battery technology and consequential routes to achieving reduced energy inputs and so emissions are bounded by loss of power through the mains electricity transmission grid, the efficiency of the transfer process as batteries are charged from the mains supply, the internal efficiency of a battery to absorb and retain its charge over its life, and finally the manufacture and disposal of the lead battery itself (Trebilock, 2008). New battery types using lithium are slowly emerging, especially for low-level pedestrian riders. Tesco started using these in the UK in 2011 (*Handling and Storage Solutions*, 2011). However, the immediate focus for businesses using forklift trucks is on achieving better performance from existing battery technology (MacLeod, 2008).

Improvements in lead-acid batteries, from plate to tubular cell construction and from water-filled flooded units to low-maintenance sealed units, have improved energy performance, although individual energy efficiency in the charging phase (grid to battery) remains at around 70–80 per cent. In a typical 10-hour charge cycle, 80 per cent of the charge is achieved in the first five hours, with the remaining time being required to complete the full charge cycle (Trebilock, 2008). Interrupting or exceeding this charge cycle reduces the power retained and overall life of the battery. Overcharging through this period can create additional heat, thus distorting the internal cell structure, which in turn reduces cell efficiency and life as well as causing the additional venting of potentially combustible gases. Batteries are usually charged to perform over a single shift of 8–10 hours, so for extended operating periods multiple batteries will be required. Typically, in multi-shift operations, a battery to truck ratio of 2:1 will be maintained. Managing this recharge cycle is important to minimize the energy required and achieve the maximum battery life, which is restricted to a fixed number of recharge cycles over the battery's life. For larger fleets, especially where continuous shifts are worked, the management of the total battery fleet using a combination of high-frequency fast charging, advanced battery management monitoring and individual battery monitoring over weekly recharge cycles reduces the ratio of batteries to vehicles required to 1.6:1, extends the operating life and minimizes waste heat and gases. In the short term, capital costs for high-frequency chargers are higher, but over a five-year period power consumption should be 11 per cent lower and whole-life cost savings of 10 per cent are projected (*SHD*, 2009).

The traditional approach to maintaining maximum operational efficiency over a working period has been to fit over-capacity-sized batteries despite the disadvantage of additional energy costs, which are often not separately monitored. The introduction of 3-phase AC high-frequency fast-charging systems and opportunity-charge batteries has enabled batteries to be more appropriately specified. Opportunity charging can take the form of rapid charging from the mains during coffee breaks and short operational breaks, or direct charging by on-board regenerative motors, linked to returning energy produced during braking or the lowering of the mast and forks via the hydraulic system direct to the battery (Davies, 2009). Trials reported by Toyota Material Handling and Jungheinrich (Davies, 2009) suggest that using recovered energy reduces power consumption from the battery by between 15 and 25 per cent. These approaches are very effective at getting a battery back up to the 80 per cent capacity level when used with a correctly specified battery. However (even along with other truck improvements to lift controls, transmission and gearbox design, hydraulic systems and on-board performance diagnostics that have reduced the overall cost of ownership), 'fundamental improvements in truck design are currently limited by battery technology' (Davies, 2009: 16).

As mentioned earlier, there are of course also energy efficiency opportunities in other equipment types, including automated equipment, such as conveyors, sorters and automated storage and retrieval systems (AS/RS). As well as technical advances in drive motors, gear reducers etc, there are control mechanism opportunities such as distributed controllers (so that only those parts of the conveyor transporting goods are running rather than the whole conveyor system) and low-energy algorithms (so that AS/RS cranes optimize their performance based on energy use rather than on speed or cost) (Meneghetti and Monti, 2013).

Energy audit

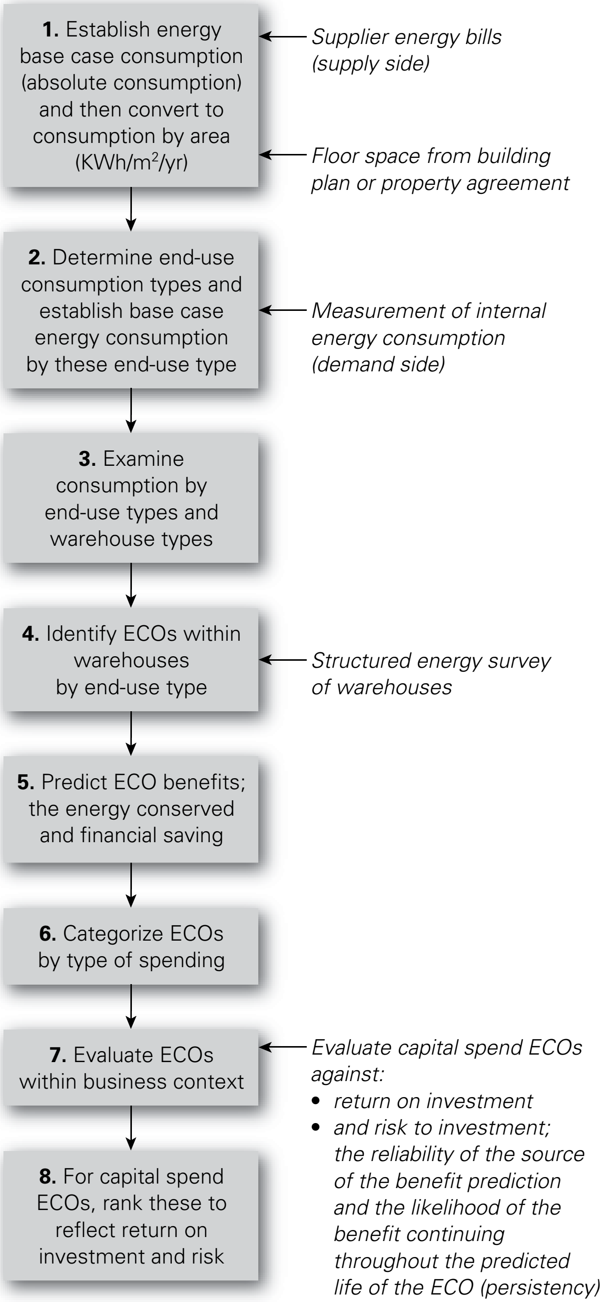
To analyse energy consumption in an existing warehouse an energy audit should be conducted. Dhooma and Baker (2012) suggest a method for doing this, as shown in Figure 9.4. The first three steps are to establish the total energy consumption of the warehouse and explore exactly how this energy is used. Frequently, the only information available is the total electricity and gas consumption, without any knowledge of precisely what equipment has used this energy. Various methods can be employed to measure or estimate energy usage by equipment type, using devices such as fitting data loggers and clamp meters. If this is not possible you can selectively shut down items of equipment and note the change in consumption, or examine energy consumption data stamped on the equipment (although this is not always reliable over time). The fourth step is to identify energy conservation opportunities (ECOs) by conducting a survey of the warehouse. Such a survey should be conducted by a multidisciplinary team, using a pre-prepared template and with prior view of the total asset register of equipment. For each ECO the potential energy, and financial, savings can then be estimated within defined error margins. Step 6 involves the classification of the ECOs in terms of spend type – for example, whether they require significant capital expenditure, minimal spend, or rental expenditure. Each ECO can then be categorized according to its spend type, its return on investment (if applicable), its level of reliability (ie in terms of estimated or calculated energy reduction) and also its likely duration. For example, if predicted energy savings rely on a change of behaviour, the likelihood of these savings being maintained over a long period of time should be taken into account. These factors can then form the basis for future management decisions.

So far, the actions considered for reducing the level of demand for energy have been centred on adopting technologies with lower energy inputs and better operational controls by relating equipment performance specification to activity and need. This is an essential first step, but to engage more actively with the need to reduce emissions a move to local and renewable sources of energy is the next phase towards achieving a sustainable warehouse.

Stage 2: Harness green energy

Green energy can be defined in terms of the generating of power from a range of low-carbon renewable sources close to or at the point of use. The primary aim of adopting green energy is to achieve a shift from carbon-intensive energy sources principally based on coal or oil, either directly or indirectly

FIGURE 9.4 Energy audit of an existing warehouse



SOURCE: Reproduced from: Dhooma, J and Baker, P (2012) An exploratory framework for energy conservation in existing warehouses, *International Journal of Logistics: Research & Applications*, 15 (1), pp 37–51, with permission of the publisher Taylor & Francis Ltd via the production of grid-based electricity. The main forms of renewable green energy sources include:

- biomass (wood chip or other waste), wind, solar thermal, solar photovoltaics;
- recovered process waste energy, such as heat from refrigeration plants or air compressors;
- recovered kinetic energy;
- air, ground or water thermal-exchange units.

In addition, low-carbon alternatives such as natural gas and biodiesel could be included, although there are substantial additional sustainability issues associated with these fuels, which have been discussed elsewhere.

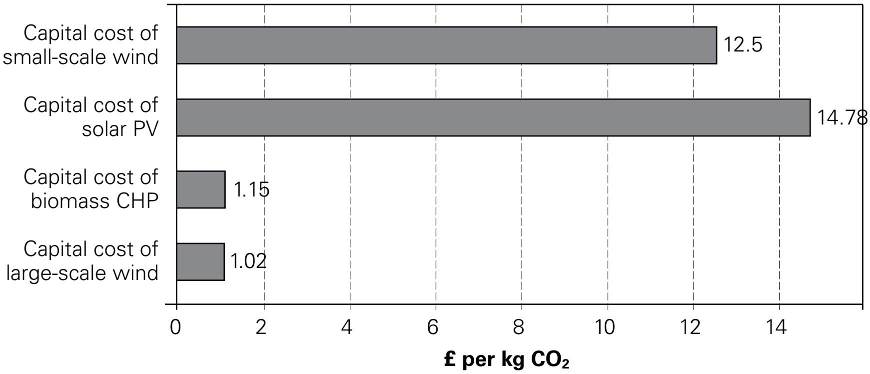
The suitability and potential applicability of the four sources of power on the energy mix for an individual warehouse depends upon a wide range of operational, cost, environmental and market factors. Principal among these are:

- the operational pattern of energy demand versus the generating characteristics of the alternative green energy supply;
- the cost and scalability of each green energy technology;
- the relative generating efficiency and life-cycle emissions levels of alternative technologies;
- the rate of technology maturity and innovation;
- regulatory and market conditions affecting price, demand and supply conditions.

Demand for energy within the warehouse in the form of either electricity or heat is not constant. It is dictated by hourly and weekly throughput patterns as well as longer seasonal weather changes over the year. Further local variation in generating periods due to local weather conditions, the proximity and orientation of buildings or levels of associated activity adds further complexity. This creates issues of managing total energy demand against short-term fixed generating capacity, the availability and cost of sourcing variable additional short-term external energy supplies, and the disposal or sale of surplus green energy or a means of storing that surplus energy. Consequently, local generation of green energy is likely to provide only a partial solution. Studies looking at these demands and generating patterns suggest that 44 per cent of onsite renewable energy will be exported (sold) while only 38 per cent of demand can be satisfied by green energy (UK GBC, 2007).

Like most transformational processes, the economics of power generation are subject to economies of scale and a balance between capital costs, fuel input costs versus lifetime operating costs and not just the greenhouse emissions and energy conversion rates. A review of each technology goes beyond the scope of this analysis but some studies suggest a tenfold cost per kg-CO_2 benefit of using offsite renewable versus onsite generating (see Figure 9.5), highlighting the need for companies to proceed with caution in this area. On the other hand, recovered process energy systems or solar thermal systems

FIGURE 9.5 Comparison in estimated cost of on- and offsite renewables



SOURCE: Adapted from UK Green Building Council (2007: 48)

for pre-heating water appear to lend themselves effectively to local site applications on an energy conversion, cost and operational basis. Similarly, ground source heat pumps need only '100 kWh to turn 200 kWh of environmental or waste heat into 300 kWh useful heat' (Gazeley, 2004: 137). Also, large-scale onsite wind generation can be established at suitably located warehouses, such as the six 1.5-MW wind turbines at Nike's European Distribution Centre in Belgium (CILT Sustainable Distribution Forum, 2008).

Technologies such as solar photovoltaics are still a maturing technology where current payback periods are still calculated in periods of 15–20 years, which is far longer than the current rate of technology improvement. Interestingly, indirect benefits of photovoltaic panels have been identified as they provide roof shading during the day and additional insulation at night (Dominguez, Kleissl and Luvall, 2011). The use of combination technologies such as self-cleaning transparent-film technologies in conjunction with solar photovoltaic laminates such as ethylene tetrafluoroethylene (ETFE) rooflight panels may prove more cost and energy efficient, even in the medium term. These are reported as having 50 to 200 times less embodied energy, with a trial 33,900 m^2 distribution centre installation generating 80 MWh of power and saving 32 tonnes of CO_2 (Gazeley, 2008). By comparison, small wind generators with an estimated five-year payback may offer better short-term alternatives, although these may convert only 30 per cent of the wind energy into electricity. By comparison, while a 600 kW wind turbine would have a capital cost of £400,000 and generate 1.5 GW, a solar photovoltaic array would require an investment of £10 million and a roof space of 20,000 m^2 (UK GBC, 2007). In contrast, combined power and heat (CHP) systems using biomass are capable of achieving viability in the scale of generating low life-cycle emissions at acceptable costs. However, studies do suggest that CHP systems require extended operating periods of 14 hours per day as well as proximity to other domestic and commercial users to achieve overall viability (UK GBC, 2007).

The final factors affecting the growth of green energy are planning restrictions on specific developments and the regulatory regime within the wider energy market. In Europe there is a wide range of schemes to promote energy efficiency and the use of energy from renewable sources. For example, the European Commission has introduced the Energy Performance of Buildings Directive, whereby Energy Performance Certificates are required for new buildings, rating their energy efficiency. In the UK, these are required whenever warehouses are built, rented or sold. It is proposed that from 2018 there will be a minimum mandatory rating (which is currently on a scale of A to G) and therefore energy-inefficient buildings will need to be upgraded. Other measures in the UK include the Carbon Reduction Commitment Energy Efficiency Scheme whereby medium to large companies are required to purchase carbon credits; a Climate Change Levy is imposed on energy suppliers (which may be alleviated for some industries by Climate Change Agreements); Feed-in Tariffs offer companies payment for electricity from low-carbon sources fed into the National Grid; Non-Domestic Renewable Heat Incentives and Enhanced Capital Allowances give tax relief for certain green technologies. In 2013, the mandatory greenhouse gas reporting scheme was introduced whereby UK quoted companies must report on their greenhouse gas emissions in their annual reports. It is further proposed under the Energy Savings Opportunity Scheme (ESOS) that from late 2015 companies must have independent energy audits undertaken every four years. The approach to encourage energy efficiency is thus through a combination of regulation and incentives. The latter is now supported by such initiatives as the setting up of the UK Green Investment Bank in 2012 and the Non-Domestic Green Deal in 2013. Further incentives for energy efficiency schemes may be supported by the pilot Environmental Discretionary Reward (EDR) scheme launched in 2014 (DECC, 2013b).

However, several studies have shown that this approach, even when linked to reducing energy intensity, is unlikely to meet the UK government's carbon reduction targets. To go to the next stage of sustainability and approach zero emissions, companies need to incorporate many of the previously mentioned features within their buildings and operations and then go beyond current building standards (Carbon Trust, 2009; UK Green Building Council, 2007; Reed and Wilkinson, 2005; Papadopoulos, Stylianou and Oxizidis, 2006). The next section highlights the advantages to be gained by designing sustainability, energy management and green energy generation into the next generation of buildings.

Stage 3: Design sustainability into buildings

Building regulations in the UK have principally been aimed at establishing minimum standards for the thermal characteristics of buildings' operator comfort in terms of light, heat and ventilation. The introduction of

TABLE 9.3 Energy consumption benchmarks for setting good practice design targets in storage and distribution property

Building standard	Building-related energy (kWh/m^2 per year)					
	Heating & hot water (fossil)	Fans, pumps controls (electricity)	Lighting (electricity)	Other (electricity)	Total electricity	Total
Typical	185	8	25	10	43	228
Improved	135	7	12	10	29	164
New	80	5	5	10	20	100

SOURCE: Carbon Trust (2000)

Non-Domestic Energy Performance Certificates in 2008 in the UK as part of the EU Energy Performance Buildings Directive aimed to encourage progress towards higher energy efficiencies. While undoubtedly these standards have both sought and achieved higher energy efficiencies, as can be seen in Table 9.3, they have not necessarily challenged the commercial property sector to become either carbon neutral or fully sustainable. The UK government has stated that its ambition is for carbon emissions from buildings to be 'close to zero' by 2050 (Carbon Trust, 2009) and for new non-domestic buildings to be 'zero carbon' by 2019 (Department of Communities and Local Government, 2008). That challenge has largely been left to the market to achieve through the adoption of voluntary building certification systems and best practice programmes.

There are a number of voluntary sustainable building award schemes that encourage developers and users to go beyond current building and energy standards as well as incorporating a wider socio-economic life-cycle perspective. Some of the main building benchmarking schemes are:

- BREEAM (Building Research Establishment Environmental Assessment Method), established in the UK in 1990, encompasses all forms of public and commercial properties. It sets the standard for best practice in sustainable design and has an award banded from pass to outstanding (www.bream.org).
- LEED (Leadership in Energy and Environment Design) was established by the US Green Building Council in the United States in 1998. The voluntary audit, for domestic and commercial (new and refurbished) developments, grades buildings from certified to platinum (www.usgbc.org).

- GREENSTAR is a voluntary environmental rating system based in Australia. Established in 2003, it has a six-star rating system (www.gbca.org.au).
- CASBEE (Comprehensive Assessment System for Building Environmental Efficiency), inaugurated in 2004 by Japan Sustainable Building Consortium, has five grade bands from C to S (www.ibec.or.jp/CASBEE).
- DGNB (German Sustainable Building Council) is based in Germany and is used to assess buildings and urban developments. It has bronze, silver and gold awards (www.dgnb-system.de).

These schemes all seek to capture elements that not only encompass the resources used in terms of direct energy, water and land, but also the indirect energy embedded in the construction materials, the amount of recycled materials and the construction process itself. Wider social, ecological and environmental aspects are also included, with reference to the quality of the working environment, transportation planning and management of the surrounding ecology. Within this broad approach there are considerable differences between organizational standards in respect to assessment weighting, the method of assessment, input standards of performance, the means of accreditation and the final output measures, as can be seen by the comparison of weighting factors in the BREEAM and LEED schemes in Table 9.4. This undoubtedly creates substantial issues when undertaking any form of comparison between buildings across the world (Holmes and Hudson, 2002) in that each is highly adapted to local conditions, which means that 'none of these systems, including BREEAM, travel well' (Saunders, 2008). Even within one country there may be substantial differences in how the schemes need to be applied. For example, a study by Kneifel (2011) indicated that the energy reduction potential for 'low energy' office buildings was greater in the southern states of the United States, as features such as overhangs and daylighting can easily be applied.

Within the BREEAM scheme, the overall score for a building is translated into a rating designated as: pass, good, very good, excellent or outstanding. Similarly, for the LEED scheme the following ratings are used: certified, silver, gold or platinum. The highest ratings are intended to be used sparingly for sites showing real innovation with, for example, the 'outstanding' BREEAM rating being applied to less than 1 per cent of new builds and the LEED 'platinum' rating applying to about 3 per cent of new warehouses (BRE Global, 2012; US Green Building Council, 2013).

The various voluntary schemes have provided a catalyst for change in the market. A number of international commercial property groups have developed both speculative and bespoke buildings to recognized sustainable building standards. For example, Prologis have committed to registering all new developments with the intent of obtaining certification with internationally recognized sustainable building standards (Prologis, 2013). At the end of 2012, Prologis had 3.6 million m^2 of warehousing certified with green building rating schemes worldwide (Prologis, 2013). It should be recognized

TABLE 9.4 Comparison of weighting factors in the BREEAM and LEED accreditation schemes

BREEAM		**LEED**	
Energy Pollution	19% 10%	Energy and atmosphere	33%
Health and well-being	15%	Indoor environmental quality	16%
Materials	12.5%	Material and resources	13%
Management	12%	Integrative process	1%
Land use and ecology	10%	Sustainable sites	10%
Transport	8%	Location and transport	16%
Waste	7.5%	('Construction and demolition waste management': 2%, included in 'Material and resources' category)	–
Water	6%	Water efficiency	11%
Total	100%	Total	100%
Innovation	10% (additional to 100%)	Innovation and regional priority	10% (additional to 100%)

SOURCE: BRE Global (2012) and US Green Building Council (2013)

that while this is a small percentage of Prologis's worldwide property holding of 51.5 million m^2, it does represent a significant percentage of its current build programme. Adopting these higher standards offers developers benefits of shorter vacancy periods from construction to occupancy, and higher rental yields by providing long-term lower energy and operator costs for tenants and compliance with wider corporate social responsibility objectives (RICS Green Value Report, 2005, cited in KingSturge, 2007). However, despite these advantages the perception of 67 per cent of smaller UK developers in 2005 remained that they would not go beyond the current minimum regulatory requirements owing to concerns over their long-term rentals not offsetting higher capital costs (RICS Green Value Report, 2005, cited in KingSturge, 2007). This mismatch between industry stakeholders remains a major structural barrier to achieving substantial environmental improvement (Hesse, 2004; Altes, 2008). Although a BNP Paribas (2010) survey indicated that 69 per cent of respondents would be prepared to pay a rental premium for sustainable initiatives that saved operational costs, the authors of that survey recognized that this sentiment is yet to translate into actual deals and rents achieved. This view is supported by research showing that there is still little evidence of the expected link between energy ratings and market rent or market value (Fuerst and McAllister, 2011).

In the past decade, through initiatives such as Gazeley's 'eco templates' or Prologis's 'low-carbon' warehouse, a number of exemplar developments have been built around the world to some of the highest certification standards. These buildings, by taking a holistic approach, have shown that the dilemmas of capital costs, emission levels, energy cost and environmental improvement can be commercially reconciled.

The first BREEAM 'outstanding' rating was given to a speculative development by Gazeley at Chatterley Park, Newcastle-under-Lyme, UK, completed in 2009. This facility is now occupied by JCB as their central receiving hub for supplier-bought components used in the manufacture of JCB machines (Gazeley, 2013). The 34,000 m^2 building achieves airtightness rates 25 per cent above current standards to minimize heat loss. Air circulation and ambient heat levels are enhanced by the use of under-floor heating ducts built into the floor slab, with south-facing walls incorporating solar-absorbing wall panels. Power for light and heat is provided by a biomass CHP power plant that can provide power to a further 650 private homes nearby. Energy needs are further reduced by using 15 per cent rooflights, rather than the standard 10 per cent, with the use of solar cell ETFE rooflight panels to generate energy and reduce night light pollution. Kinetic plates incorporated into the gatehouse area recover and convert energy from vehicles arriving at and departing from the site. An innovative roof design recovers and manages rainwater for use within the warehouse as well as the overall site. Additional site access, landscaping and extensive planting have been incorporated to meet both site commercial and recreational use (Gazeley, 2008).

A recent LEED 'platinum'-rated building is the Nike Logistics Centre in Shanghai, China. This comprises two adjacent warehouses, totalling 300,000 m^2. This was awarded maximum points for water efficiency, with features such as a low-water-consumption vacuum sewage system, minimization of impervious areas, and three large ponds to hold storm water run-off (for fire-fighting, irrigation of natural plants, prevention of soil erosion, etc). Other features include ground source heat pumps, solar hot water, high-efficiency lights, sleep-mode conveyor systems and the use of Forest Stewardship Council (FSC) certified wood and local materials. An older Nike facility of note is the European Distribution Centre at Laakdal in Belgium. This is also a very large warehouse covering an area of about 260,000 m^2. As well as natural air conditioning by underground cooling tubes, this warehouse features six industrial-scale wind turbines (providing a total of 9 MW) and over

4,000 solar panels, sufficient to provide its annual power needs. In addition, it is located next to a trimodal container terminal and is thus able to receive its inbound containers via barge along the Albert Canal from the major ports of Antwerp and Rotterdam (US Green Building Council, 2014; The Climate Group, 2007; Invest in Flanders, 2011).

An example of a DGNB 'gold' award warehouse is a high-bay AS/RS facility for Alnatura at Lorsch, Germany (see Figure 9.6). This automated distribution centre for organic foodstuffs is 9,000 m^2 in area and 17.5 m high. The most unusual feature is that the structure and cladding are made of wood, spruce and larch respectively, from sustainable sources certified by the Programme for the Endorsement of Forest Certification (PEFC). The building is sunk 2.5 m into the ground. The good insulation and ground temperature effect enables the building to operate without any heating or artificial refrigeration. Photovoltaic panels are installed in the roof for power generation (DGNB, 2014; SHD, 2013b; Swisslog, 2013).

FIGURE 9.6 Alnatura distribution centre in Lorsch, Germany (under construction)

SOURCE: Swisslog

Another example of a design to reduce embodied energy (ie the energy used in the production of building materials such as concrete and steel) is that of Adnams warehouse at Southwold, UK, which received the BREEAM 'excellent' rating (see Figure 9.7). This warehouse uses lime and hemp (which is a natural substance storing carbon) in its walls as well as glulam beams from sustainable forest sources in its roof supports (Lane, 2006).

It also has a soil-covered roof, on which the plant *sedum* is grown, and this helps to maintain a constant natural temperature for the storage of wines and beers. This type of roof not only provides thermal insulation but also results in cooling benefits from evapotranspiration and the metabolic processes of the plants (Martens, Bass and Saiz Alcazar, 2008). The environmental benefits of using lime and hemp walls have been demonstrated by Ip and Miller (2012).

FIGURE 9.7 Adnams distribution centre in Southwold, UK

SOURCE: P Baker

These schemes are having an impact on the warehouse property market, particularly for new builds. In fact, the importance of gaining a high accreditation is demonstrated by analyses into how to obtain high ratings at the lowest possible cost (eg Target Zero, 2010). Whilst one can discuss the merits of such an approach (eg whether it demonstrates a company's green credentials to focus on the relative number of points gained per monetary investment in bicycle sheds or good heat insulation), it does highlight the importance of the weights allocated by the accreditation bodies to specific aspects of the overall rating scheme, as these will affect building design.

Within each rating area, there is also a need for whole-life-cycle impacts of the warehouse to be taken fully into account, for example, combining both embodied and operational energy use. A computer simulation study of a conventional 7,807 m^2 distribution centre, located in Sheffield, UK, was undertaken to analyse life-cycle CO_2 emissions (Rai *et al*, 2011). This concluded that embodied energy (primarily in the concrete and steel used) can represent one-third of the carbon emissions over a 25-year operating life. Possible optional materials are concrete manufactured from ground granulated blast-furnace slag and steel with higher recycled content, as well as the possible use of timber cladding and hemcrete walling systems, particularly if the ability of these two materials to store carbon is taken into account. The study also found that energy savings from improved insulation can be offset by the embodied energy within the insulation materials themselves. Conventional rooflights may also lead to higher emissions, principally due to heat loss being more significant than savings in lighting. Such life cycle analyses are still in their infancy for warehouses, but these results demonstrate their importance.

Research undertaken by the Green Building Council suggests that owing to the size of these buildings, their continuous activity levels over extended periods and consequential direct energy needs make a zero-carbon warehouse virtually impossible even with onsite renewable generation. Further, it also highlights that 'the actual energy use of buildings appears higher than those modelled' (UK Green Building Council, 2007). This complements the observation that 'as with the heating benchmarks differences of +/–15 per cent between site specific benchmarks and PI (performance index) should not be regarded as significant' (Carbon Trust, 2002b).

The relative cost of providing energy efficiency measures is likely to be higher in warehouses than most other non-domestic buildings because of the lower construction costs and the limited opportunities for exporting heat produced from onsite renewables (Department of Communities and Local Government, 2008).

Conclusion

So where does this leave our understanding of the environmental impact of warehousing and the means of mitigating those effects? Certainly the change in scale and intensity of activity levels within warehouses has been and continues to be a challenge to achieving sustainability. This challenge extends beyond the operational needs of managing energy and resources such as fuel, and in particular electricity, water and land. Sustainability needs also to encompass wider economic, societal, ecological and environmental aspects. However, there appear to be many easy gains that firms can take and should be taking by controlling and reviewing lighting and heating, and managing ventilation rates and heat loss, as well as the use of LPG for counterbalance or high-frequency chargers for electric battery trucks. This simple business-as-usual strategy can reduce direct energy use and emissions by 50 per cent but by itself will not offset the overall growth in the energy intensity of warehouses. This energy-efficient state should therefore be seen as the baseline from which further points of improvement should be measured rather than justifying any additional accolade.

To move beyond energy efficiency a firm needs to engage with more active steps through switching to green energy sources that are both more local and more sustainable. In many buildings small-scale improvements can be achieved through recovered heat and solar heating. For larger warehouses CHP may appear viable, although in the medium term the use of photovoltaic or small wind units for micro-power generation still remains questionable, as does the use of fuel cells and lithium-ion batteries for forklift trucks. In fact, the production of green energy by major power generators seems both commercially and environmentally a better option. This will need to be a key element in any successful national plan to reduce warehouse GHG emissions (Carbon Trust, 2009). In this second stage towards sustainability, only warehouses that both actively manage all forms of energy use and procure and generate viable green energy should be regarded as achieving low-emission status.

Addressing more significant and deeper changes that encompass the entire site requires more input from regulators. As with other commercial activities, most companies see compliance to regulation as the principal motivation for change, despite the example of positive and short-term paybacks now emerging from leading developers and operators. International building standards such as BREEAM or LEED have been a motivator, but a lack of consistency in approach and measurement makes these methods of accreditation in their current form difficult to use as objective measures towards the goal of sustainability. These systems have helped to close the historical separation in the market between the roles of developers, property managers and operators that has made investment decisions more difficult (Low Carbon Innovation Coordination Group, 2012). There is some evidence that greater awareness is now entering the market, especially for new builds, in an effort to reduce operational costs and emissions rather than just concentrating on short-term rental yields and capital investment. However, the scale of the warehouse property footprint and the relatively long replacement cycle mean that there will be a long time lag in achieving the goal of sustainability within the warehouse sector. BRE (2010) predict that pre-2010 buildings will still form the majority of the non-domestic building stock in 2050 and therefore action is required on existing buildings as well as new ones. There are in-use and refurbishment certifications available from the main accreditation schemes and it is to be hoped that these may help to stimulate the same focus on the environmental impact of existing buildings as they have done with new buildings.

Developments such as those achieving the highest certification standards show that with a holistic approach the term ‘sustainable warehouse’ does have a reality, although the lack of wider agreement on process boundaries or of incorporating building construction with use means that terms such as ‘low carbon’ are ambiguous and of greater use for publicity than as a means of classification.

It is hoped that this chapter has demonstrated the importance of including warehousing in supply chain environmental measurements and has highlighted the complexity of the various factors involved. It is common for many environmental supply chain research studies to either ignore warehousing or to calculate these as a standard figure per square metre of floor area (eg Cholette and Venket, 2009; Harris *et al*, 2011; Mallidis, Dekker and Vlachos, 2012; Zanoni and Zavanella, 2012; Pan, Ballot and Fontane, 2013). In fact, many factors need to be taken into account including the warehouse height, airtightness, insulation properties, extent of rooflights, working hours and days, the annual throughput of goods, and the variety of other influences mentioned in this chapter.

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PART THREE

Operational perspective

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10

Optimizing the routeing of vehicles

RICHARD EGLESE and DANIEL BLACK

Introduction

A large proportion of freight distribution is carried out by road vehicles. Assigning customers to the vehicles, followed by routeing and scheduling them, involves a set of decisions that can have a significant impact on the costs and levels of service provided. The problem of organizing and routeing a fleet in such a way is called the Vehicle Routeing and Scheduling Problem (VRSP). Where the set of customers and their demands change little, then experience can lead to good sets of routes that meet constraints concerning the vehicles, such as their capacities, and service requirements, such as time windows for deliveries at customers, and are close to minimizing the economic costs of the operation. However, when the customer base and demands are changing, then it is often advantageous to make use of a computer to solve the problem. A variety of VRSP software packages are available that will provide routes and schedules. It has been suggested that 'the use of computerized procedures for the distribution process planning produces substantial savings (generally from 5 per cent to 20 per cent) in the global transportation costs' (Toth and Vigo, 2001).

Reduction in costs comes partly from a reduction in unnecessary distance travelled from the use of better routes, which in itself can lead to a reduction in fuel consumption and hence a reduction in greenhouse gas emissions. However, there are additional factors to be taken into account when aiming to reduce the environmental impact of a fleet of vehicles. Not only must each journey be driven in an efficient manner using the most appropriate route, but work items should be ordered in such a way that difficult journeys (for example, into a congested city centre) are scheduled for a time of day when their impact will be minimized.

Reducing commercial vehicle emissions is a key concern on the green logistics agenda. Many companies are looking at this area to help reduce their carbon footprint and improve their green credentials. Walmart are aiming to double their fleet efficiency within 10 years of a 2005 benchmark (Walmart, 2014). In the UK, Tesco intends 'to reduce our distribution emissions per case of goods delivered by 25 per cent by 2020 compared to 2011' (Tesco, 2014) and J Sainsbury report 'we are delivering 34 per cent more volume versus 2005/06 yet emitting 1 per cent less absolute CO_2' (J Sainsbury, 2014).

The aims of this chapter are to define the VRSP in its basic form, introduce some of the sub-problems that arise when considering real-world features of VRSPs and discuss some of the issues relating to reducing emissions when solving VRSPs.

Vehicle routeing problems

The basic Capacitated Vehicle Routeing Problem (CVRP) consists of a set of customer deliveries to be made by a vehicle fleet based at a central depot. The travelling distances between each pair of customers as well as to and from the depot are known, each delivery item is of a known amount and each vehicle has a fixed capacity. The aim of the problem is to minimize the total distance driven by the vehicles while satisfying all of the customer orders. Further problem objectives can also be considered such as minimizing the fleet size or balancing the set of vehicle routes to make them as equal in length as possible.

The problem was first introduced by Danzig and Ramser (1959) and it has received considerable attention since. An overview of the work into the VRSP can be found in books by Golden and Assad (1988), Toth and Vigo (2001) and, more recently, Golden, Reghavan and Wasil (2008). The VRSP is classified as an 'NP-hard' problem which implies that as the problem size increases, the computation time required to find the optimum solution for any known method increases exponentially. Optimum solutions can be found for problems of limited size; however, in order to find an optimum solution, an impractical amount of computation effort can be required to discount all non-optimal routes. In practice, heuristic methods are usually applied. Heuristics are not guaranteed to find the optimum solution; however, a well-designed heuristic will find good quality solutions in a reasonable computation time.

There are many commercial software packages available to provide solutions to real-world VRSPs. Such packages offer significant advantages over any manual method through the use of heuristics. Software vendors are keen to publicize the significant sums of money that such an approach can save. However, most are only concerned with maximizing the economic savings which are usually achieved through minimizing the total travel cost measured from the distance travelled or time taken and minimizing the fleet size. Such improvements will, inevitably, reduce the emissions produced by vehicles; however, none currently aims to minimize the environmental impact directly. *OR/MS Today* regularly publishes surveys of available packages (*OR/MS Today*, 2014).

Problem varieties

The basic CVRP has been introduced in the previous section; however, routeing problems are rarely so straightforward in practice. For example, additional constraints that can have a major impact on the operation include legal requirements on driving and working times and certain customers requiring delivery by particular vehicles (for loading and unloading reasons). This section introduces some more of the problem features which can occur in practice and some of the research into the resulting models.

Time windows

A very common constraint concerns when a delivery can be made. The time window for a delivery is defined by a start and an end time. Depending on the problem considered, the time window may be treated as either a hard or soft constraint. A hard constraint requires that a vehicle must wait until the time window begins before making a delivery or must not arrive until the time window begins. Once the time window ends the delivery cannot be made. A soft constraint allows the delivery to be made outside the time window at a penalty cost. This cost can either be a fixed cost or can be proportional to the earliness or lateness of the delivery. The aim of the problem is then to trade total schedule time with punctuality. Algorithms to find the exact solution to the problem with hard time windows have been developed by Kolen, Kan and Trienekens (1987) and Kallehauge, Larsen and Madsen (2006). Heuristic methods have been used by Bräysy (2002) and more recently by Lau, Sim and Teo (2003) and Fu, Eglese and Li (2008) who consider both hard and soft time windows.

Backhauls

Problems which allow backhauls include customers who require an item be collected and delivered to the depot. This is in addition to the customers expecting deliveries (also referred to as linehauls). It is common that all deliveries are made before backhauls are considered. Approaches giving exact solutions to problems of limited size have been developed, for example Toth and Vigo (1997) or Mingozzi, Giorgi and Baldacci (1999). Heuristic methods have also been applied to the problem, for example Duhamel, Potvin and Rousseau (1997), Brandão (2006) and Tavakkoli-Moghaddam, Saremi and Ziaee (2006).

Pick-up and delivery

In this case each item is picked up from one location and delivered to another (neither of which is the depot). Obviously, each pair (pick-up and delivery) must be assigned to the same vehicle and the pick-up must occur before the delivery. Again, there is a limit on the capacity of the vehicle at any one time. Berbeglia *et al* (2007) review a wide variety of such problems including the Dial-A-Ride Problem (DARP) which concerns itself with the transportation requests of bus passengers (usually the elderly or disabled). The DARP can include restrictions on the time between pick-up and delivery which are more relevant to passenger transport. Cordeau and Laporte (2003) have devised a heuristic approach to the DARP and Wassan *et al* (2008) have tackled the more general pick-up and delivery problem.

A problem which is related to both the VRP with backhauls and the VRP with pick-up and delivery is the problem with simultaneous pick-up and delivery. In this case, items are delivered to a customer from the depot and, as the delivery is made, other items are returned to the depot. Originally introduced by Min (1989) to model the movement of library stock, a heuristic approach has been developed by Montané and Galvão (2006).

Non-homogeneous vehicles

The vehicle fleet is often made up of different types of vehicles with different characteristics and this may be critical when determining vehicle routes. The vehicles used may have different capacities and this may affect how they are used. In addition, some items may only be delivered by certain vehicles, due either to restrictions at the customer location (the Site-Dependent VRP) or the nature of the item (eg heavy or hazardous items). Nag, Golden and Assad (1988) were among the first to consider such restrictions and implement a heuristic which solves the problem by way of a three-stage process assigning vehicles to deliveries before attempting to create vehicle routes. A more recent heuristic approach has been presented by Chao, Golden and Wasil (1999).

Open VRSP

The Open VRSP introduces the idea that routes need not start or end at a depot. This may better reflect the cost structure when distribution is assigned to a third-party logistics provider and the vehicle does not need to return to the depot after the last delivery, but is allowed to go elsewhere to undertake other jobs. Brandão (2004) considers this problem and discusses the subtle differences which occur when not routeing to and from a central location. An exact approach to the Open VRSP can be found in Letchford, Lysgaard and Eglese (2007).

Dynamic VRSP

The Dynamic VRSP allows the rescheduling of customer requests once some new information is known. This is different from the standard approach where all information is known and fixed schedules are generated at the start of the day. This new information can be in the form of new customer requests or information regarding possible travel delays. Scheduling new customer requests is the most common dynamic feature and has been tackled by, among others, Gendreau *et al* (1999) and more recently Ichoua, Gendreau and Potvin (2006). Papastavrou (2006) investigates the problem where there is no initial set of customers at the start of the day and all demands occur dynamically. The heuristics developed take into account traffic density which would in practice allow the consideration of travel delay information. Taniguchi and Shimamoto (2004) consider dynamic routeing to avoid congestion and apply their heuristic to a real-world problem instance with successful results.

Although there have been technical advances in being able to modify routes according to real-time demands and traffic conditions, there are limits to the benefits that can be achieved in practice. For example, if the logistics operation is concerned with distributing specific orders from a central depot to a set of customers, then the decision of which customers can be serviced on which route must be taken initially when the vehicles are loaded and cannot be subsequently changed, even if traffic conditions change in such a way that a different allocation of orders would have produced better routes.

Stochastic VRSP

In Stochastic VRSPs, uncertainties in the demands or travel times are explicitly modelled. A stochastic demand model may be appropriate when the vehicles deliver a resource and the amount required by each customer is not known until the customer is visited. Using an estimate of the demand for each customer, an initial set of routes can be defined. However, should a customer require more of the resource than the vehicle contains, the vehicle will need to return to the depot to get more stock before it can satisfy the customer demand. Each time a delivery is made a decision must be taken on whether to deviate from the planned route either to visit an alternative customer or return to the depot. Approaches to this problem are given in Yang, Mathur and Ballou (2000) and Secomandi (2001).

Travel times may also be treated as uncertain and modelled according to a probability distribution. Fu (2002) considers stochastic travel times for the Dial-A-Ride Problem. A minimum service rate is defined on the maximum time between pick-up and drop-off for each passenger. A heuristic is used to produce a schedule which, on average, will satisfy this service rate. A different approach is taken by Ando and Taniguchi (2006) where a penalty cost is used to try and eliminate probable delays.

Arc routeing problems

The problems discussed so far relate to serving customers located at specific locations on a road network. Arc routeing problems arise when a set of roads is required to be visited to provide a service or treatment. Practical examples of services are postal delivery or refuse collection. Examples of treatments are snow ploughing or winter gritting, when salt or some other substance is spread on the roads to prevent ice forming. Similar constraints may need to be considered as for the VSRP, such as the capacity of the vehicles used and any time constraints on the operation. Practical details need to be clear in the modelling, such as whether a vehicle can deliver the service or treatment to a road by travelling down it once in either direction (as is sometimes the case for refuse collection in suburban streets) or whether the vehicle needs to travel down the road twice, once in each direction (as is usually the case where a road has been divided into a dual carriageway). Algorithms and software have been developed for arc routeing and take advantage of the different structure of the problem to the VRSP counterpart. Overviews can be found in Wøhlk (2008) and Dror (2000).

Transportation of hazardous materials

Research into the routeing of hazardous materials tends to focus on evaluation of the environmental impact of different routes between two locations rather than scheduling routes between several locations. A main area of interest is the risk associated with a route. Erkut and Verter (1998) define risk as a combination of, for each section of the route, the probability of an accident and the population size affected. The different real-world routes generated by several measures of risk from this basic definition are examined. Karkazis and Boffey (1995) consider further issues such as the weather on accident impact. An overview of such risk evaluations is given by List *et al* (1991). Kara and Verter (2004) propose a system whereby a regulator restricts access to sections of the road network based on risk assessments and the haulier subsequently optimizes routeing decisions over the remaining network. Lozano *et al* (2011) provide two case studies in Mexico City and incorporate the impact on the travelling population (a significant factor during rush hour).

Environmental impact

The environmental impact of a fleet will be affected not only by the routes and schedules operated but also by other factors such as the size of the vehicles and the type of fuel used. Practical measures, such as the way the vehicles are driven, can have an impact on emissions. In the UK the Safe and Fuel Efficient Driving (SAFED) programme provides driver training to encourage safe and fuel-efficient driving through a wide range of factors. Issues include aerodynamics and loading, braking technique, the use of gears, cruise control and the determination of optimal speeds. Companies can provide efficiency awards to drivers who achieve targets such as using less fuel. These methods emphasize the importance of the fleet's efficiency to the drivers who will be required to implement the results of any more complex analysis. Such measures have been shown to reduce fuel consumption by between 1.9 and 13.5 per cent (Department for Transport, 2006) in one study and by 4.35 per cent in a before and after study of Greek bus drivers (Zarkadoula, Zoidis and Tritopoulou, 2007).

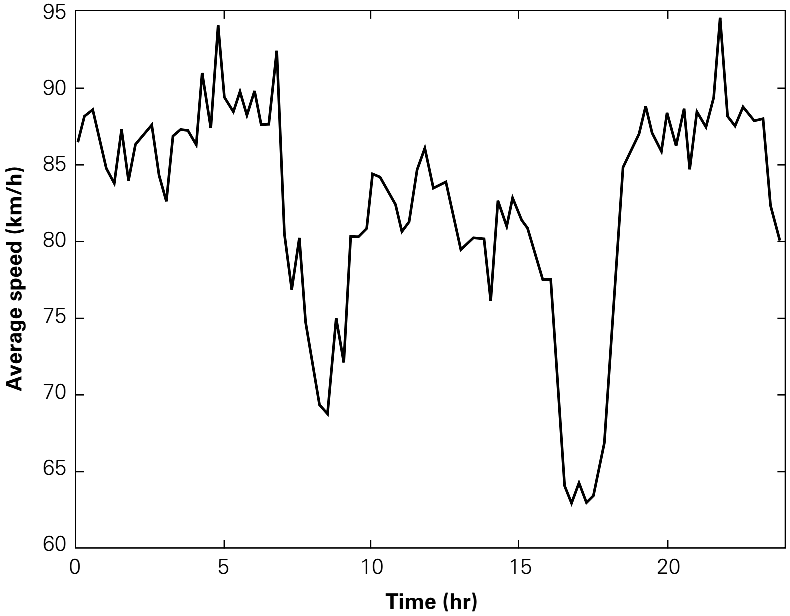
Environmental impact may also be reduced by using vehicles with alternative power sources to conventional petroleum-based fuels. However, such vehicles may have a limited range and limited opportunities to refuel. Erdoğan and Miller-Hooks (2012) formulate a variant of the VRSP where such constraints are taken into account.

Emissions auditing

Emissions auditing is the process of calculating the amount of greenhouse gas or other pollutants released into the atmosphere by a given activity. When estimating vehicle emissions, a variety of factors can be taken into account including load weight and distribution, vehicle age, engine size, vehicle design, driving style, road gradient and speed. Speed is the major factor with reference to vehicle routeing and a route generated while optimizing distance may emit more CO_2 or other polluting gases due to slow speeds than a longer alternative route.

A simple method of estimating emissions from a vehicle is to take the distance of the planned journey and assume an average driving speed or fuel consumption per unit of distance. Such an approach is included in the model of Dessouky, Rahimi and Weidner (2003). However, this assumption implies a linear relationship between such an estimate and the total distance travelled that makes minimizing emissions in such a way equivalent to minimizing distance. A more detailed approach would break each journey down by road type (eg highways, major roads, minor roads, residential streets) and assume an average speed/fuel consumption for each type. Such an approach is already used in many software packages to estimate driving times. However, speed, particularly within city centres, has been shown to vary substantially during the course of the day (Eglese, Maden and Slater, 2006; van Woensel, Creten and Vandaele, 2001). Figure 10.1 shows how the average speed for a particular section of a primary road varies. Any estimate of emissions which fails to take this variation into account will be limited in its accuracy. Furthermore, failure to consider congestion reduces the robustness of computer-generated schedules when implemented in the real world. Palmer (2007) has shown that routes take 10 per cent longer in practice than the estimates provided by computer software. Any environmental gains from the use of vehicle routeing and scheduling software may be lost due to

FIGURE 10.1 The average speed on a primary road in the UK



schedules being infeasible in practice or even ignored by the driver through lack of faith in their predicted timings.

Routeing and emissions

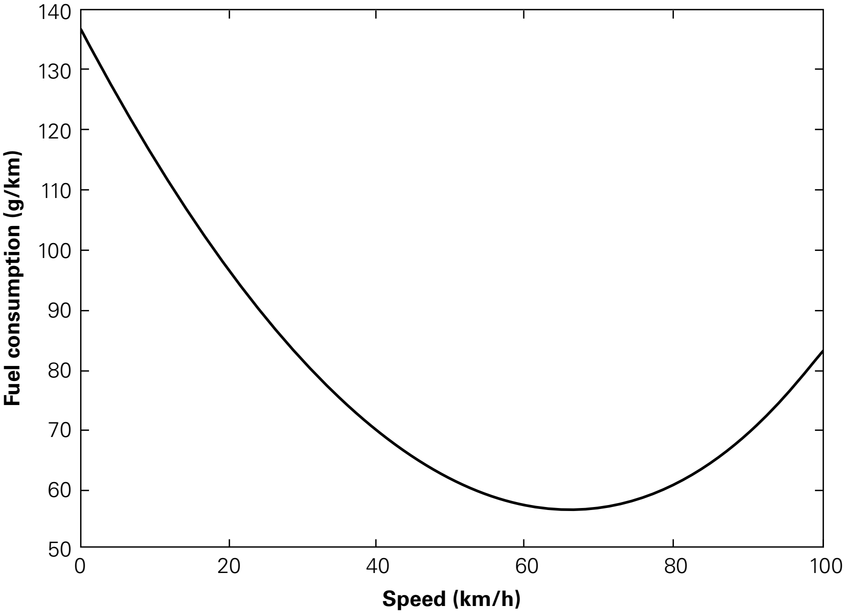
More recent research has extended the estimation of vehicle route emissions by incorporating load weight into calculations (Bektaş and Laporte, 2011; Suzuki, 2011; Xiao *et al*, 2012). Suzuki (2011) uses real-world data to demonstrate potential to reduce emissions by up to 6.9 per cent. Bektaş and Laporte (2011) investigate the relationship between emissions and overall costs (including fuel and labour). Following on from this Demir, Bektaş and Laporte (2012) introduce speed optimization to reduce emissions. In a subsequent paper Demir, Bektaş and Laporte (2014) formulate a bi-objective Pollution-Routeing Problem that performs a trade-off between fuel use and driving time.

Pradenas, Oportus and Parada (2013) consider a vehicle routeing problem with backhauls and demonstrate the advantages of cooperation among transport companies to reduce emissions. Wygonik and Goodchild (2013) evaluate trade-offs between CO_2 emissions, costs and service quality using a model based on a case study in the USA. Their analysis shows a strong positive correlation between CO_2 emissions and cost.

Congestion

It has already been mentioned that the average speed on a road will vary at different times of day. The main cause of this variability is congestion. Congestion prevents a vehicle from driving at an optimum speed and subsequently has a negative impact on total vehicle emissions. McKinnon (2007) identifies exposure to congestion as one of the key freight variables which the UK government needs to manage in order to reduce CO_2 emissions. Figure 10.2 shows the relationship between vehicle speed and fuel consumption (which varies directly in proportion to CO_2 emissions). As speed decreases below the optimal speed, considerably more fuel is used. To make matters worse, congestion forces driving in a stop–start manner which results in increased fuel consumption and emissions as the vehicle accelerates and brakes instead of travelling at a steady speed. This means that estimates of fuel consumption based on vehicle test cycle data may not accurately represent the fuel used in typical driving conditions as discussed in McKinnon and Piecyk (2009).

FIGURE 10.2 The relationship between speed and fuel consumption for a light duty diesel vehicle



SOURCE: Estimates produced using the method of the EMEP/CORINAIR Emission Inventory Guidebook (European Environment Agency, 2007)

Kok, Hans and Schutten (2012) define peak hour congestion within a VRSP model by investigating causal factors such as urbanization and the direction of commuter traffic. Modern technology, particularly with the advent of GPS devices, allows the monitoring of vehicles. Data from vehicles is stored and then transmitted to a central location and analysed. Typically speed and location (accurate to a particular section of road) are recorded; however, modern devices also include information on fuel flow. Hopefully, in the future, information on fuel consumption collected this way will aid emissions auditing. However, in the meantime, data on vehicle speeds have been compiled so that the average speed for a section of road at each time of the day is known. This provides a way of measuring the congestion that occurs on a daily basis.

This data has been used by Eglese, Maden and Slater (2006) and Maden (2006) to find solutions to VRSPs which minimize the total driving time. The aim of this approach is to produce more reliable vehicle schedules, but a potential environmental benefit is the construction of routes that tend to avoid congestion and the emissions produced in slow-moving traffic. Such an approach will also provide more robust schedules which will reduce overtime and improve customer satisfaction through more punctual deliveries and collections. Ehmke, Meisel and Mattfeld (2012) show how data-mining techniques can be used to produce time-dependent travel times from a database of past information on vehicle speeds for use in city logistics applications.

Figliozzi (2011) reports on a case study carried out in the USA showing how patterns of congestion affect CO_2 emission levels. It demonstrates the importance of determining departure times and the location of the depot to reduce emission levels. Jabali, Van Woensel, and de Kok (2012) also formulate the problem using speed as one of the decision variables in periods that are free from congestion.

Conclusions

Modern computer software systems are able to produce efficient sets of vehicle routes for road freight deliveries that produce economic savings and environmental benefits compared with manual planning systems, particularly when the customers and demands vary from day to day. Modern developments in tracking technology are opening up new opportunities to improve vehicle routeing and scheduling further by taking account of expected congestion and also to modify routeing plans dynamically by taking into account current traffic conditions. Baumgaertner, Léonardi and Krusch (2008) describe a qualitative survey of trucking companies and software providers which is used to assess the importance of computerized vehicle routeing systems and other technologies to reduce fuel consumption and CO_2 emissions.

Vehicle routeing and scheduling are only one of many factors that will influence the economic and environmental performance of a distribution system, but good routeing and scheduling have the potential to contribute to reductions in greenhouse gas emissions and other pollutants.

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Opportunities for improving vehicle utilization

11

ALAN McKINNON

Introduction

In most developed countries, road transport is the dominant mode of freight movement. The efficiency of the road freight sector is therefore a major determinant of the overall environmental impact of logistics. If all trucks and vans were fully laden on all trips, this environmental burden could be greatly reduced. The extent of the resulting environmental benefit is difficult to quantify at a national or international level as little official data is collected on the use of vehicle capacity, particularly in terms of floor area and cube.

Raising vehicle load factors is one of the most attractive sustainable distribution measures to companies because it yields substantial economic as well as environmental benefits. Increasing transport costs and the prospect of oil prices rising steeply in the future are giving companies a strong incentive to improve their vehicle loading. Modelling by Rizet *et al* (2012) suggests that doubling the load factor on a 'heavy duty vehicle' from 50 per cent to 100 per cent reduces the fuel consumption per 100 tonne-kms from 2.1 to 1.2 litres. Improved vehicle loading and reduced empty running also cut traffic levels and ease congestion on the road network. Governments have recognized these economic, environmental and infrastructural advantages. In the UK, for example, improving vehicle loading and minimizing empty running were key objectives of the government's first Sustainable Distribution Strategy (DETR, 1999) and reiterated in subsequent sustainable transport policies (DfT, 2008a; DfT, 2013). There have also been several industry-led initiatives to promote 'transport optimization' across particular sectors, such as groceries (IGD 2003, ECR Europe, 2009).

A sample of 100 logistics specialists surveyed in the UK in 2007 predicted that by 2020 the proportion of truck-kms run empty would drop from 27 to 22 per cent and the average (weight-based) load factor increase from 57 to 64 per cent (Piecyk and McKinnon, 2010). This suggested that the potential existed to achieve substantial improvements in vehicle loading and reap the resulting economic and environmental rewards.

In this chapter we begin by examining the different measures that can be used to assess road vehicle utilization. We then review a series of constraints on truck utilization and outline various ways in which they can be relaxed.

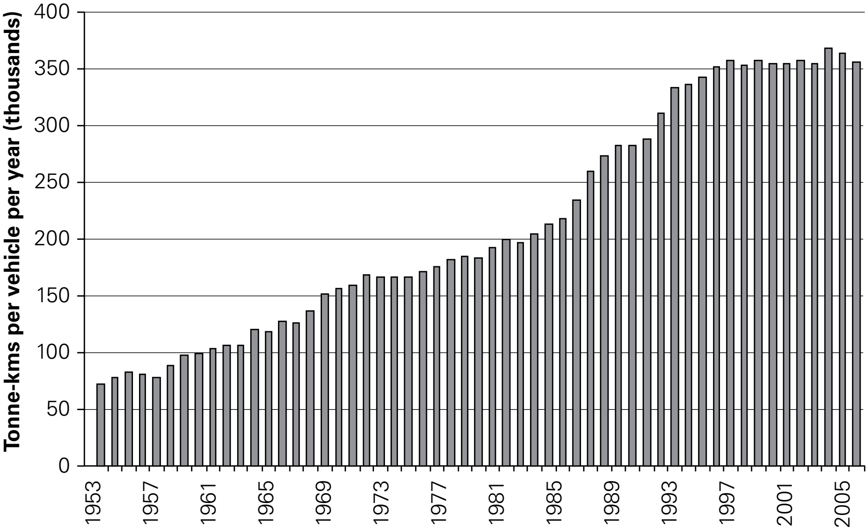
Measuring vehicle utilization

Different indices can be used to calculate the utilization of vehicle fleets, each giving a slightly different impression of transport efficiency. At a macro-level, most of the parameters measure freight in terms of weight rather than volume, reflecting a lack of government data on the cubic volume of freight transported (McKinnon, 2010).

Tonne-kms per vehicle per annum

This indicator is essentially a measure of productivity, and as such, generally presents the trucking industry in a favourable light. Between the early 1950s and late 1990s in the UK there was a fivefold increase in the number of tonne-kms carried annually by the average truck (Figure 11.1), due mainly to increases in maximum truck size and weight and the use of vehicles for

FIGURE 11.1 Improvement in truck productivity in the UK: tonne-kms per truck per annum



SOURCE: Department for Transport

more hours in the day. After 1999 this metric levelled off for the UK truck fleet, despite two increases in the maximum truck weight, and experienced a significant drop during the 2008–9 recession (DfT, 2010). It is a rather poor measure of the sustainability of the road freight sector as it gives no indication of the proportion of vehicle capacity actually utilized or the potential to raise load factors.

Weight-based lading factor

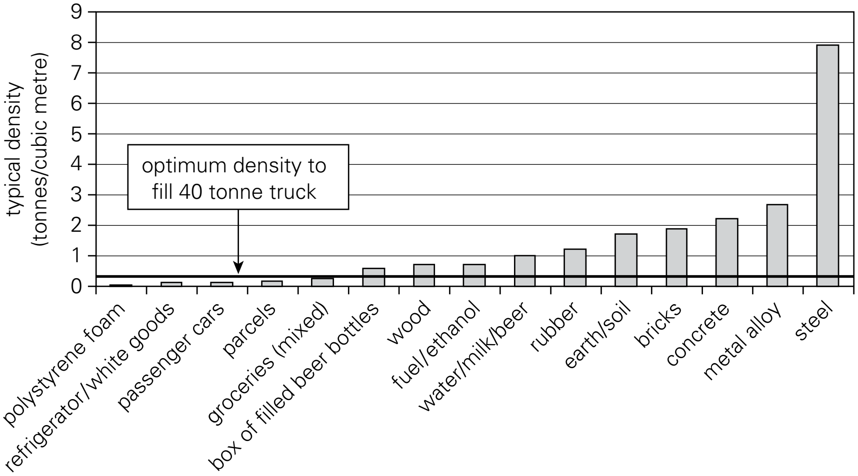
This measure is exclusively weight-based and is generally expressed as the ratio of 'the actual goods moved to the maximum tonne-kilometres achievable if the vehicles, whenever loaded, were loaded to their maximum carrying capacity' (DfT, 2008b). It gives a less favourable impression of capacity utilization in the road freight industry. In the UK, for example, average load factors declined from 66 per cent in 1984 to 56 per cent in 2006 before rebounding to 59 per cent in 2010 (Piecyk and McKinnon, 2014). Some of the reduction since 1999 is attributable to the increase in maximum lorry weight from 38 tonnes in 1999 to 44 tonnes from 2001 onwards. These increases in maximum carrying capacity occur overnight, but it can then take several years for industry to adapt its ordering patterns to exploit this additional capacity. In the meantime, the average percentage load factor can drop. The recent decline in this lading factor may also be partly attributed to a decline in the average density of road freight, due to a switch from heavier materials, such as metal and wood, to lighter plastics, and an increase in the amount of packaging. This increases the proportion of loads that 'cube-out' before they 'weigh-out' and is reflected in a decline in the weight-based measures of vehicle lading. For lower-density products, space-related measures of lading are more appropriate.

Space utilization/vehicle fill

Vehicle fill can be measured in three dimensions by the percentage of space occupied by a load or in two dimensions by the proportion of the floor (or deck) area covered. In the case of unitized loads (of, for example, pallets, roll cages or stillages) the actual number of units carried can be divided by the maximum number to calculate the percentage fill. This should be accompanied by an assessment of the internal loading of the units and the average height of the pallet-loads (Samuelsson and Tilanus, 1997). No governments systematically collect volumetric data for road freight flows, so assessing vehicle fill at an industry or country level is very problematic. The Transport KPI surveys commissioned by the UK government over the period 1997–2009 were exceptional in compiling this data, though conducted in relatively few sectors and on few occasions (McKinnon, 2009). This series of surveys was discontinued in 2010.

Weight-based and volumetric indices give very different impressions of the level of vehicle utilization and partly reflect the density of the product.

FIGURE 11.2 Variations in the average product density



SOURCE: Adapted from Glaeser, 2010

In utilization terms, the ideal product to be transported by a 40-tonne articulated truck with a 13.6-metre-long, 4-metre-high trailer (the typical 'workhorse' of the European road freight industry) would have a density of around 0.3 tonne per cubic metre (McKinnon, 2010). Freight of this density would fill the available space in the trailer and reach the maximum vehicle weight simultaneously. In practice, the actual density of freight varies widely around this benchmark figure (Figure 11.2).

Empty running

Empty running is generally expressed as the proportion of vehicle-kms run empty. It is an inevitable consequence of the uni-directional movement of freight consignments and the difficulty of balancing freight flows in opposite directions. Usually the final leg of a multi-drop journey, or the initial leg in a multiple collection round, is also run empty. Within the EU, the empty running of trucks varies considerably by country, between 44 per cent (Eire) and 15 per cent (Denmark) and averaged around 24 per cent in 2010 (De Angelis, 2011). The level of empty running tends to be inversely proportional to the length of haul, because the longer the journey the greater the economic incentive to find a backload.

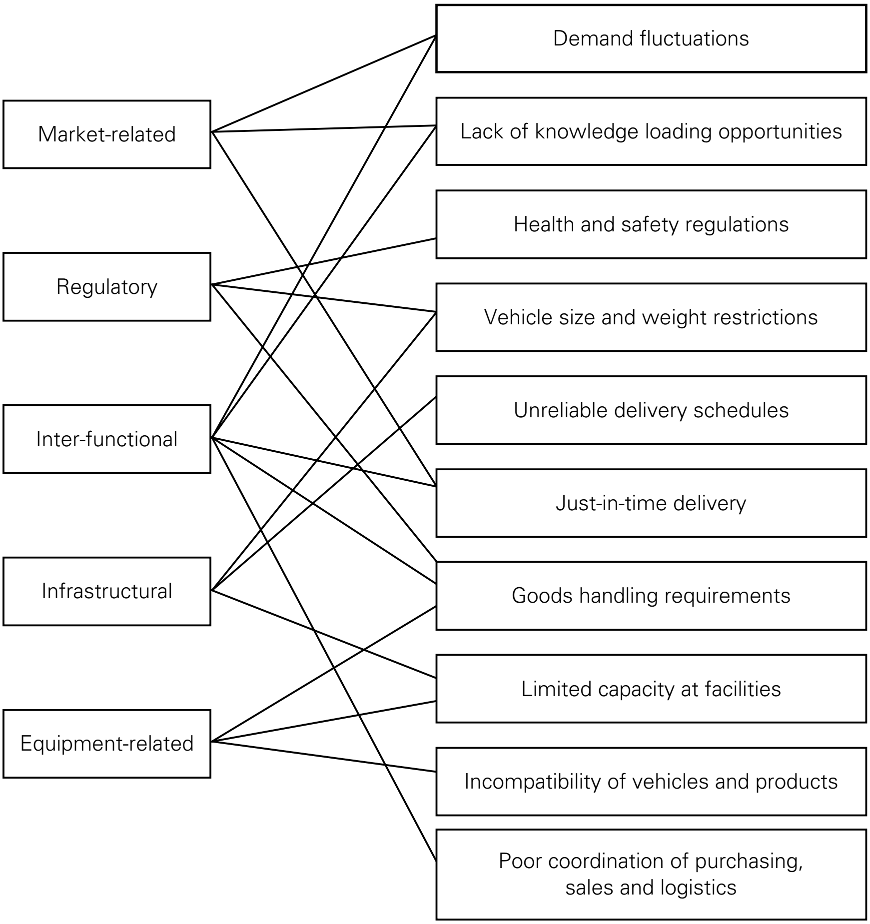
Empty journeys are not only wasteful economically, but also carry an environmental penalty. Between the early 1970s and 2004 the proportion of empty running by trucks in the UK steadily declined, yielding significant economic and environmental benefits. McKinnon and Ge (2004) estimated that, 'other things being equal, if the percentage of empty running had remained at its 1973 level, road haulage costs in 2003 would have been

£1.3 billion higher and an extra 1.1 million of tonnes of CO_2 would have been emitted into the atmosphere by trucks'. Since 2004 this beneficial trend has gone into reverse, raising the level of empty running to 29 per cent in 2010, the last year for which statistics are currently available (DfT, 2012).

Factors affecting the utilization of truck capacity

Companies do not wilfully under-load their vehicles. Nor is poor loading very often a result of careless management. There are many good reasons for trucks travelling around empty or only partly full. Figure 11.3 identifies the

FIGURE 11.3 Fivefold classification of the constraints on vehicle utilization



main constraints on vehicle loading and classifies them into five categories (McKinnon, 2007):

- market-related constraints associated with the spatial pattern of trade and fluctuations in the volume of freight flow;
- regulatory constraints governing the size and weight of vehicles, the timing of deliveries and health and safety aspects of vehicle loading/unloading;
- inter-functional constraints imposed on transport management by other departments within the business;
- infrastructural constraints related to the physical capacity of transport networks and storage capacity at both ends of a freight movement;
- equipment-related constraints resulting from the incompatibility of vehicles, handling equipment and loads.

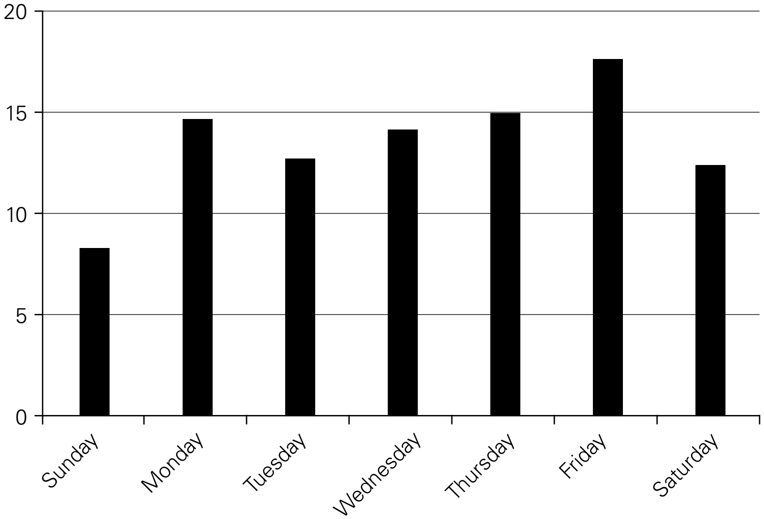
We will now examine some of the more important constraints in greater detail and consider what, if anything, companies can do to ease them. This review reveals that in under-loading their vehicles companies are sometimes making perfectly rational trade-offs between transport efficiency and other corporate goals, such as minimizing inventory, optimizing the use of warehouse space or maximizing staff productivity at the loading bay. As a result total logistics costs may be minimized. When environmental costs are factored into the calculation, however, the trade-offs usually have to be rebalanced to give greater priority to vehicle utilization.

Demand fluctuations

Sales volumes can vary widely over daily, weekly, monthly and seasonal cycles. Figure 11.4, for example, illustrates the average daily flow of groceries in the UK food supply chain. Vehicle capacity is often planned to accommodate peak demand, inevitably leaving the fleet with surplus capacity at other times. Companies subject to pronounced, and quite predictable, seasonal fluctuations can hire additional vehicles or outsource more of their transport at peak periods. It is more difficult to adopt this strategy where there are wide and unpredictable variations in transport demand from day to day.

If transport managers and carriers can be given more advanced warning of future demand they can plan the use of vehicle capacity much more effectively. One of the key objectives of collaborative transportation management (CTM) is to involve managers responsible for the transport operation at an earlier stage in the logistics process (Browning and White, 2000). By creating an ‘extended planning horizon’ some carriers have been able to increase the utilization of their regional truck fleets in the United States by between 10 and 42 per cent, mainly as a result of improved backloading (Esper and Williams, 2003).

FIGURE 11.4 Daily demand fluctuations in the food sector: percentage by volume



SOURCE: Department for Transport (2007)

The Nominated Day Delivery System (NDDS) helps firms achieve much higher levels of transport efficiency by getting customers to adhere to an ordering and delivery timetable. They are informed that a vehicle will be visiting their area on a 'nominated' day, and that to receive a delivery on that day they must submit their order a certain period in advance. By concentrating deliveries in particular zones on particular days of the week, suppliers can achieve higher levels of load consolidation, drop density and vehicle utilization. This practice is, however, resisted by some sales managers on the grounds that it impairs the standard of customer service and can weaken the company's competitive position.

Some demand fluctuations are artificially induced by standard business practices. Promotional activity, for example, destabilizes the flow of goods, making it more difficult to manage transport capacity at a uniformly high level. The normal practice of paying bills at the end of the calendar month and giving sales staff monthly targets also causes freight volumes to peak at the start of the month. Vehicle capacity provided to meet this peak is often under-used later in the month. Relaxing the monthly payment cycle and moving to a system of 'rolling credit', in which customers are still given the same length of time to pay but from the date of the order rather than the start of a calendar month, can significantly improve vehicle utilization. It has been suggested, for example, that this could significantly cut supply chain costs and environmental impacts in the European chemical industry (McKinnon, 2004).

Lack of knowledge of loading opportunities

If transport operators had perfect knowledge of all the loads available for delivery in all locations at all times they would be able to attain much higher levels of vehicle loading on both outbound and return journeys. Many load-matching opportunities are missed because of a lack of communication between potential carriers and shippers (ie the users of the transport service).

Traditionally it has been the role of intermediaries in the freight market, such as freight forwarders and brokers, to act as clearing houses for information about available loads and vehicles. They relied on market knowledge, personal networking and the telephone to arrange deals between shippers and carriers. With the advent of the internet, a new generation of freight exchanges emerged, providing web-enabled tendering, online auctions and bulletin boards for road haulage services (Sarkis, Meade and Talluri, 2000; Lewis, 2001). Several attempts have been made to classify online freight procurement platforms and to assess their capabilities, potential benefits and technical challenges (Caplice, 2007; van de Klundert and Otten, 2011). Wang *et al* (2011) explain how the internet can be used to create 'electronic logistics marketplaces' (ELMs) within which groups of companies can collaborate in ways that might reduce environmental impacts. They acknowledged, however, that the environmental benefits had 'yet to be empirically tested in depth' (p 164) One online freight exchange estimated that companies using its procurement services have been able to cut their transport costs by 8 per cent by increasing 'carrier's asset utilization while protecting their margins' (Mansell, 2006: 27). This transport cost saving is likely to be associated with a reduction in externalities. The impact of e-commerce on the freight and logistics sector is discussed more fully in Chapter 15.

Geographical imbalances in traffic flow

Unlike passengers, who normally make return journeys, almost all freight moves in one direction. The quantities of freight moved between pairs of countries and regions are seldom balanced. Even if there is parity in the level of trade in monetary terms, the physical amounts of freight moved in opposite directions can be quite different. It was estimated that, in 2003, 130,000 lorries travelled empty between Scotland and England, reflecting a ratio of 1:1.31 in the tonnage of freight moved by road between the two countries.

The main way in which carriers deal with such traffic imbalances is by adopting a practice called 'triangulation'. Instead of running vehicles on A–B–A bilateral routes, they send them on more complex inter-regional trips (eg A–B–C–A), which can allow them to exploit traffic imbalances in opposite directions along the route and thus raise the average load factor across the journey as a whole.

Just-in-time (JIT) delivery

The goal of JIT is to achieve a continuous flow of materials through the supply chain in an effort to keep inventory to a minimum. The synchronization of transport with the production process and time-criticality of JIT deliveries often result in supplies being delivered at short notice and in small quantities. Under these circumstances, efficient utilization of transport capacity can be sacrificed for lower inventory and more flexible production. Arvidsson *et al* (2013) note that most of the published research on this subject is qualitative and argue that more studies are required to quantify the impact of JIT on transport efficiency. As low-inventory policies and JIT delivery are now the norm across many industrial sectors, it is hardly surprising that JIT receives much of the blame for the under-utilization of trucks and consequent growth in freight traffic. As discussed in Chapter 1, it is generally portrayed as being bad for the environment.

The adverse effects of JIT on transport efficiency can, however, be eased by rationalizing the inbound logistics system. For example, some car manufacturers, such as Nissan (DETR, 1998a), employed logistics service providers to collect components from suppliers and consolidate them at a hub prior to JIT delivery directly to the production line. The clustering of suppliers' plants, vendor hubs and warehouses around car and computer assembly plants has also minimized JIT delivery distances. In the retail sector, the equivalent 'quick response' pressures have resulted in the insertion of an additional 'primary consolidation' tier between the factory and the distribution centre where different manufacturers' products are aggregated into viably-sized loads. The use of advanced routeing and scheduling algorithms can also help to minimize any additional economic and environmental costs resulting from the application of JIT to retail deliveries in urban areas (Bhusiri *et al*, 2014).

Lack of inter-functional coordination

Poor truck utilization can be a consequence of the departmental 'silo' structure in many businesses, which inhibits communication and coordination between functions. Lack of liaison between purchasing and logistics staff often results in potential opportunities for backloading being missed, while sales staff can make commitments to customers that entail the delivery of goods in poorly loaded vehicles. This problem can be alleviated by the application of good business practice, involving the replacement of silos with more effective cross-functional management of core processes, one of which is the fulfilment of customer orders (Christopher, 2010).

Priority given to the outbound deliveries

Companies naturally give priority to distribution of their products to customers and are reluctant to backload a vehicle when they fear that it may not return in time for reloading with the next outbound consignment. This fear has been identified as one of the main constraints on backloading, particularly where delivery schedules are unreliable (McKinnon and Ge, 2006). The main way of addressing this concern is to improve the reliability and 'visibility' of road freight operations so as to give managers greater confidence in distribution schedules. The extent of logistical unreliability is discussed below.

Lack of cooperation across the supply chain

There is a limit to how much any individual company can do on its own to improve the utilization of vehicles carrying its products. The decisions of companies upstream and downstream in the supply chain can limit the opportunity to improve load factors and cut truck-kms. If supply chain partners are prepared to collaborate, much higher levels of utilization can be achieved. A distinction can be made between horizontal collaboration, where companies at the same level of the supply chain work together, and vertical collaboration, which involves collective action by trading partners at different levels in a supply chain. In both cases, logistics service providers can play a key role.

Horizontal collaboration

This form of collaboration has been defined as follows by an EU research project on the subject called CO3:

> Horizontal collaboration requires that multiple independent shippers proactively work together in clusters or communities to 'bundle' their overlapping freight flows. Bundling in this context means that the compatible freight flows of the shippers are consolidated in space, as well as synchronized in time.
>
> Source: http://www.co3-project.eu/innovation/

Cross-company/industry collaborations can take various forms. In the petroleum sector, for example, swap agreements between oil companies allow refineries to supply all the filling stations in a local area regardless of brand, maximizing drop density and minimizing empty backhaul distances.

In the fast-moving consumer goods (FMCG) sector there are examples of firms merging their logistics operations at a shared distribution facility and combining vehicle loads. This is well exemplified by the consolidation of Unilever and Kimberly-Clark products for the Dutch retail market at a distribution centre operated for them by Kuehne and Nagel in Raamsdonksveer (Cruijssen, 2007). The two companies make 80 per cent of all their deliveries in the Netherlands through this 'shared supply chain' (Cooke, 2011), As a result of this collaboration the companies have been able to cut their logistics costs by 12–15 per cent while responding to retailers' demands for faster and more frequent delivery. In the UK, Nestlé and United Biscuits, competitors in the biscuit and confectionery markets, have worked together to cut empty running of trucks between Yorkshire and the Midlands (Clements, 2008). This is part of a wider food industry initiative involving '37 of the UK's leading food and consumer goods companies' that has 'removed the equivalent of 53 million journey miles from UK roads' (IGD, 2008a). Computer modelling has also been used to assess the possible CO_2 savings from pooling the road transport operations of two French retail chains (Pan *et al*, 2010). These savings were estimated to be around 14 per cent.

Horizontal collaboration between shippers goes beyond the standard groupage service that carriers have been providing for generations. This usually requires companies to modify their operations to exploit logistical synergies and thereby cut costs and emissions. It is well illustrated by a recent collaboration between Nestlé and Pepsico in Benelux, supported by the EU CO3 project and involving the logistics provider, STEF. The carbon intensity of these companies' combined distribution operation (expressed as gCO_2 per tonne of product delivered) was 26 per cent lower with horizontal collaboration than with a standard groupage service (Jacob *et al*, 2014).

Vertical collaboration

Vertical collaboration involves companies at different levels in a supply chain coordinating their logistics to cut costs and/or environmental impacts. There are several different types of vertical collaboration. It often takes the form of a backloading initiative. For example, it is now common practice in the retail grocery sector for trucks returning from supermarkets to make a triangular trip to pick up orders from suppliers and transport them to the distribution centre. This form of 'supplier collection' substantially reduces empty mileage (DfT, 2005a). For example, in 2007 the UK supermarket chain Tesco used returning store delivery vehicles to collect 55,432 'supplier backloads', eliminating 4.2 million vehicle-kms and saving around 3,590 tonnes of CO_2 (DfT, 2010) A variant of this scheme, known as 'onward delivery', involves suppliers' vehicles delivering to the retailer's shops on their way back from the distribution centre to the factory.

Where trading partners in the vertical channel adopt a vendor-managed inventory (VMI) strategy, the supplier assumes control of the replenishment process and can then phase the movement of products in a way that optimizes the use of vehicle capacity. Disney, Potter and Gardner (2003) used simulation modelling to demonstrate the potential transport benefits of VMI over a 'traditional supply chain'. Although VMI can result in more inventory being held at the customer's premises, they would typically only be charged for supplies as they are actually used (or 'called off').

Vertical collaboration in the field of reverse logistics can maximize the return flow of waste, damaged and unwanted products on backhauls. This offers considerable potential for reducing empty running and rationalizing the reverse flow of returned products from shops (Cranfield University, Sheffield Hallam University and CILT, 2004). Reverse logistics is the main focus of Chapter 16.

Unreliability in logistics schedules

To plan backhauls and the more complex routes that are often required to maximize vehicle loading, managers must have confidence in the scheduling. Fortunately, much traffic congestion is regular and predictable, allowing companies to accommodate related delays by building some slack into their supply chain operations (McKinnon *et al*, 2009). More problematic are the unforeseen, random traffic incidents, such as major accidents and road works, which can significantly increase transit time variability. It has been estimated that in the UK around 24 per cent of freight deliveries are delayed, and approximately 34 per cent of these delays are attributable mainly to traffic congestion (McKinnon, 2009). Deviations from schedule are also due to a range of other factors, including backdoor congestion at distribution centres, vehicle breakdowns and staff absenteeism.

Advances in IT and telematics now permit the tracking of trucks, providing advance warning of delays and allowing fleet managers to re-plan routes in real time while the vehicle is on the road to minimize the impact of congestion. The rescheduling of deliveries into the evening and night can also reduce transit time variability (Holguín-Veras *et al*, 2014). For delays originating in factories, warehouses and shops, some re-engineering of internal processes is often required and, in the case of backdoor congestion, the provision of additional capacity. Increasing the ratio of tractors to trailers in an articulated vehicle fleet (ie the 'articulation ratio') can decouple the transport operation from the loading/unloading activity, reducing the risk of inbound delays constraining the outbound load factor.

Design of packaging and handling equipment

The nature of the packaging influences the efficiency with which space is used in buildings and vehicles across the supply chain. Its shape, dimensions and stackability can result in poor use of vehicle capacity. In their choice of handling equipment companies often trade off lower vehicle cube utilization for faster and easier loading and off-loading of consignments.

Handling equipment can be modified to permit convenient handling as well as efficient use of transport and storage capacity. A French food manufacturer, for example, was able to improve vehicle fill by 35–41 per cent by packing orders into modules of varying heights (University of St Gallen, 2000). The total amount of packaging on products can also be reduced, often without increasing damage levels across the supply chain. The so-called 'right-sizing' of packaging improves the efficiency with which space is used right across the supply chain, including inside vehicles and containers. For example, by altering the packaging of its tea candles, IKEA was able to carry 30 per cent more product on each load unit and cut the annual number of containers required to move this item by 400 (Steffanson, 2008).

Incompatibility of vehicles and products

Some vehicles are limited to carrying only certain commodities, restricting the types of load they can collect on a backhaul. It is not possible, for example, to carry palletized loads on a tanker, or refrigerated goods in a trailer without temperature control. This constrains the matching of loads with available vehicle capacity on particular routes.

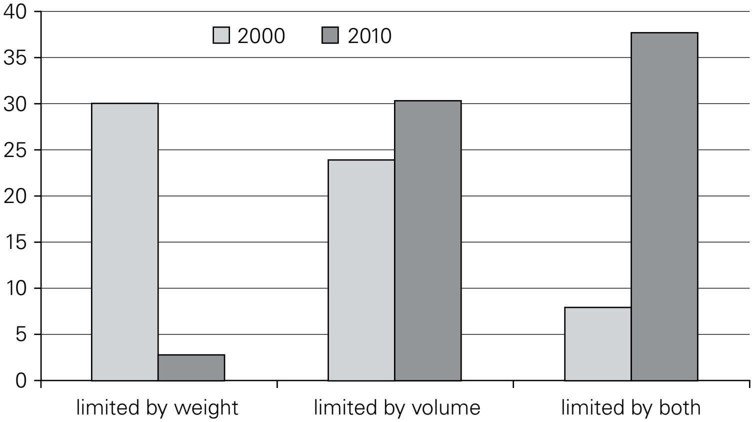
It has been possible to redesign vehicles to accommodate a wider mix of products, often on the same journey. The compartmentalization of trucks has enabled grocery retailers and their contractors to combine the movement of products at different temperatures on a single journey. This so-called 'composite distribution' has also involved channelling ambient, chilled and frozen products through the same distribution centres (Fernie *et al*, 2010). By 2007, just over half of the 11,000 trailers operated by nine of the UK's largest food retailers were 'multi-temperature' (IGD, 2008b).

Vehicle size and weight restrictions

As discussed above, many loads 'weigh-out' before all the vehicle space is filled or 'cube-out' before the vehicle reaches its maximum gross weight. Legal restrictions on vehicle weights and dimensions, therefore, result in either weight- or volume-carrying capacity being under-utilized (McKinnon, 2005). As weight limits have been raised by a greater margin than size limits in recent decades, over a period when the average density of freight has been declining, a higher proportion of loads are now volume-constrained than weight-constrained. This is clearly illustrated in the UK, where the proportion of truck loads subject to a volume constraint increased from 38 per cent to 68 per cent between 2000 and 2010 (DfT, 2012) (Figure 11.5).

Increasing the maximum size of trucks can allow companies to consolidate loads, achieving greater vehicle fill and thereby cutting truck-kms and related externalities. It is possible to gain extra cubic capacity vertically or horizontally. In some countries, most notably the UK where bridge and tunnel clearances over the road network are relatively high (mainly to accommodate double-deck buses), it is possible to increase vehicle height and insert a double-deck to permit the carriage of two layers of pallets. Britain actually has no legal limit on vehicle height, although, because of infrastructural constraints, five metres is generally considered the maximum. The floor of the vehicle can also be lowered by using smaller wheels to carry higher loads. Companies carrying low-density products have the most to gain from the use of double-decks, and for this reason they are now extensively used by major retailers and parcel carriers in the UK. One large UK retailer has demonstrated the benefits of double-decking by comparing operating parameters for deliveries using a double-deck vehicle and two single-deck vehicles with similar capacity. Unit delivery costs, vehicle-kms and CO_2 emissions were all around 48 per cent lower (DfT, 2005b).

FIGURE 11.5 Percentage of UK road freight movement (in tonne-kms) constrained by vehicle weight and/or volume restrictions



SOURCE: DfT, 2012

Across much of the European mainland a 4-metre height limit applies, tightly restricting, but not eliminating, opportunities for double-decking. In other European countries, such as Sweden, Finland, the Netherlands and Denmark, companies have gained extra cube 'horizontally' by lengthening the vehicle. These countries have taken advantage of the provision in EU Council Directive 96/53/EC for member states to increase to 25.25 metres the maximum length of trucks undertaking distribution within their national border. Often this increase in length and axle numbers has been accompanied by a relaxation of the maximum weight limit to 50 or 60 tonnes. Finland has recently increased the maximum weight of its longer class of vehicles to 74 tonnes.

Studies of the environmental and economic impact of longer and heavier vehicles (LHVs) have been conducted in many countries, including the US (Transportation Research Board, 2002), the Netherlands (Aarts and Honer, 2010), Belgium (Debauche and Decock, 2007), Sweden (Vierth *et al*, 2008), the UK (Knight *et al*, 2008), at an EU level (Transport and Mobility Leuven *et al*, 2008; Christidis and Leduc, 2009) and across OECD countries (OECD / International Transport Forum, 2010). The European Parliament has also commissioned a review of earlier European research on this subject (Steer Davies Gleave, 2013). Most of these studies and long experience of LHV use in countries such as Sweden, Canada and Australia confirm that relaxing truck size and weight limits yields a combination of environmental, economic and safety benefits.

Rail freight organizations (eg UIC *et al*, 2007) and some environmental groups (eg European Federation of Transport and the Environment, 2007) are, nevertheless, vehemently opposed to the legalization of what they call 'mega-trucks', mainly on the grounds that they are likely to erode freight traffic from rail and generate more freight movement overall. Some studies have claimed that the environmental disbenefits associated with these secondary impacts more than offset the environmental gains from load consolidation in bigger and heavier trucks (eg Doll *et al*, 2009). They tend, however, to be in the minority and based more on theoretical simulations than on the observed experience with LHVs in countries where they have been operating for many years. For a fuller discussion of this issue, see McKinnon (2011).

Health and safety regulations

These regulations constrain the height to which loads can be stacked on a vehicle to minimize the risk of operatives being injured. The double-decking of vehicles can help to relax this constraint without compromising safety, though only where vehicle height clearances permit.

Capacity constraints at company premises

The size of an order is often constrained by the amount of storage capacity available at the delivery point. In some sectors, this storage capacity has been shrinking, partly in line with the downward pressure on inventory but also to intensify the use of floor space. Retailers, for example, have been compressing back-storeroom areas in their shops to maximize the floor area available for product display and merchandizing. Where deliveries are to warehouses, the dimensions of slots in the racking systems can dictate the maximum pallet height. Under these circumstances, the size and shape of unitized loads may optimize space utilization in the warehouse but not in the delivery vehicle (AT Kearney, 1997). In some sectors, such as chemicals and agriculture, the storage space in tanks and silos has failed to increase in line with vehicle carrying capacity. Expanding their capacity would improve vehicle fill and often yield a healthy return on investment.

Conclusions

It has been suggested that if all trucks had glass sides, people would be surprised by the amount of air they carried. This chapter has tried to show that the under-utilization of vehicle capacity has many causes and can sometimes be justified on solid commercial grounds. Companies cannot afford to be complacent, however, in the way that they manage this capacity. In response to a combination of economic and environmental pressures they are now giving greater priority to vehicle fill and trying much harder to overcome the traditional constraints on load size and weight. This requires an internal realignment of business objectives within companies as well as greater external collaboration along and between supply chains. Advances in vehicle, materials handling and information technology can assist efforts to improve loading, as can investment in more storage space at critical points in the supply chain. As discussed more fully in Chapter 18, government also has a role to play by optimizing vehicle size and weight limits for sustainable distribution, adopting charging mechanisms that incentivize efficient loading, and running best-practice programmes for road freight operators.

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Increasing fuel efficiency in the road freight sector

12

ALAN McKINNON

Introduction

The environmental impact of freight transport is closely related to the amount of energy consumed. This link is particularly close in the case of carbon dioxide emissions, with one litre of diesel fuel emitting around 2.63 kg of the gas. It has weakened, however, in the case of other noxious gases as a result of the tightening of vehicle emission standards (relating to pollutants such as nitrous oxide and particulates), the removal of sulphur from fuel and the switch to cleaner, alternative fuels. The desire to cut exhaust emissions, nevertheless, continues to offer a strong incentive to reduce fuel consumption. For most companies, though, the main incentive is economic, as fuel costs represent a large proportion of total vehicle operating costs. For example, they typically account for around 32–33 per cent of the costs of operating a heavy truck (with a gross weight between 38 and 44 tonnes) in the UK (DFF International, 2011).

As oil prices are predicted to increase steeply in future years, improvements in fuel efficiency are likely to yield a healthy financial return as well as climate change and air quality benefits.

It is possible to measure the energy efficiency of a freight transport operation in different ways. The main distinction is between a measure that relates energy consumed to the distance the vehicle travels, known as energy or fuel efficiency (eg litres per 100 km), and one that expresses it in relation to the amount of freight movement (eg tonne-kms per litre), which is often called energy intensity. Energy intensity is a function both of fuel efficiency and the loading of the vehicle. As the utilization of vehicle capacity is discussed in Chapter 11, this chapter will focus on ways of improving fuel efficiency.

It should be noted, however, that in formulating an energy conservation strategy for a freight transport operation, it is never enough for a company to maximize fuel efficiency in isolation. Just as much attention should be paid to filling the vehicles on both outbound and return journeys.

Almost all the energy used to move freight comes from the burning of fossil fuels at point of use in the vehicle. The main exceptions are electrified rail freight services and battery-powered delivery vehicles but, globally, these currently account for only a small percentage of freight tonne-kms. In this chapter we will concentrate on ways of improving the fuel efficiency of road freight vehicles.

There have been several studies of macro-level trends in the energy efficiency of road freight transport both internationally (eg Kamakate and Schipper, 2009; Eom *et al*, 2012) and in specific countries such as the United States (Langer, 2004), the UK (Sorrell *et al*, 2009), Spain (Pérez-Martinez, 2009), Finland (Liimatainen and Pollanen, 2010) and China (Li *et al*, 2013). These have generally revealed long-term improvements in energy efficiency relative to vehicle-kms and tonne-kms. Ruzzenenti and Basosi (2009), for example, report a 60 per cent improvement in the average energy efficiency of the European road freight sector over the previous three decades. Eom *et al* (2012), on the other hand, found the energy intensity of trucking exhibiting 'a very large variation' across the 11 countries they examined (including the US, Japan and Australia) and 'their overall trends… mixed'. They also detected little evidence of road freight demand decoupling from GDP over the past few decades, suggesting that public policy makers should be prioritizing measures that decouple energy use and emissions from the amount of freight moved by road. This highlights the need to improve fuel efficiency in the trucking sector. This chapter provides a micro-level perspective on how this might be achieved, examining what individual companies can do to reduce truck fuel consumption.

Research over the past few decades has shown that businesses can apply a broad range of fuel economy measures to their road haulage operations. Much of the early work focused on the design of the engine and vehicle chassis. There was a tendency to underestimate the contribution that the driver, supervisor and manager could make to improved fuel efficiency. Today, there is much greater recognition of the importance of the human element in fuel conservation. We will begin by examining recent trends in the fuel efficiency of new trucks and then consider what vehicle operators can do to minimize their fuel consumption.

Fuel efficiency of new trucks

There has been a steady flow of technical refinements to trucks that have raised their fuel efficiency. Over the 40 years up to 2007, the average fuel efficiency of new trucks improved at a rate of around 0.8–1 per cent per annum (IEA, 2007). The rate and sources of improvement varied between vehicle size and weight classes. For example, for the heaviest category of vehicles, roughly two-thirds of the increase in fuel efficiency came from advances in engine performance and the remainder from better aerodynamics and tyres (Duleep, 2007).

The main improvements were made in the 1970s and 1980s. The rate of fuel efficiency improvement has been relatively slow since 1990. This is partly because incremental improvements from the refinement of existing vehicle technology have been diminishing, but it is mainly because of the need to meet tightening emission controls, particularly on nitrogen oxide. It was estimated in 2007 that if these controls had not been imposed, average truck fuel efficiency could be around 7–10 per cent higher (IEA, 2007). One estimate for the US trucking industry puts this fuel penalty at 15–20 per cent over the period 1988–2010. This illustrates the environmental trade-off that has been made in giving the reduction of noxious emissions priority over fuel economy and carbon dioxide savings.

This trade-off has been further complicated by the need to introduce new systems to enable trucks to achieve Euro 4, 5 and 6 emission standards. Most truck manufacturers have opted for the selective catalytic reduction (SCR) system, which, it is claimed, yields better fuel efficiency than the alternative exhaust gas recirculation (EGR) system, but which requires the addition of a urea-based chemical called AdBlue to the combustion. Trials have confirmed that SCR does generally improve fuel efficiency, though the percentage fuel savings depend on the nature of the transport operations. To meet the Euro 6 standard, it has been necessary for truck manufacturers to combine SCR and EGR. This may still result in a 3 per cent loss in average fuel efficiency initially, though it is predicted that this will fall 'closer to zero within 3 years of introduction due to technological developments' (AEA Technology/Ricardo, 2011: 117).

Future opportunities for increasing the fuel efficiency of new trucks are explored in Chapter 8.

Vehicle design: Aerodynamic profiling

The external shape of the vehicle can have a major influence on its fuel efficiency. Streamlining the flow of air over the vehicle body can significantly cut fuel consumption. In 1993 the UK government's Energy Efficiency Office claimed that 'the importance of aerodynamic efficiency and its effect on fuel economy cannot be over-emphasized'. Around the same time, however, the Freight Transport Association (1993) issued a word of caution, describing some aerodynamic aids as 'little more than decoration'. Some early adopters of aerodynamic kits complained that they did not achieve the fuel savings claimed by the suppliers and that payback periods were longer than expected. Since then, aerodynamic styling has greatly improved, become more cost-effective and been shown to yield significant fuel savings both in trials and in commercial operation. A series of good practice guides (available at www.freightbestpractice.org.uk) and case studies (eg DfT, 2006a) have reported potential fuel savings in the range 6–20 per cent for improved aerodynamic profiling of trucks.

Aerodynamic drag is one of three forces resisting the vehicle motion. The other two are rolling resistance at the point of contact between the tyre and the road surface and internal friction in the engine, gearbox and transmission. Table 12.1 shows how the relative importance of these forces varies with the speed of the vehicle. The fuel savings from aerodynamic profiling clearly increase as the truck goes faster. One European study has shown that fuel savings from 'drag reduction devices' on a 40-tonne gross weight truck operating on a slower urban driving cycle are roughly half of those on a faster, long-haul driving cycle (Mohammed-Kassim and Filippone, 2010). As the magnitude of fuel savings from aerodynamic profiling is critically dependent on vehicle speed, its effectiveness as a fuel economy and emission reduction measures varies widely around the world. For example, at the average European truck speed of 70 kmph, aerodynamics represent roughly 40 per cent of the total resistance force; in India at the average truck speed of 34 kmph, the equivalent percentage is only 12 per cent. The environmental and financial benefits of vehicle streamlining in India are correspondingly lower.

Over-cab spoilers (or wind deflectors) have been the most widely used form of profiling. It is estimated, in the case of articulated trucks, that for every 10 cm of gap between the top of the driver's cab and the top of the trailer, fuel efficiency declines by 0.1 mpg (0.04 km per litre) (DfT, 2009a). Spoilers effectively close this gap, smoothing the upward flow of air over the whole vehicle. The height of some spoilers can also be adjusted by the driver to match the height of the load unit. This is beneficial, for example, in the road movement of deep-sea containers whose height can vary from 8.0 to 9.5 feet.

TABLE 12.1 Variations in the average amount of resistive force experienced by a heavy truck at differing speeds

Speed km/hour	Internal vehicle friction	Rolling resistance of tyres	Aerodynamic resistance
10	12	87	1
25	15	77	8
50	16	60	24
75	14	45	41
100	12	34	54

SOURCE: Michelin

While streamlining of the cab is important, around 85 per cent of the potential fuel savings from improved aerodynamics come from the trailer design. This is particularly true in the case of high-cube/double-deck trailers, which are now relatively common on UK roads and can be up to 5 metres tall. An increasing number of double-deck trailers have sloping fronts, permitting up to 10 per cent fuel savings. Improved profiling of the rear of trailers can also have a significant impact on fuel efficiency. It is estimated that air drag caused by turbulence at the rear of trailer accounts for as much as a third of total air resistance and that halving this drag can save around 4–5 per cent of fuel. One way of cutting this drag is by attaching retractable flaps, called 'boat-tails' in the United States, to the back of the trailers. US regulations on vehicle dimensions allow boat-tails to protrude by up to 1.5 metres. The European Parliament has recently approved an increase in EU truck length and weight limits to permit greater aerodynamic profiling of trucks. 'Teardrop' trailers, which slope downwards both at the front and rear, reducing the need to fit separate boat-tails, are now a common sight on UK roads. Initial trials suggested that these trailers offered fuel efficiency gains of as much as 10 per cent (*Commercial Motor*, 8 January 2009). Now that they have become more widely used in a variety of distribution operations, fuel savings in the 2–5 per cent range appear more typical.

It is not just the front, top and rear of the truck which can be streamlined. The addition of side-skirts and 'spats' over the wheels smooths the flow of air over the sides of the vehicle. The air flow under the trailer can also be improved by the installation of an 'under-tray'. The US Department of Energy has estimated that if all truck trailers in the United States were fitted with these devices, diesel fuel consumption would be reduced by 1.5 billion gallons (5.7 billion litres) per annum (Anon, 2011).

The addition of all these drag-reducing devices increases the tare (or empty) weight of the vehicle, offsetting some of the fuel efficiency benefits. As discussed in the next section, this runs counter to efforts to 'lightweight' trucks.

Reducing the vehicle tare weight

Fuel efficiency can also be enhanced by reducing the tare weight of the vehicle. Greszler (2009: 111) notes that:

> the benefits of weight reduction are more significant in weight-limited operations... where less vehicle weight translates directly into increased freight weight, and improved freight movement efficiency. For volume-limited trucks, vehicle weight impacts energy input due to rolling resistance, acceleration and hill climbing.

Use of lighter materials, such as aluminium or carbon fibre, and fittings can substantially cut the tare weight. For example, the US Department of Energy and the American Trucking Association have a programme that aims to reduce the combined tare weight of the tractor and trailer in a Class 8 articulated truck by 2.3 tons (13–19 per cent depending on truck configuration). This may require a reversal of recent trends towards higher cab specification and the installation of larger fuel tanks, both of which carry a weight penalty. On vehicles meeting higher emissions standards by SCR, the installation of an additional tank for AdBlue further increases vehicle weight. Existing trucks already have widely varying tare weights. One study in Germany found that, across a sample of road haulage operations, the average tare weight of a 40-tonne gross weight vehicle was 14 tonnes while the minimum weight was 11 tonnes (Léonardi and Baumgartner, 2004). One major truck manufacturer has indicated that it is relatively easy to remove just over half a tonne from the tare weight of an articulated truck without adversely affecting its performance or carrying capacity.

Improvements to the fuel performance of new trucks are only one source of fuel savings, however. Companies' vehicle purchasing decisions determine the rate at which new fuel-efficient technologies and designs are applied in practice. The way in which they subsequently operate and maintain the vehicles over a typical 10–15-year lifespan also has a major influence on total fuel consumption.

Vehicle purchase decision

For technical improvements in fuel efficiency to be widely diffused and truck manufacturers to be incentivized to make them, operators will have to attach greater importance to fuel efficiency in their vehicle purchasing decisions. Research in Finland has found variations of 5–15 per cent in the fuel efficiency of different brands of new truck (Nylund and Erkkila, 2007). This suggests that a haulier's choice of vehicle can have a large impact on future fuel consumption. A survey of 500 truck operators in the UK in 2013 found that fuel efficiency was the second most important purchasing criterion, after reliability, with 77 per cent of respondents considering it 'very important' (Road Transport Media, 2014). Ninety-one trucking industry executives in 13 countries interviewed by IBM (2009) considered fuel efficiency to be the vehicle purchasing criterion likely to increase most in importance between 2008 and 2020. Hauliers, nevertheless, should analyse the full-life cost (or 'total cost of ownership') of each vehicle and likely residual value before making their choice. As fuel expenditure can represent 30 per cent or more of the full-life cost it is a major component in this calculation.

Some companies purchase tractor units that are more powerful than they strictly require for a particular type of distribution operation. This is sometimes attributed to machismo on the part of the transport manager or owner-driver. A more rational explanation is that trucks with more powerful engines tend to retain higher residual values. This longer-term financial benefit, however, must be set against the additional fuel costs incurred in the interim. Because higher-powered vehicles are more highly geared, they tend to suffer greater loss of fuel efficiency at slower speeds. As road networks are getting more congested and average road speeds diminishing, the fuel penalty associated with over-powering is gradually increasing.

Vehicle maintenance

There is a huge range of technical imperfections that can prevent a truck from operating at optimum fuel efficiency (DfT, 2006b). Many of them go unnoticed for weeks, months or years, wasting substantial amounts of fuel quite unnecessarily. Regular maintenance can help to detect and correct these defects. On a day-to-day basis, however, drivers need to be encouraged to look out for obvious signs that a vehicle's fuel efficiency is being impaired. Typical defects include:

- Under-inflated tyres: according to a UK government report (DfT, 2006b), 20 per cent under-inflation of tyres will result in a 10 per cent increase in rolling resistance and cause a 2 per cent reduction in fuel efficiency. It is estimated that 75 per cent of all vehicles on UK roads have at least one tyre that is significantly under-inflated, increasing fuel consumption by 370 million litres and CO_2 emissions by 1 million tonnes annually (Tyrepal, 2013).
- Misalignment of axles: it is estimated that a 1° misalignment of a single axle on a multi-axle trailer will raise fuel consumption by roughly 3 per cent, while a 2° misalignment will increase it by 8 per cent. In addition to yielding fuel and CO_2 saving, correcting axle misalignment can significantly enhance tyre life (DfT, 2010a).
- Fuel leaks: these can, for example, originate from the internal fuel supply system or the neck of the fuel tank (DfT, 2006b).
- Poor combustion: the emission of black smoke from the exhaust generally indicates that the fuel is not being properly combusted and energy is being wasted.

The choice of oil for the engine and gearbox can also have a significant impact on fuel efficiency. Impressive claims have been made for synthetic lubricants that 'boast lower viscosity... and create less drag than do conventional mineral oils'. Depending on the state of the vehicle, they can yield up to 4 per cent savings in fuel (Anon, 2006).

Major advances have been made in the electronic monitoring of vehicle condition and performance, facilitating the detection of the range of technical shortcomings that depress overall fuel efficiency. Fuel efficiency is being given greater priority in truck maintenance programmes, partly because high fuel prices ensure a healthy payback for such measures, but also because of tightening controls on exhaust emissions.

Increasing the fuel efficiency of trucking operations

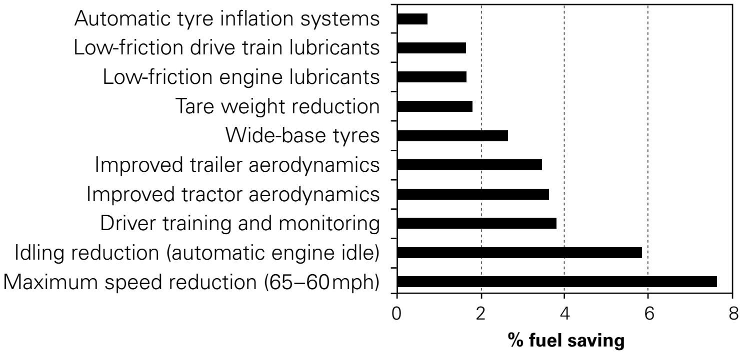
Companies can improve their fuel efficiency in many different ways. Several manuals have been published by government agencies, trade associations, magazines and oil companies providing advice on the broad array of measures that can be applied. At various times in the past, some measures have been hyped as offering a quantum leap in fuel efficiency only to disappoint hauliers that tried to implement them. A good example is the attachment of magnets to diesel engines supposedly to improve combustion efficiency and reduce the amount of unburnt fuel. As a government-sponsored report has pointed out, however, 'There is no evidence that even quite strong magnetic fields can cause ionization in gases or significantly influence combustion. Suppliers have produced little or no evidence that these types of fuel-saving device actually work' (DfT, 2003: 4).

Many of the claims made for fuel economy measures rest on quite flimsy empirical evidence. Some years ago, the US government's Environmental Protection Agency tested 106 fuel-saving devices and found that only five 'indicated a statistically significant improvement in fuel economy without an increase in exhaust emissions' (DfT, 2003: 4). These five related either to changing driver habits or improving the efficiency of air conditioning systems. (This finding on air conditioning cannot be directly extrapolated to other countries, where average summer temperatures are significantly lower than those in most of the United States.)

Another problem with checklists of fuel economy measures is that they often give the impression that all the savings are additive. Claims are often made that individual measures yield fuel savings of 1–3 per cent. In theory, if a haulier implemented 20 of these measures, it might cut its fuel consumption by 20–60 per cent. Research in the United States, for example, has assessed the percentage fuel savings that an average trucker might achieve by applying a range of 10 measures (Ang-Olson and Schroeer, 2002) (Figure 12.1). These savings vary from under 1 per cent for automatic tyre inflation systems to almost 8 per cent for a reduction in maximum speed from 65 mph to 60 mph. If all these savings were cumulative, aggregate savings of 33 per cent might be achieved. In practice, this is unrealistic. Some measures, after all, are counteracting. For example, cutting maximum speed will reduce the effectiveness of 'improved trailer and tractor aerodynamics'.

A fuel economy initiative should not, therefore, comprise a loose collection of measures. It is much more effective to integrate a specific set of measures into a well-structured programme tailored to the needs of particular operators. As part of its Freight Best Practice programme, for example, the UK government developed a fuel management guide, which not only outlines some of the more promising fuel economy measures, but also sets out a management framework within which these measures can be implemented and their effects evaluated (DfT, 2006b). The oil company Shell has also 'advocated a holistic approach to the whole issue of transport efficiency'

FIGURE 12.1 Estimated fuel savings from fuel economy measures: US trucking



SOURCE: Ang-Olson and Schroeer (2002)

and has given this approach the brand name 'Fuel Stretch' (Anon, 2006). Its programme comprises 25 fuel-saving tips, including advice on how to manage the programme.

It is very difficult to assess the overall potential for improving the average fuel efficiency of road haulage operations for several reasons:

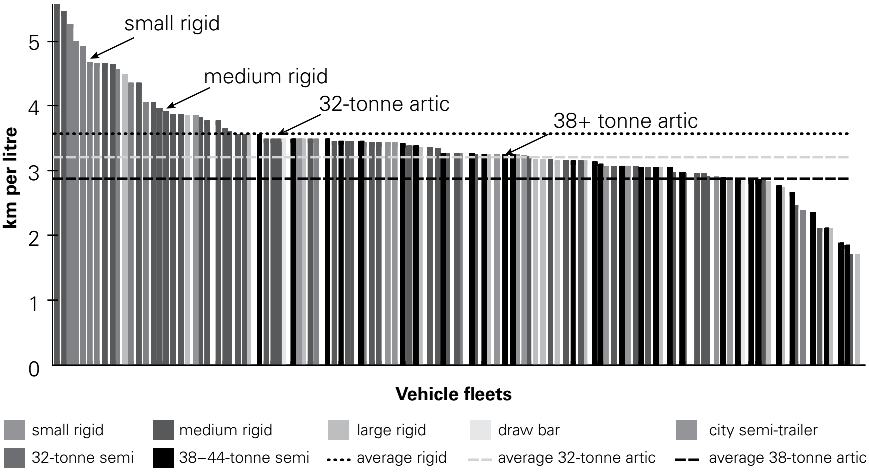
1. There are many different sources of efficiency improvement.
2. There is a complex interaction between different types of improvement measure; in some cases there is mutual reinforcement while in others they are counteracting.
3. There are often quite wide variations in the estimates of potential fuel savings from different sources.
4. It can be unclear from what baseline potential savings are being calculated, particularly when they are generalized at an international level.

By benchmarking the fuel efficiency of fleets engaged in similar types of distribution operation, one can get a rough indication of potential savings given currently available technology. This is discussed in the next section.

Benchmarking the fuel efficiency of trucks

Several attempts have been made to benchmark the fuel efficiency of truck fleets in countries such as the US, UK, Germany and Canada. The general message to emerge from these surveys is that even within relatively homogeneous sub-sectors there are significant variations in fuel efficiency. Figure 12.2 shows the variability in the average fuel efficiency of trucks of specific types carrying food products (McKinnon and Ge, 2004). The variability was much

FIGURE 12.2 Variation in fuel efficiency across vehicle fleets in the food supply chain



SOURCE: McKinnon and Ge, 2004

greater for rigid vehicles than for articulated trucks. The more disaggregated the benchmarking exercise, the less easy it is for managers to dismiss inter-fleet variations in fuel efficiency on the grounds that the transport operations are not directly comparable.

By benchmarking other companies against the most energy-efficient operator in their sector, it is possible to estimate the potential for fuel savings. For example, key performance indicator (KPI) data collected during the course of 'synchronized audits' of transport efficiency in the UK food supply chain were used to estimate by how much energy consumption and fuel costs might be reduced if companies whose energy efficiency was below the average for their sub-sector could bring it up to this mean (McKinnon and Ge, 2004). According to the results of this survey, this would cut the amount of fuel consumed and CO_2 emissions by 5 per cent, reducing annual fuel costs for the average vehicle by £1,115 (at 2003 prices). Similar analyses have been conducted in other sectors and, in each case, they demonstrate significant potential for cutting fuel consumption while maintaining the same level of freight movement (McKinnon, 2009).

The UK is not alone in benchmarking the fuel efficiency/energy intensity of road haulage. Studies done in other countries have employed different methodologies but arrived at very similar conclusions. For example:

- Germany: a survey of 153 trips made by 50 German hauliers found a wide variation in the ratio of CO_2 emissions to tonne-kms (Leonardi and Baumgartner, 2004). The number of tonne-kms per kg of CO_2 varied enormously, from 0.8 to 26. As CO_2 emissions are very closely correlated with fuel consumption, differences in tonne-km per litre of fuel would be similarly wide.

- Canada: a survey of 42 inter-city trucking fleets was conducted across Canada to provide benchmark fuel efficiency data (Transport Canada, 2005). The highest fuel efficiency recorded was 3.01 km per litre for articulated trunking vehicles, with half the fleets surveyed achieving average fuel efficiency values between 2.5 and 3.0 km per litre.

One must always exercise caution in interpreting benchmark data, because some of the variation in fuel efficiency will reflect justifiable differences in the nature of the distribution operation and composition of the vehicle fleet within each sub-sector. The available benchmark data, nevertheless, suggests that there is considerable scope for making further improvements in energy efficiency in freight transport operations given current levels of technology and market conditions. Future advances in technology and strengthening commercial and environmental pressures to economize on fuel will raise the energy efficiency benchmark even higher.

More fuel-efficient driving

It is generally accepted that driving style is the single greatest influence on fuel efficiency. Driver training programmes have been shown to improve fuel efficiency by around 8–10 per cent. The Safe and Fuel Efficient Driving (SAFED) programme launched by the UK government back in 2003 has recorded average 'on-the-day' improvements in fuel efficiency of just over 10 per cent (DfT, 2009b). To date over 13,500 truck drivers and 9,500 van drivers have had SAFED training. If the entire population of truck drivers in the UK were to have SAFED training, if they achieved an average 10 per cent improvement in their driving performance and if they maintained it in normal operation, admittedly three large 'ifs', total fuel consumption by trucks in the UK would drop by 880 million litres per annum, and CO_2 emissions by 2.3 million tonnes. Truck simulators can also be used to provide training in safe and fuel-efficient driving techniques. A pilot project in the UK found that, between the first (pre-training) and second (post-training) run on a truck simulator drivers achieved an average increase in fuel efficiency of 13 per cent.

To derive longer-term benefit from training in so-called 'eco-driving', companies have to maintain awareness of the fuel efficiency issue and incentivize drivers to continue using their skills in fuel-efficient driving. Many companies now offer financial incentives in the form of prizes or bonuses. For such schemes to operate effectively, however, the collection and analysis of fuel data must be seen to be fair and consistent. This can be a complex exercise where drivers regularly switch vehicles and delivery runs (McKinnon *et al*, 1993).

The most effective way of 'embedding' fuel-efficient driving practices is to install electronic equipment in the cab to monitor the driver's performance against a series of criteria, such as harshness of the acceleration and braking, over-speeding and timely gear changing. This allows companies to determine how fuel efficiently the vehicle was driven on every trip. They typically use a 'traffic light' colour coding system to differentiate good (green), average (yellow) and poor (red) performance both by individual criteria and overall fuel rating. In subsequent driver debriefing sessions, the reasons for any under-performance are discussed and, where necessary, drivers given additional training. In accordance with the so-called Hawthorne effect, merely monitoring driving behaviour can significantly improve fuel performance. Reported fuel savings resulting from this telematic enforcement of good driving practice range from 5 to 15 per cent depending on the baseline fuel efficiency of the fleet prior to its introduction.

It is not only when driving the vehicle that drivers can have a major impact on fuel consumption. By leaving the engine idling while the vehicle is stationary, drivers can waste significant amounts of fuel. A 'typical heavy duty vehicle' in the UK consumes around 2 litres of fuel and emits 5 kg of CO_2 per hour while idling (DfT, 2010b). Running 'anti-idling campaigns' to encourage drivers to switch off the engine when the vehicle is parked have been shown in four UK trials to cut fuel consumption by between 1 and 5 per cent (DfT, 2010b). Rather than rely on drivers to change their behaviour, it is possible to install 'anti-idling' devices in the vehicle which stop the engine after a few minutes of stationary running.

Drivers should also be instructed and encouraged to adopt a broader set of fuel economy rules, such as checking tyre pressures at the start of a journey and reporting engine problems that are likely to impair fuel efficiency (DfT, 2009a).

Fleet management

Once the right vehicles are purchased and adequately maintained, the fleet manager must ensure that they are deployed in a way that maximizes their operational efficiency. This includes assigning the 'right vehicles to the right jobs'. Available survey evidence suggests that this basic rule of good fleet management is often broken, at the expense of higher fuel consumption by trucks that are bigger or heavier than they need to be for the load they are carrying. Efforts to match the capacity of the vehicle to the size/weight of the load run counter to the common practice of standardizing vehicle weights and dimensions within a fleet. There is scope, however, for improving this match, particularly with the use of fleet management software.

Fleet management can also be reinforced by the appointment of a 'fuel champion' whose job it is to analyse the pattern of fuel consumption, promote fuel-saving initiatives and generally instil a fuel-saving culture in the workforce (DfT, 2006b). With or without a 'fuel champion', management needs systems in place to monitor fuel consumption and analyse variations in fuel efficiency at a disaggregated level by driver, vehicle, depot and contract. In the absence of such data, it is very difficult to devise an effective fuel management programme. Such a programme will require meaningful and realistic KPIs and targets to give the staff clear goals. Establishing these targets can be difficult given the wide variety of factors that exert an influence on fuel efficiency. Research by Coyle (1998), for example, revealed how the average fuel efficiency of a fleet can be around 10 per cent lower in the winter than in the summer, mainly because more energy is used to heat the vehicle.

There is a plentiful supply of literature advising trucking companies how to cut their fuel consumption, but very little on the extent to which companies actually put this advice into practice. A survey of 33 businesses belonging to UK Logistics Carbon Reduction Scheme (LCRS) indicated the adoption rate of a range of fuel economy measures by company, vehicles and drivers (Table 12.2). In equal first place by company were regular checks on driver

TABLE 12.2 Adoption of fuel-efficiency measures by members of the UK Logistics Carbon Reduction Scheme (2013)

Category	Measure	% of companies implementing measure	No. of trucks involved
Vehicle transmission	automated manual transmission	73	11926
	reduce engine idling	73	12857
Vehicle body	install cab roof air deflectors	67	11158
	install aerodynamic panels	47	6357
	use sloping front trailer	35	1054
	lower vehicle height	20	2322
	use tear-drop trailers	13	504
Vehicle maintenance	periodic maintenance/inspection	61	19107
	more frequent tyre inflation	52	21607
	low viscosity lubricants	37	6680
	automatic tyre pressure adjustment	4	208
Vehicle speed	set speed limiters at lower speed	45	8754
Vehicle and tyre selection	fuel efficient tyre designs	28	3868
	use of engine mapping to match vehicle spec to application	10	2210
			drivers
Monitoring and training of drivers	regularly checking fuel efficiency	73	45309
	eco-driving scheme	66	54604

SOURCE: Freight Transport Association, 2013 fuel efficiency, automated manual transmission and reduced engine idling, closely followed by aerodynamic profiling of the cab and eco-driver training. In terms of diffusion across the truck fleet more frequent tyre inflation also scored highly. As members of the LCRS tend to be the more efficient and progressive operators, these figures may not be representative of the UK road haulage industry as a whole.

A much larger survey in four Nordic countries (Denmark, Finland, Norway and Sweden) used a system of 'energy efficiency index points' to rate the importance of 16 truck fuel economy measures (Liimatainen *et al*, 2014). Matching vehicle size and load emerged as the most popular measure from the research, but the other top-rated measures were similar both to the UK LCRS ranking and across the four Nordic countries. In a survey of almost 300 road hauliers in Finland, Liimatainen *et al* (2012) enquired about future plans to enhance fuel efficiency by 2016. They found that the implementation of fuel economy measures would be constrained by the carriers lacking knowledge and resources and their clients offering too little support. Although the economic and environmental case for improving truck fuel efficiency is overwhelming, making it happen, even in advanced, developed countries, can be slow and problematic.

Conclusions

There are numerous ways in which the fuel efficiency of road freight operations can be improved. Those who manufacture, maintain, operate and drive trucks all have a key role to play in minimizing the amount of fuel consumed in moving freight by road. In recent years, a general view has emerged that opportunities for further technical improvements to the energy efficiency of new vehicles are limited and that future gains will come mainly from their operation and maintenance. As discussed in Chapter 8, this view underestimates the potential for future technological advances in engine and vehicle design outlined by AEA Technology/Ricardo (2011), Vyas *et al* (2013) and others. Benchmarking surveys also reveal that wider dissemination of current best practice in fuel management by truck operators could substantially reduce the energy intensity of road freight transport. Rising oil prices, environmental taxes, carbon trading, government campaigns and intensifying competition in the road freight market are all likely to promote this dissemination over the next 10–20 years.

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Alternative fuels and freight vehicles

Status, costs and benefits, and growth

13

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Introduction

The promotion of alternative fuels (AF) is an important strand of strategy to tackle climate change in transport. Key fuels of relevance for the development of alternative fuels for use in vehicles in the freight and logistics sector are biodiesel, natural gas (NG), biomethane, hydrogen and electricity. An innovative global market is emerging, and a great deal of international effort and money is being expended on the development and production of AFs and vehicles which use such fuels. Public policies promoting the use of AFs are targeting vehicle manufacturers, fuel suppliers and vehicle operators. Studies of vehicle and fuel purchasing behaviour have shown that government intervention is needed to develop national markets for AFs (Savvanidou *et al*, 2010). The market is fragmented and growing in different ways for passenger and freight vehicles. Road transport forms the principal focus of attention, with solutions targeting other modes such as electric rail freight, solar barges, bio-kerosene for aircraft, biofuels or hydrogen for ocean vessels considered to be rather longer-term prospects (McKinnon, 2007).

Even though many countries such as the UK have developed low-carbon strategies for freight, a recent policy review shows that increasing the number of vehicles running on low-carbon fuels appears to be a method that lacks popularity among operators (DfT, 2012a). Market barriers include high upfront capital costs, lack of refuelling infrastructures and uncertainty over costs and benefits. In addition to model-based calculations, an increasing number of trials with AFs are being performed under real-world business conditions. Such tests help determine the costs and benefits to the end user, thus helping these markets to develop. Some trials are undertaken at a large scale from the outset, with a sustainability report from DHL revealing that by 2013 around 1,100 of its vehicles were powered by AFs, a figure which continues to increase (DHL, 2014).

Despite the trialling of different options for many years now, the use of AFs in vans and HGVs is still at an embryonic stage but, according to literature, can be expected to increase if the above-mentioned barriers can be removed or reduced (DfT, 2014). This chapter analyses the various alternative fuels used in the freight transport sector and assesses their business case and environmental impacts, with the objective of providing insights relevant for decision making in businesses and the public sector. The chapter starts with sections on biofuels, gaseous fuels (natural gas, LPG and CNG) and hydrogen. It also considers the use of electric and hybrid vehicles, which are increasingly being used in van and goods vehicle fleets.

State of development of alternative fuels for freight vehicles

This section sets out the status of the main types of AFs together with the development of innovative freight vehicles. It also considers their market applications in logistics and goods transport.

Biofuels

The term biofuels refers to liquid and gaseous fuels produced from organic matter from plants or animals. Global biofuel production grew from 16 billion litres in 2000 to more than 100 billion litres in 2010 (IEA 2011). According to IEA (2011), whilst improving efficiency is the most important low-cost way of reducing CO_2 emissions in the transport sector, biofuels will need to play a significant role in replacing liquid fossil fuels suitable for planes, marine vessels and other heavy transport modes that cannot be electrified.

There are three types of biofuel in significant use in freight transport: biodiesel, bioethanol and biogas. These biofuels account together for about 3 per cent of total fuel use in road transport in UK (for passenger and freight vehicles) in 2010–2011 (DfT, 2012b; UKPIA, 2011).

Biodiesel

Biodiesel is produced from plant and animal oils through a process called trans-esterification (ie the production of esters from oil or fat); hence it is also referred to as FAME, fatty acid methyl ester. In this process, the fat or oil reacts with alcohol in the presence of a catalyst to produce biodiesel and glycerine. The main sources of oil used in the production of biodiesel vary according to country, depending on local growing conditions. In Asia palm oil is the norm, in the United States soybean oil is common and in Europe the norm is rapeseed oil (or canola). Other plant oils that can be used include sunflower, cottonseed, mustard seed, coconut and hemp oils. In 2006, the United States produced 250 million gallons of biodiesel, up from 2 million gallons in 2000, but this still represented less than 1 per cent of total highway diesel fuel used (Union of Concerned Scientists, 2012). In 2010–11 in the UK, 853 million litres of biodiesel were supplied (DfT, 2012b).

Bioethanol

Bioethanol can be produced from any biological feedstock containing sugar or materials such as starch or cellulose that can be made into sugar (IEA, 2011). The main sources of sugars for bioethanol are wheat, corn, sugar beet/cane, straw, maize, reed canary grass, cord grass, Jerusalem artichokes, miscanthus, sorghum, sawdust and willow and poplar trees, although sugar beet and corn accounted for 80 per cent of all bioethanol produced in the world in 2007 (Sperling, 2008). Bioethanol has been used as a fuel for decades. Brazil has been using bioethanol made from sugar cane since the 1930s, and indeed by the 1980s was selling cars that ran exclusively on such fuel (Sperling, 2008). The United States has also been using bioethanol produced from corn for many years. In the UK, 610 million litres of bioethanol were supplied in 2010 (DfT, 2012b; UKPIA, 2011).

Biomethane

Biomethane is a biogas generated from waste or organic sources. The biogas is upgraded to transport biomethane, compressed and concentrated, and used in natural gas engines (see below). Since 2007, there has been a series of developments in Europe and UK leading to an increasing use of biomethane in transport, though starting from a very low level. CO_2 emissions are reduced by up to 60 per cent compared to diesel (Ricardo, 2009a).

Gas-fuelled vehicles

Natural gas (NG)

Natural gas vehicles (NGVs) are methane-powered vehicles. The methane is derived from either fossil sources or biomethane (a raw biogas upgraded for vehicle use). According to the Natural and Bio Gas Vehicle Association (NGVA, 2011), in 2011 there were 13.4 million NGVs in use worldwide, of which 220,000 were medium duty and heavy duty vehicles. When using fossil-fuel-derived methane, NGVs produce slightly lower emissions of CO_2 than traditional petrol-engined cars and about the same levels of CO_2 as the equivalent diesel-powered trucks. Some manufacturers produce heavy goods vehicles that run purely on NG. Vehicles can be refuelled overnight at depots equipped with the required compressors. Dual-fuel NG/diesel or NG/petrol vehicles are available.

Natural gas is still, however, fossil-fuel dependent, so does not represent a clean fuel. Methane is classed as a greenhouse gas (GHG) (although the NGVA argue that it should not be) and has a global warming potential 21 times that of CO_2. However, biogas, the NG produced from biomass, actually reduces emissions of methane as it harnesses the methane normally emitted in the waste disposal process and transforms it into energy. Anaerobic digestion plants can extract and process methane from farm and municipal waste and sewage.

Liquefied petroleum gas (LPG) and compressed natural gas (CNG)

LPG is a mixture of propane and butane with traces of some other gases, kept in a liquid state at high pressure in metal containers. CNG is natural gas (methane) compressed to about 1 per cent of its volume at normal atmospheric pressure, and mainly used in a gaseous form in petrol/CNG engines. LPG is mainly used for cars, with a share of 0.4 per cent of total fuel sales in the UK, but declining over the last few years (UKPIA, 2012). As an example of a much higher market share, in Hong Kong 99.8 per cent of taxis and most new minibuses run on LPG. However, this does require some vehicle modifications, and although there has been an international push towards providing LPG refuelling stations, it is not yet as widely available as conventional fuels, and indeed is not available at all in some countries.

The main benefits of LPG and CNG are sizeable reductions in exhaust emissions of nitrogen oxides and particulate matter, and a much lower noise level. This makes NG vans and trucks well suited to freight distribution in urban areas. However, when LPG and CNG originate from fossil fuels and not from biomethane, the well-to-wheel emissions of GHGs are high.

Hydrogen and fuel cell powertrains

Hydrogen is another alternative energy source for transport with potential for freight and logistics. In 2003 the International Partnership for the Hydrogen Economy (IPHE) was established, supporting demonstration projects and a market shift towards hydrogen vehicles (IPHE, 2012). The impetus for this shift has, however, slowed as various issues have emerged.

To date, much of the research and demonstration activity on hydrogen as an AF has focused on passenger cars and buses rather than freight vehicles, although there is considerable interest in the potential for hydrogen use in the light goods vehicle (LGV) sector. With future technological advances and experience gained from the use of hydrogen in the van fleet, the extension of this energy source to larger vehicles is possible in the longer term.

The principal development in the use of hydrogen in transport is the hydrogen fuel cell. This is a device that converts hydrogen gas and oxygen into water via a process that generates electricity. Fuel cell vehicles are generally powered by pure hydrogen, which comes in the form of compressed hydrogen gas, metal hydrides stored in cylinders or as liquid hydrogen, though any hydrogen-containing feedstock (such as petrol and diesel oil) could be used. The hydrogen fuel cell is an efficient form of energy production and is almost totally recyclable.

The key environmental benefit of hydrogen is that its only tailpipe emission is water vapour. The main operational advantage is that electric motors can be powered with fuel cells without grid electricity.

Recent studies confirm the high potential for hydrogen, but acknowledge several barriers that hamper its use in freight and logistics at present. The main barriers are that: the primary energy sources used to produce hydrogen need to be renewable in order to obtain a CO_2 benefit; the fuel cell powertrains are not available commercially for vans and HGVs; the fuel storage volume is high; and the safety risks in handling hydrogen during refuelling call for special training (Ricardo, 2009a).

Electric and hybrid vehicles

While fully electric vehicles are driven by a battery-powered electric motor only, hybrid vehicle configurations utilize various combinations of powertrains in which diesel engines are coupled with electric motors.

Fully electric vehicles depend on batteries, which are still relatively heavy and bulky and offer a limited distance range. Recent improvements in this range (now in excess of 250 miles), however, have led to wider application of this technology for van-based deliveries particularly to urban centres and to the home (MacLeod, 2007). Although large-battery fully electric-powered trucks are not yet available, there are many hybrid trucks on the road that combine electric and diesel power. Conventional power units can be replaced by electric-driven differential units that produce electricity to help power vehicles up hills and at the same time recharge the batteries when not in use. A growing number of vehicles also use regenerative braking systems to recharge the battery with energy recaptured during deceleration.

Electric vehicles have been in use for deliveries for decades, with the British milk float being an early and enduring example. The technology is now further developed for example with new plug-in hybrid electric buses tested in Gothenburg, using a much smaller diesel engine, capable of recharging batteries from grid in seven minutes, and reducing diesel use by 81 per cent compared to standard diesel buses (Volvo, 2014). As the pressure on logistics companies to become more environmentally friendly grows, interest in electrically powered goods vehicles is likely to increase. For the moment, only small electric vehicles and vans capable of operating at reasonable costs are on sale on the market.

The main environmental benefits of electric vehicles are the almost total elimination of both tailpipe emissions of noxious gases and engine noise. While these local impacts are indisputable, the wider environmental gains depend on the primary energy source used to generate the electricity that recharges the batteries. Unless electricity is produced from renewable resources, the environmental impact is merely being transferred from the vehicle to upstream power plants. As at 2014, the total number of electric freight vehicles in operation in Europe is very small, far below 0.1 per cent of the total fleet.

Current use of alternative fuels for freight vehicles

This section describes a range of current market developments and trials in the freight and logistics field.

Alternative fuels and AF vehicles: market development and policy

Biofuels are normally blended with conventional fuel to make them usable. Biodiesel is usually blended with conventional diesel and bioethanol with conventional petrol ('gasoline' in the United States), although it can be blended with diesel after some modification (IEA, 2004). Thus, B7 means there is a 7 per cent blend of biodiesel with conventional diesel and similarly E5 means that there is a 5 per cent blend of bioethanol with conventional petrol. As the percentage blend of ethanol increases, so its corrosive impact increases, and when it exceeds about 10 per cent susceptible conventional vehicle components (particularly the rubber elements) need to be replaced by ethanol-resistant components. However, with biodiesel this problem is reduced. In the United States, the most common blend is B20, but in Germany, Austria and Sweden, 100 per cent pure blended biodiesel is used in goods vehicles and buses with minor engine modifications (IEA, 2004). Vehicles that can use conventional fuel or any blend of biofuels are known as flexible-fuel vehicles (sometimes called 'flex-fuel' vehicles).

One of the main reasons why biofuels have gained so much attention is that low blends (5 per cent bioethanol and 7 per cent biodiesel) can be used directly in existing cars, vans and trucks with no engine modifications, and the refuelling infrastructure is exactly the same as for conventional fuel. This makes it very convenient and cheap to use these biofuel vehicles in comparison with other renewable fuel alternatives (such as hydrogen, electric power or LNG/CNG), which require major modifications to both vehicles and refuelling distribution systems.

The EU Biofuels Directive, adopted in May 2003 (Directive 2003/30/EC), aims to promote the use of transport fuels made from biomass and other renewable sources. The directive set a reference value of 5.75 per cent of total energy consumption as the target market share of biofuels by 2010.

As part of the UK's 2006 Climate Change Programme, a target of 5 per cent (by volume of fuel sold in UK) was set as the proportion of road transport fuel to be derived from renewable sources by 2013. To achieve this quantitative objective, a Renewable Transport Fuel Obligation (RTFO) was established in April 2008. Under the RTFO, large fuel supply companies are required to blend biofuel into standard fuels, with the proportion increasing annually by 0.5 per cent up to the 5 per cent target set for 2013. Suppliers are also requested to measure and report on biofuels sales, origins and quality, and on how much carbon their fuel has saved on a life-cycle basis (DfT, 2012b). The RTFO rewards fuels according to their carbon savings, in order to encourage their uptake. It also aims to trace the origins of the biofuels imported, increase the sustainability of their production and raise their market share. Recent data suggests that this target of 5 per cent biofuel was missed in 2013 in the UK (DfT, 2014).

As stated earlier, the use of AFs in goods vehicles needs to satisfy certain conditions in order to become commercially successful. Vehicles that are regularly fuelled and maintained in-house and run on fixed daily routes are particularly suited to AFs. More widespread use of AFs and batteries will have to await the development of public refuelling/recharging infrastructure and networks. Nevertheless, at present, individual companies have to come up with their own solutions. The most proactive companies are working with vehicle manufacturers on an individual basis to develop tailor-made solutions. Some examples of this are given below.

Howard Tenens, a UK logistics service provider, has established a large-scale trial with a fleet running on dual-fuel natural gas/diesel. The company has built gas refuelling infrastructure in three depots to support the roll-out of dual-fuel (gas/diesel) vehicles across the HGV fleet (Howard Tenens, 2014). Two stations are grid connected, in line with the ultimate objective of ensuring a direct supply of gas to use as road transport fuel. The sustainability of this option will increase further in the future as the share of biomethane in the gas supply is increased. Access to the refuelling stations is possible for contractors, allowing other operators to enter the gas vehicle market without the high cost of building their own refuelling infrastructure.

The Green Link started business in 2009 with 100 per cent battery electric vehicles in central Paris, delivering parcels for commercial clients. The early years saw strong growth and the fleet has now reached 60 electric tricycles and vans. The fleet was purchased in the start-up phase, but tricycles are now manufactured in-house (The Green Link, 2014). This success is now being replicated across France and many other new start-ups in Europe are developing commercial solutions involving small vehicles and electric fleets for urban freight.

Recent cases of electric van and tricycle use for last mile deliveries in London demonstrate clear benefits in reduced vehicle-kms, savings in emissions and lower parking space occupancy, at no additional cost to the customers or the carrier (Browne *et al*, 2011). In such demonstrations, specific business conditions have applied, relating to parcel size and weight, the ability to use space in a local transhipment facility, the purchase of green electricity and a highly concentrated pattern of customer demand.

Costs and benefits

The various alternative fuels and vehicle technologies discussed in this chapter can be seen to offer different benefits. Moreover, the magnitude of such benefits varies depending on whether a business profitability point of view or an emission reduction/external cost perspective is adopted. According to Ricardo (2009a, 2009b) biogas can be produced as cost effectively as CNG whereas the market price for biodiesel is in most cases higher than conventional diesel. Depending on the sources and the production patterns, however, the biodiesel well-to-wheel (W2W) CO_2 balance can be either negative (increasing environmental costs compared to diesel) or can show a strong benefit of up to 65 per cent (Ricardo, 2009a). Cost and benefits of electric vehicles have so far been measured in small-scale trials and independent research only for a limited number of business types (Browne *et al*, 2011). According to the comprehensive assessment undertaken by Ricardo (2009a), every low-carbon solution for freight vehicles and AF can show positive and negative elements, and none of the solutions can be considered to be consistently beneficial across all aspects of private profitability, service level, environmental, safety and societal impacts.

Profitability and uncertainty about the total costs of ownership (all costs including purchase and maintenance) for logistics providers are important current issues. Various European research projects such as SMARTFUSION, STRAIGHTSOL and BESTFACT have collected data in order to help business arrive at investment decisions. Policies have been developed to support the growth and market uptake of AF, but these have had only limited effect so far (FTA, 2013). Some of the most convincing examples of business profits through the use of AF are now documented for urban electric fleets (Permala and Eckhardt, 2014), but solid before-and-after studies of the costs and benefits of using AF in freight and logistics businesses are rare. A study by Leonardi *et al* (2012) collected logistics business and environmental data, and demonstrated the benefits of using cycles and electric vans, based on the examples of the Office Depot and Gnewt Cargo companies active in parcels deliveries in central London. Further studies and multi-actor electric freight trials are ongoing in Belgium, Germany, France and the Netherlands (Lebeau, 2014; Gruber, 2014; Jorna and Jongsma, 2014).

Table 13.1 provides an overview of the benefits and costs for each solution, covering business case and environmental or societal impacts, but excluding – for the purpose of clarity – conditions that need to apply in order to obtain these benefits.

TABLE 13.1 Costs and benefits of using AF-powered vehicles in logistics

AF	Costs	Benefits
Biodiesel (FAME)	W2W CO_2 balance can be negative depending on method of production No added costs if blended to diesel, but increased vehicle costs if 100% FAME is used	Up to 65% less CO_2 Compatible with existing infrastructure End-user price of 100% FAME may be lower than diesel due to tax incentives
CNG/LPG	Vehicle purchase costs currently 20–25% higher than diesel Limited infrastructure Leaks could lead to explosion	10–15% lower CO_2 emissions, much lower air pollutants and noise emissions End-user fuel price is lower than diesel
Biogas	Requires the development of nationwide production and tank fuelling infrastructure HGV and van prices are considerably higher than diesel vehicles Fuel price similar to CNG	Up to 60% CO_2 benefits compared to diesel vehicles Good image
Hydrogen	Fuel infrastructure and trucks are not yet commercially available Production needs to be from regenerative energy sources	Zero tailpipe emission Medium distance range and autonomy
Fully electric	Expensive batteries increase the vehicle purchase price Long recharging time overnight Short distance range limiting applications to urban freight Lower capacity by weight	Zero tailpipe emission Very low electricity consumption costs Low noise High customer acceptance and image Potentially exempt from congestion charge and low emission zone restrictions (eg London)
Hybrid electric	Business case demonstrated for heavy vehicles only for urban buses HGVs above 12 tonnes are not commercially available Lower capacity by weight	Emission reduction depends strongly on usage share of electric/diesel powertrains Long distance range and autonomy

SOURCES: Ricardo 2009a, 2009b, authors' research

In terms of business benefits, current market trends appear to favour electric freight development. In the UK, electric vehicles incur no vehicle excise duty (VED), no London congestion charge and no London Low Emission Zone restriction, and the use of electricity rather than diesel fuel strongly reduces running costs. For urban deliveries in Paris, the logistics provider Deret (2011) claims that 6-tonne battery–electric trucks cost around 4–5 euro per 100 km for their electricity supply, much lower than the 20–25 euro per 100 km needed for diesel fuel for comparable trucks and urban delivery conditions. However, the purchase price of such a vehicle is around double that of a similar-sized diesel van.

Growth potential

Creating a mass market for environmentally sustainable fuels is complex. Many technological breakthroughs are strongly dependent upon the car and bus manufacturing industries and the biofuels industry with truck and van manufacturers having less influence. An even smaller part of the overall trajectory towards a higher market share for AF can be influenced by decision makers in logistics and fleet management. Institutional decision makers are however becoming more active and relevant in market development. In 2014, in addition to financing research, the European Commission is developing a strategy for the deployment of AF refuelling infrastructures. It is envisaged that this strategy, once in place, will be followed by strong investment across EU member states. But at a time of scarce public funds, such public-sector support and investments are likely to remain limited.

Despite the fact that more is now known about the costs and benefits of AF, many uncertainties remain for end users. Currently, only a few sectors and a few types of businesses have robust data on the costs and benefits of using AF in logistics, and such uncertainty about the full life-cycle effects and total costs of ownership of these fuels and vehicles is deterring many operators from investing in them. Many are waiting for an official system of environmental accreditation to be introduced before committing to a major shift to alternative fuels. Many of the producers of AFs such as biodiesel and biomethane are increasing output only slowly and lack the capacity to support a steep increase in demand. Hence there are constraints on both the demand and supply sides of the AF market. Interestingly, in attempting to address this issue, one of the conclusions of a policy modelling study of future low-carbon transport was that policies targeting both demand and supply sides are likely to have the greatest impacts (Brand *et al*, 2012).

Fuels such as natural gas (CNG and LPG), hydrogen and biofuels all face direct market barriers that hinder their future development and which need to be overcome by public policies and private investment strategies (Steenbergen and Lopez, 2008). In countries such as Brazil, the market share of biofuels in the freight sector is likely to increase substantially by 2030, possibly with the use of flexi-fuel vans (Schmitt *et al*, 2011), if land use questions can be resolved.

Attention is increasingly turning to what are termed second-generation biofuels. These are fuels that can be produced from waste materials (such as residual oil or municipal waste) and cellulosic crops (dedicated energy crops). According to the EU (EC, 2008: 11), use of cellulosic biomass feedstock allows new methods of biofuel production from 'products, by-products and waste from agriculture, forestry and wood, pulp and paper with more sophisticated chemical reactions'. As the Royal Society (2008) argues, biofuels may form part of the solution for the future but only a small part, and hence other solutions to the climate change problem will also be required. It appears that hydrogen fuel cells are unlikely to be the panacea that they were once predicted to be. CNG is widely seen as a transition technology leading to large reductions in pollutants and noise, and being compatible with biogas. In the medium to long term we are likely to see a substantial growth in biomethane use in road freight operations.

There has been significant development of AF in recent years, mostly relating to investments in battery-powered vans and rigid vehicles. For example DHL has continued to increase its fleet powered by AF, reaching around 3,000 vehicles in 2013, of which 300 were fully electric vans. This however remains a small proportion of the total DHL road vehicle fleet of 89,000 trucks and vans in operation worldwide (DHL, 2014). Within the EU the trend towards electric vehicles has been reinforced by the European Green Car Initiative and supported by a large network of local authorities, electricity suppliers, vehicle manufacturers, logistics providers and national/ regional development agencies. However, the trend towards electric fleets in logistics is starting from a very low base and most of the vehicles available on the market tend to have high purchase prices. These cost differentials will need to be reduced, or offset by government financial incentives, if a mass market in electric freight vehicles is to be established.

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PART FOUR
Key issues

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14

Sustainability strategies for city logistics

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Introduction

Approximately 80 per cent of European and North American citizens live in an urban environment. In Japan the urban population is over 90 per cent (CIA, 2014). The absolute and relative number of people living in urban areas is expected to continue to increase over the coming decades, especially in less developed regions. In 2011, 47 per cent of the population in less developed regions was living in urban areas; this is forecast to increase to 64 per cent by 2050 (United Nations, 2012). Due to their large populations and extensive commercial establishments, urban areas require large quantities of goods and services for commercial and domestic use. The growing importance of urban freight transport is related to increases in urban populations and continued economic growth in urban areas. This results in increasing levels of demand for freight transport services (European Commission, 2007).

Urban freight transport and logistics involves the delivery and collection of goods and provision of services in towns and cities. It also includes activities such as goods storage and inventory management, waste handling, office and household removals and home delivery services.

Freight transport in towns and cities responds very effectively to the requirements of modern urban economies. However, it is a major contributor to environmental impacts, particularly to local air pollution and noise and, as a result, has an important impact on the health of the most vulnerable residents of cities. Urban freight activities involve economic, social and environmental issues simultaneously and can result in conflicts. Under current conditions the economic viability of urban areas might actually be benefiting from socially and environmentally damaging freight transport operations. Moving towards a more sustainable urban freight system requires changes and innovations in the public and private sectors.

Urban freight research and policy making

It would be expected that, because of its importance to the urban economy and urban lifestyles, the topic of urban freight transport would have received much attention from government at the local, regional, national and internatland level as well as from researchers. However, surprisingly little attention has been paid to urban freight by researchers and policy makers until relatively recently. The majority of studies conducted on sustainable urban transport focus on passenger transport. A widely recognized requirement for reaching sustainable urban transport is integrated transport planning, but freight is rarely explicitly discussed as part of this integration (Lindholm and Behrends, 2012).

Research into urban freight transport issues took place in the UK during the 1970s. Much of this was related to concerns about the safety of heavy goods vehicles in urban areas and their exhaust emissions. This prompted several studies of urban transhipment and vehicle restrictions (for example, see Battilana and Hawthorne, 1976; GLC London Freight Conference, 1975; Hassell, Foulkes and Robertson, 1978; Nathaniel Lichfield and Partners, 1975). This took place against a backdrop of several national enquiries and reports into freight transport in the UK, such as the work of the Pettit enquiry (1973), the Lorries and the Environment Committee (1976) and the Armitage enquiry (1980). This UK research was not replicated in other European countries, and did not translate into policy making.

The level of urban freight research in the UK diminished, and between the late 1970s and mid-1990s, researchers and policy makers paid relatively little attention to the increasingly severe logistics problems facing urban areas. However, during the late 1980s and early 1990s there was much interest in city logistics and urban transhipment in France, Germany, and to a lesser extent the Netherlands, where numerous research projects were undertaken. In the case of Germany this frequently led to operational consolidation centre schemes being set up (usually referred to as City Logistik schemes). However, many of these have since closed (Flämig, 2004; Köhler, 2001; Köhler and Groke, 2003). In the United States, freight research was a subject of increasing interest up to the early 1980s when deregulation of the freight industry led policy makers to conclude that the government had no role in freight policy. This situation changed in the late 1990s when environmental issues forced policy makers to adopt a more proactive freight policy stance.

The urban freight transport and distribution considerations of national governments and local authorities have traditionally tended to take place as a reaction to problems, usually arising from complaints made by residents and other road users. Most local authorities with an urban remit have not developed coherent freight transport policies to the same extent that they have their passenger transport policies. However, this has begun to change over the last 10–15 years with growing interest in the logistics of collection and delivery services in town and city centres on the part of the various tiers of government both from the perspective of its economic importance and in terms of its impact on urban environmental sustainability. For example, in the UK local authorities have been encouraged by central government to focus greater attention on freight transport and to include consideration of urban distribution and its sustainability in their local transport plans over the last decade. The Department for Transport also encourages local authorities to include freight initiatives, especially Freight Quality Partnerships (FQPs)[1] in their local transport plans (DfT, 2009).

European and international research into urban freight transport has also increased since the late 1990s (for recent examples see Dablanc, 2009; Giuliano *et al*, 2013; Gonzalez-Feliu *et al* (eds) 2013; Muñuzuri *et al*, 2012; Rhodes *et al*, 2012; Taniguchi and Thompson, 2012; Vaghi and Percoco, 2011; Holguín-Veras *et al*, 2011).

Major EC-funded projects on urban freight have taken place over the last decade researching urban freight requirements and strategies, exploring the feasibility of new logistics equipment, developing intelligent transport systems, investigating the opportunities for increasing the sustainability of operations and achieving modal shift, and demonstrating new technologies, equipment and operations. Further information about these past and current EC-funded urban freight projects is available from several efforts to synthesize this material (BESTFACT, 2013; C-LIEGE, 2012; Stanchev and Whiteing, 2006; SUGAR, 2011). The EC-funded Best Urban Freight Solutions (BESTUFS) thematic network was formed in 2000 and continued until summer 2008. The main objective of BESTUFS was to identify, describe and disseminate information on best practices, success criteria and bottlenecks of urban freight transport solutions. Furthermore, BESTUFS aimed to maintain and expand an open European network between urban freight experts, user groups/associations, ongoing projects, the relevant European Commission directorates and representatives of national, regional and local transport administrations and transport operators. The project team organized regular workshops and conferences all over Europe and reports about interesting urban commercial transport-related developments, demonstrations and events at European, national, regional and local levels. Topics addressed at BESTUFS workshops included: vehicle access and parking regulations, urban goods vehicle design, e-commerce and last-mile solutions, non-road modes for urban distribution, road pricing, urban consolidation centres, public–private partnerships in urban goods transport, night delivery, ITS in urban goods transport, and urban waste logistics. The initiative received considerable attention from practitioners as well as from researchers, and all information was made publicly available via the website (BESTUFS, 2008).

A project entitled Transferability of Urban Logistics Concepts and Practices from a World Wide Perspective (TURBLOG) took place between 2009 and 2011 and aimed to achieve the same goals as BESTUFS but at a global scale, especially with reference to Latin America (TURBLOG, 2014). The Sustainable Urban Goods Logistics Achieved by Regional and Local Policies (SUGAR) project which was completed in 2011 aimed, by means of inter-regional cooperation, to improve the effectiveness of urban freight transport policies by promoting the exchange, discussion and transfer of policy experience, knowledge and good practice. A best practice guide to urban freight policies was one output of the project (SUGAR, 2011). The current Best Practice Factory for Freight Transport (BESTFACT) project has continued the urban freight information collection and dissemination work at an EU level that was started in BESTUFS (BESTFACT, 2014).

The Institute for City Logistics (ICL) was established in Kyoto, Japan, in 1999. The Institute is a centre of excellence for research and development in city logistics and urban freight transport, bringing together academics and practitioners to exchange knowledge, experience and information through conferences and short courses (Institute for City Logistics, 2014).

The METRANS Transportation Center organized and hosted the first Annual National Urban Freight Conference in North America in 2006. This brought together North American researchers and practitioners to consider urban freight in a specialist conference setting for the first time and has continued to grow and extend its international reach since then (METRANS, 2013).

The first EU–US urban freight research symposium bringing together academics and practitioners from both continents took place in 2013. This was jointly funded by the European Commission, the US Department of Transportation and the Transportation Research Board (Transportation Research Board, 2013).

In addition, the Volvo Research and Educational Foundations (VREF) have established two centres of excellence in urban freight transport as part of its Future Urban Transport programme. One named Metrofreight is researching ways to streamline the transportation and storage of goods in city centres while at the same time seeking to reduce the impact on traffic congestion, air quality and urban livability. It consists of university partners in Los Angeles, New York, Paris and Seoul, South Korea. The other, called Center of Excellence for Urban Freight Systems (CoE-SUFS, www.coe-sufs.org) is aiming to study and influence behavioural change in urban freight systems by seeking ways in which to internalize the external costs. CoE-SUFS contains 22 core and associate research partners in 16 countries (covering North America, central and south America, Africa, Asia, the Middle and Far East, Australasia and Europe). Both VREF centres will promote the practical application of knowledge and will collaborate closely with cities and industry partners (CoE-SUFS, 2014).

Efficiency problems in urban freight transport

The complexity of urban freight distribution along with the potential conflicts between key stakeholders (customers, local government, logistics service providers, inhabitants, retailers) requires an all-inclusive solution. Indeed, the movement of goods in an urban area is inherently complex due to the high number of stakeholders involved, intricate routeing patterns and the diversity of goods (Stathopoulos *et al*, 2012). Urban freight transport operations are responsible for a range of negative social and environmental impacts. These are relatively well understood and include fossil fuel consumption, greenhouse gas emissions, air pollution, noise, visual intrusion, physical intimidation (of pedestrians and cyclists), road safety and accidents, and road traffic congestion/disruption.

The problems experienced by those performing freight transport and logistics operations in urban areas are far less well understood. These include (Allen *et al*, 2000; Browne and Gomez, 2011):

- traffic flow/congestion issues caused by traffic levels, traffic incidents, inadequate road infrastructure, narrow street layouts and poor driver behaviour;
- transport policy-related problems, including neglect of freight transport issues in town and traffic planning, and other policy issues such as vehicle access restrictions based on time and/or size/weight of vehicle and width of bus lanes;
- parking and loading/unloading problems, including loading/unloading regulations, fines, lack of unloading space and handling problems;
- customer/receiver-related problems, including queuing to make deliveries and collections, difficulty in finding the receiver, and collection and delivery times requested by customers and receivers.

It is important to distinguish between the three different groups who are capable of implementing changes to the urban freight system, namely:

- Public policy makers (especially urban authorities) who make changes to urban freight transport operations through the introduction of policy measures that force or encourage companies to alter their behaviour.
- Freight transport companies that implement initiatives which reduce the impact of their freight operations because they derive some internal benefit from this change in behaviour. These benefits can be internal economic advantages from operating in a more environmentally or socially efficient manner, either through improved economic efficiency or through being able to enhance market share as a result of their environmental stance. Instances of company-led initiatives include increasing the vehicle load factor through the consolidation of urban freight, making deliveries before or after normal freight delivery hours, the implementation of IT for communications or planning purposes, improvements in the fuel efficiency of vehicles, and improvements in collection and delivery systems. Some of these initiatives are technology-related, some are

concerned with freight transport companies reorganizing their operations, and some involve change in the supply chain organization.

- Receivers of the supplies can exert a great deal of influence on urban supply chains, though only recently their role has been identified and exploited to foster urban freight sustainability. Inducing receivers to accept deliveries at night is at the core of the off-hour delivery project conducted in New York City (Holguín-Veras *et al*, 2011). Moreover, receivers could be encouraged to consolidate deliveries, as done within Delivery and Servicing Plans[2] (Transport for London, 2013), or to stagger their deliveries. These examples of demand modification – part of what may be called freight demand management – could lead to dramatic improvements in sustainability. More research is needed to identify the best ways to modify demand.

Inefficiencies in urban freight transport can occur as a result of existing road layouts or traffic levels. They can also come about due to non-freight urban transport policies that have unintended consequences on freight transport operations (eg the introduction of bus lanes). Another cause of inefficiency in urban freight transport can result from variations in urban freight transport policy measures in different urban areas or different parts of a single urban area. For example, different access or loading-time restrictions or vehicle emissions requirements within different parts of a city can be problematic for companies serving these locations with a single vehicle. It can result in the need for additional goods vehicles and goods vehicle trips. Such inefficiencies can have both financial and environmental impacts and are therefore best avoided from the perspective both of companies and of the wider society. This suggests the need for collaboration between public policy makers with responsibility for freight transport regulations in urban areas, as well as consideration of the benefits of harmonizing such regulations in order to avoid causing operational inefficiency.

The efficient usage of infrastructure in urban areas is of high priority to European cities, as in most cities urban space cannot be further increased for private transport purposes. The management of urban infrastructure usage in terms of time and space is of fundamental importance for city transport planners, resulting in various measures for regulating the use of urban infrastructure. For example, some cities already provide loading zones or bays for commercial traffic in order to improve the working conditions for transport operators in cities and to avoid negative effects due to delivery operations (eg second-lane parking).

Efficient and reliable deliveries are required to support the urban economy, both from local planners' and from the transport operators' perspectives. In order to reach efficient and sustainable approaches key issues to be taken into account include:

- vehicles making the deliveries should impose as few social and environmental impacts as possible;

- planners (from urban, city, municipal or local transport authorities), freight transport companies and other businesses must cooperate to ensure that these objectives are met;
- urban planners may need to influence or control the movement of goods vehicles;
- transport companies must optimize operational efficiency to reduce traffic congestion and environmental impact;
- receivers of the supplies, who define the operational constraints that carriers must meet;
- the types of policy measures required, which depend on factors such as:
  - the economic, social and environmental objectives of the urban authority;
  - the level of freight transport and other road traffic;
  - the size, density and layout of the urban area.

Over the last few years a variety of new experimental schemes have appeared. Information and communication technologies, together with mechanical access gates or variable message signs, have become less expensive and offer a variety of complex new access schemes tailored to the individual infrastructures of delivery areas. Besides the provision of infrastructure, some cities also provide value-added services of loading zones to carry out the deliveries (eg the possibility for short-term storage or support in transhipment).

Urban freight transport initiatives

Efforts to increase the sustainability of urban freight transport can focus on improving one or more of the economic, social or environmental impacts of these activities, without worsening the impact of the others.

Urban freight transport initiatives to achieve these economic, social and environmental goals can focus on: efforts to improve the efficiency of operations, greater use of environmentally friendly modes, reductions in the demand for freight transport (through reorganization of land-use patterns or supply chain organization), regulations to influence urban transport behaviour and patterns through the implementation of traffic and transport policies, and improvements in technological applications including vehicles, handling equipment and freight facilities.

Companies tend to be most interested in operational and market initiatives, while urban authorities and regional/national governments tend to be most interested in regulations, including those concerned with traffic movement, land use and vehicle technologies.

Various types of urban freight initiative and experiment have been implemented in towns and cities over the last decade. In order to present the full range of urban freight initiatives available, a classification system developed as part of a project for the Transportation Research Board in the USA has been adopted (Rensselaer Polytechnic Institute *et al*, 2014). The review of initiatives carried out in this project led to the identification of seven major categories, which were divided into supply initiatives at one end and demand initiatives at the other. These are: infrastructure management; parking/loading areas management; vehicle-related strategies; traffic management; pricing, incentives and taxation; logistical management; and freight demand/land-use management. The first four are supply-side initiatives and the latter three are demand-side initiatives. Brief descriptions of each of these seven categories are provided below:

1. *Infrastructure management*: these initiatives are intended to enhance freight mobility and are often necessary due to increases in vehicle size and general traffic levels. Major improvements include ring roads, and new and upgraded intermodal terminals. Minor improvements include redesigning the geometry of intersections and providing truck crawler lanes. The focus is on improving the supply side of freight systems.
2. *Parking/loading areas management*: these initiatives are intended to improve the way in which loading and parking space used by freight vehicles for collections and deliveries, are used. Both on- and off-street situations are included. Initiatives include loading-time restrictions, parking reservation systems and the creation of loading zones.
3. *Vehicle-related initiatives*: these initiatives seek to improve environmental conditions by fostering the use of technology and practices that reduce the negative externalities caused by freight vehicles. They include engine emission standards, and noise reduction programmes.
4. *Traffic management*: these initiatives aim to improve traffic conditions using techniques from traffic engineering and control. They include: vehicle access restrictions (such as vehicle size and weight restrictions, truck routes, and low emission zones), time restrictions (such as daytime restrictions, night restrictions) and traffic control and lane management (including multi-lane use and dedicated truck lanes).
5. *Pricing, incentives and taxation*: these initiatives use monetary signals to achieve public policy goals such as revenue gathering, fostering the use of emerging technologies and demand management. They include: road pricing, parking charges, financial incentives for supply chain partners to take specific actions, and certification and recognition programmes.
6. *Logistical management*: these initiatives are intended to alter the way in which delivery and collection work is carried out to reduce negative externalities, so that commercial activity is more consistent with livability and sustainability goals. They include the use of urban consolidation centres, locker banks, timed collections and deliveries,

intelligent transport systems, driver training programmes and vehicle anti-idling programmes.

7. *Freight demand/land-use management*: these initiatives focus on changing the underlying demand for freight transport rather than modifying logistical activities or vehicle traffic. This is the freight counterpart of transportation demand management, which aims to reduce passenger traffic. Such strategies include voluntary out-of-hours deliveries (OHD),[3] staggered work hours programmes, receiver-led consolidation, mode shift, land-use policy and the relocation of large traffic generators.

In order to achieve successful urban freight transportation decision making and implementation through the above strategies, a constructive process of engagement between the relevant public and private sector actors is usually required. This multi-stakeholder approach is required as there are many different actors involved in urban supply chains and freight transport operations, and also because no single stakeholder is usually capable of solving the problem on its own. Such engagement processes include forming FQPs, carrying out surveys, and holding seminars.

The most prominent of the urban freight strategies used in Europe and the USA in the last decade are summarized below:

- Environmental zones: these schemes, which are often primarily aimed at goods vehicles, aim to encourage the use of less polluting engine technologies in urban areas. Schemes have existed for almost 20 years in some Swedish cities and have since been introduced in many other European cities.
- Urban consolidation centres: these schemes can be either voluntary or compulsory and aim to reduce the number of goods vehicles making deliveries to establishments in urban areas by consolidating vehicle loads at centres based in or near the town or city for which they are destined, with final delivery by well-loaded vehicles. There are several examples of such centres in the UK (for example the London Construction Consolidation Centre, the Heathrow Retail Consolidation Centre and the Broadmead Retail Consolidation Centre) as well as in France (in Paris, La Rochelle and Monaco) and in Italy (in Milan and Padua).
- Collaboration between the public and private sectors: efforts to get policy makers working with other stakeholders in urban freight transport (especially carriers and their customers) can assist in improving understanding between the public and private sectors, aid problem identification and solving, and provide policy makers with an opportunity to receive feedback on their ideas and proposals. Examples of such joint working can be found in the UK (FQPs) and in the Netherlands (in initiatives developed by Platform Stedelijke Distributie (PSD), the Forum for Physical Distribution in Urban Areas).

- Vehicle access weight/size/time restrictions: these are among the most common types of regulations imposed by policy makers, and include loading and unloading restrictions at the kerbside. Innovations in this field include automated vehicle access control systems (which identify vehicles that are permitted to serve a particular area), the multi-use of road space by time of day in Barcelona, and the Nearby Delivery Area (ELP) scheme in Bordeaux, in which town staff assist with making deliveries.
- OHD and reduced noise from operations: the PIEK programme in the Netherlands has researched quiet technologies for urban delivery that could help in reducing the noise associated with night deliveries. A night deliveries scheme operates in Barcelona that makes use of quiet technologies, while in London the Lorry Control Scheme aims to reduce goods vehicle activity and hence noise in residential areas at night. In New York a goods delivery programme has been implemented to reduce the contribution of delivery vehicles to congestion and pollution during the period 6 am–7 pm by providing incentives to receivers for their commitment to accept OHD. At last count, more than 400 commercial establishments had adopted OHD.
- Use of home delivery locker banks and collection points: with the growth in home delivery operations in recent years efforts are being made to improve the efficiency of these trips by using locker banks (such as the Packstation scheme by Deutsche Post in European cities), shop-based collection points (such as the Kiala scheme that operates in several European countries and which was purchased by UPS in 2012), and the ability to specify a day/time and an alternative delivery location (such as UPS's My Choice scheme in the United States).
- Use of non-road modes (Quak, 2011): including the use of tram systems for freight movements (for example, the Cargotram scheme in Zurich, Dresden and Vienna) as well as the use of water-based modes (including the transport of waste by barge in Liege, DHL boat for parcel services in Amsterdam, beer and beverage deliveries by boat in Utrecht) and regional rail services such as the Monoprix example in Paris.
- Lorry-routeing schemes: either voluntary or compulsory schemes to provide suitable road networks and routes for heavy goods vehicles, such as the scheme in Bremen.
- Use/design of environmentally friendly goods vehicles: including the use of environmentally friendly road vehicles such as cargo bicycles and alternatively fuelled goods vehicles. Several urban consolidation centres make use of such vehicles, including La Petite Reine in Paris, which uses electrically assisted bicycle delivery, and Cityporto in Padua, which uses LPG and electric vehicles. Chronopost in Paris and the Nearby Delivery Area (ELP) scheme in Bordeaux also use electric vehicles. Cargo cycles also operate in the US cities of New York, Boston and Portland.

- Road pricing systems: these initiatives, such as the road pricing schemes in London and Norwegian cities, tend to be aimed at all road users, but do also apply to and affect the road freight industry.

Given the size limitations of this chapter it is not possible to discuss developments with respect to each of the urban freight initiatives listed above. Attention will focus on three specific initiatives that are commonly used by policy makers and operators in Europe and elsewhere: i) urban consolidation centres, ii) collaboration between the public and private sectors, and iii) environmental zones.

Urban consolidation centres

Broadly speaking, the key purpose of urban consolidation centres (UCCs) is the avoidance of the need for goods vehicles to deliver part loads into urban areas (be that a city centre, an entire town or a specific site such as a shopping centre). This objective can be achieved by providing facilities in or close to the urban area whereby deliveries (retail, restaurant, office, residential or construction) can be consolidated for subsequent delivery into the target area in an appropriate vehicle with a high level of load utilization. A range of other value-added logistics and retail services can also be provided at the UCC.

Much of the older literature on transhipment centres (and similar public-sector-driven initiatives) can be said to focus on 'the traditional break-bulk form of transhipment being implemented at an urban level on a communal, shared-user basis', with much attention devoted to the use of small vehicles for the urban distribution (McKinnon, 1998).

In contrast, much of the literature since the late 1990s talks of UCCs, which are generally seen to be more flexible and involve break-bulk, transhipment and groupage, often with a focus on maximizing vehicle loads, thereby avoiding the need for vehicles to deliver part loads into urban centres, and with a far greater role for the private sector.

Table 14.1 shows the basic characteristics of five UCC schemes in Europe. These schemes provide a range of operating characteristics, applying to both UK and non-UK schemes, a mix of sectors covered (though predominantly retail and construction, since these are most common), and examples of optional and compulsory scheme participation. The Stockholm scheme operated for a fixed duration and is now closed; all the others are still operational.

A major literature review identified the main advantages and disadvantages of UCCs (Browne *et al*, 2005). Table 14.2 shows the main positive and negative issues associated with them. It should be noted that, in many cases, these advantages and disadvantages are not backed up with evidence, but the ones shown here are those that are most frequently referred to in the literature.

TABLE 14.1 Key characteristics of selected UCCs

Centre	Location	Sector	Status	Terms of use
Bristol (Broadmead)	UK	Retail	Active	Optional
Sheffield (Meadowhall)	UK	Retail	Active	Optional
London (Construction)	UK	Construction	Closed*	Optional
Monaco	Monaco/ France	All	Active	Compulsory**
Stockholm (Hammarby)	Sweden	Construction	Closed	Compulsory**

NOTES: * – concept now applied to new site; ** – with certain exceptions

There is also some evidence that UCCs can offer the potential to improve the management of the supply chain (Allen *et al*, 2012). Figure 14.1 illustrates the range of logistics and pre-retail activities that can be carried out by a UCC and the potential benefits of these activities.

In the major review of UCCs previously referred to (Browne *et al*, 2005), 17 schemes were considered in detail and the following results were reported: reductions in vehicle trips were calculated to range from 30 to 80 per cent; reductions in vehicle-kms ranged from 30 to 45 per cent; improvements in vehicle load factors ranged from 15 to 100 per cent; and reductions in vehicle emissions ranged from 25 to 60 per cent. All of these results refer only to the change in transport activity associated with goods handled by the UCC (ie a comparison of the transport activity from the UCC to the receivers when the UCC is used and when it is not for those goods flowing through it) rather than the changes in total freight transport operations and impacts in the area covered by the UCC or the entire town/city.

The potential transport and environmental benefits of UCCs have to be weighed against the potential costs associated with consolidation that can include:

- capital and operating costs of UCCs;
- an additional handling stage in the supply chain;
- security, liability and customer service issues associated with additional companies handling goods.

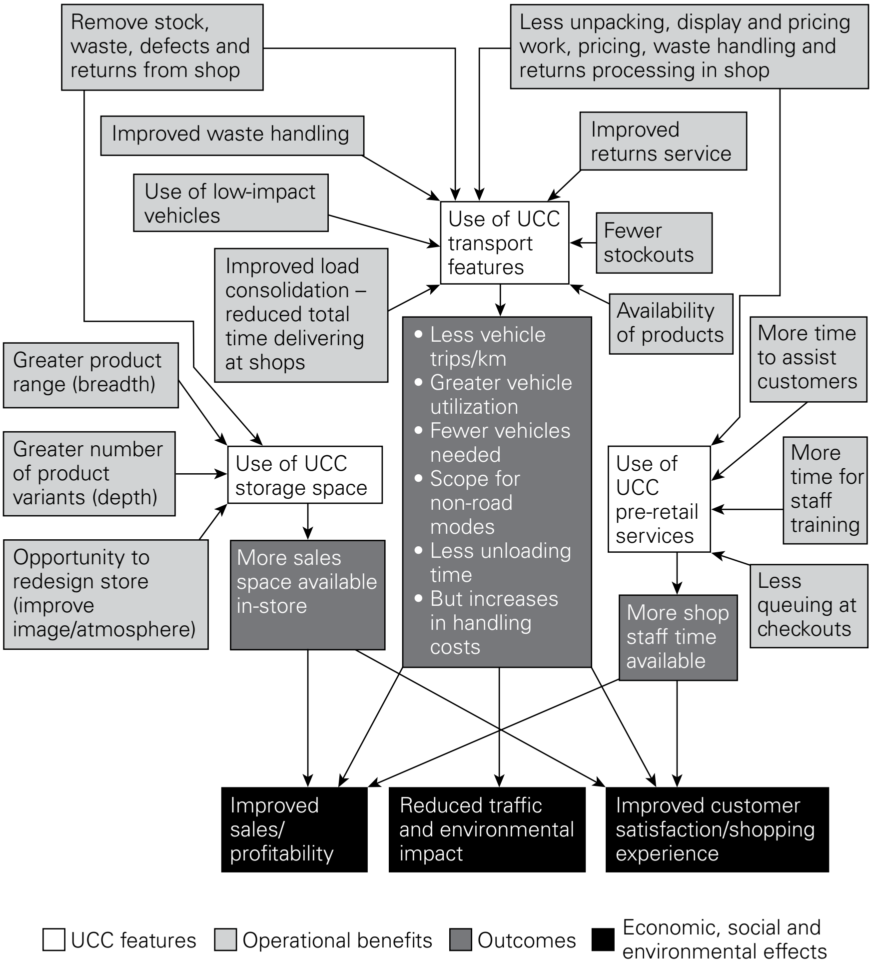
TABLE 14.2 Main advantages and disadvantages of UCCs

Main advantages	Main disadvantages
• environmental and social benefits resulting from more efficient and less intrusive transport operations within urban areas • better planning and implementation of logistics operation, with opportunity to introduce new information systems at same time as consolidation centre • better inventory control, product availability and customer service • can facilitate a switch from push to pull logistics through better control and visibility of the supply chain • potential to link in with wider policy and regulatory initiatives • theoretical cost benefits from contracting out 'last mile' • public relations benefits for participants • potential to allow better use of resources at delivery locations • specific transport advantages • opportunity for carrying out value-added activities	• potentially high set up costs (and sometimes high operating costs) • difficult for a single centre to be able to handle the wide range of goods moving in and out of an urban area, for example due to different handling and storage requirements • can result in an increase in delivery costs due to an additional stage in supply chain which imposes a cost (and often a time) penalty, though this clearly depends on how well the centre is integrated into the supply chain and the extent to which all costs and benefits are considered • a single consolidation centre for an urban area may be unattractive for some suppliers' flows due to the degree of diversion required from normal routes • lack of enforcement of regulations for vehicles not included in the consolidation scheme • loss of the direct interface between suppliers and customers

SOURCE: Browne *et al*, 2005

It is important to note that much urban freight is already consolidated at the intra-company level or by parcels carriers, so the benefits of trying to channel these flows through a consolidation centre may be limited. One of the main issues that remains largely unresolved surrounds the financial viability of UCCs. Those that operate on a voluntary basis and are not controlled by a single landlord all appear to require public funding, despite

FIGURE 14.1 Range of potential logistics and pre-retail activities at UCC and possible benefits



SOURCE: Browne *et al* (2005)

the promotion of value-added services as part of the UCC offer. UCCs are more likely to break even if participation can be made compulsory through planning or lease agreements, but this is difficult to achieve at present in most cases. Particular attention is required to ensure that private sector contributions are maximized, and that those who benefit from the UCC pay for its operation.

Collaboration between the public and private sectors

Urban freight transport and logistics involve many different stakeholders with diverse interests (including policy makers, retailers, wholesalers, freight operators, warehousing companies, residents, shoppers and workers). The global movement of people, goods and information has further accelerated the extent of diversification, which makes our lives exciting, for example by offering the consumer many choices. However, public decision making has required more efforts to coordinate these activities to ensure that they function efficiently, while at the same time minimizing the social and environmental impacts associated with them. In an attempt to reach democratic decisions that will achieve these objectives, policy makers have been working closely with other stakeholders on a range of urban freight issues.

Logistics activities are primarily performed by private companies. However, government (local and national) is expected to play a responsible role for many reasons – for example:

- coping with negative externalities such as road congestion and air pollution;
- necessary coordination with other public functions such as city planning, regional economic development and environmental management;
- cross-border administrative issues relating to international supply chain management.

Ogden (1992) argues that the urban freight system is far more complex and heterogeneous than urban passenger transport. Complexity and heterogeneity are driven by certain key features of urban goods movement, one of which is the range of participants involved in urban freight and the range of perceptions they hold of the 'urban freight problem'. Such complexity can make it difficult to develop successful participation between the public and private sectors.

During the late 1990s in the Netherlands, government became aware that the cooperation of the private sector is very important in order to implement public policies. Government therefore sought cooperation with the private sector and began to develop policies in full consultation with the private sector, in order to create win–win situations. This has meant that instead of regulation, local, regional and national governments now sign covenants with organizations representing business or directly with businesses. In these covenants the private sector agrees to behave in a particular way, while the public sector either provides facilities and finance, or reassesses and alters regulations. The policy agenda of PSD in the Netherlands was developed in cooperation with both the public and private sector. The implementation of the policy required the public and private sector to work together in a partnership (Bockel, 2002).

The Japanese national government authorized a set of policies for freight transport entitled The New Comprehensive Program of Logistics Policies in 2001, which was a revised version of an earlier programme, first launched in 1997. Urban freight transport is considered an important area in which to achieve efficient and environmentally friendly logistics systems in Japan. Two quantitative targets were set on 'the load factor of trucks' and 'peak-hour average travel speed' in three major metropolitan areas. In order to realize these targets, the programme highlighted the importance of coordination between public and private sectors, and between national and local governmental agencies, among others. The programme requested the local agencies to establish an independent organization to plan local logistics policies, and new round tables to exchange information on local logistics policies, inviting private representatives from bodies representing carriers and retailers (Browne *et al*, 2004).

Freight quality partnerships (FQPs) are a UK approach to freight transport partnerships between the public and private sectors that were launched by the Freight Transport Association (FTA) in 1996. The FTA initiative brought together industry, local government and representatives of local and environmental interest groups to pursue the following agenda (FTA, 1997):

- to identify problems perceived by each interest group relating to the movement and delivery of goods in their city;
- to identify measures within the group's competence to resolve or alleviate such problems;
- to identify best practice measures and principles for action by local government and industry to promote environmentally sensitive, economic and efficient delivery of goods in towns and cities.

The FQP initiative was tested in four UK urban areas in 1996: Aberdeen, Birmingham, Chester and Southampton (FTA, 1997).

The UK government has been promoting FQPs since 1999 (DfT, 2003a, 2003b). FQPs can facilitate improved dialogue about urban freight transport issues between local authorities, freight transport companies, retailers, manufacturers and other businesses, local residents and other interested parties. This can lead on to more efficient, less harmful operations. In their guidance document the government state that:

> Freight Quality Partnerships provide local authorities with a means to formalize the consultation and development work undertaken in their sustainable distribution strategy. Authorities have an integral role to play in helping industry, through developing partnerships to progress and develop best practice in sustainable distribution systems, and to find solutions to the issues of greatest concern.
>
> DETR, 2000

FQPs are a means for local policy makers, businesses, freight operators, environmental groups, the local community and other interested stakeholders to work together to address specific freight transport problems. The FQP provides a forum to achieve good practice in environmentally sensitive, economic, safe and efficient freight transport. The partners can exchange information, experiences and initiate projects regarding urban freight transport.

More than 120 FQPs have been developed in the UK (FTA, 2008). Their purpose ranges from regional planning through city or town-specific partnerships, to micro-level partnerships (maybe concerned with a few streets) and issue-specific partnerships. FQPs can be formed to address any type of geographical area, but the majority cover urban areas.

FQPs have resulted in a wide range of successful urban freight projects including:

- the production of specialist maps for freight operators and goods vehicle drivers;
- improved road signing;
- information boards and online truck information points (in lay-bys and service stations to provide essential information specific to goods vehicle drivers);
- reviews of parking and loading enforcement regimes and on-street loading/unloading provision.

London has been one of the most active UK cities in terms of FQPs. Four sub-regional FQPs, in central, east (Thames Gateway), south and west London were established, which act as 'umbrella' groups for all local freight initiatives. Each of these sub-regional FQPs consists of several London boroughs together with private sector participants. The issues addressed by some of these London FQPs are shown in Table 14.3.

TABLE 14.3 Issues addressed by selected London FQPs

London sub-regional FQP	Work carried out
Central	● Study of out-of-hours deliveries ● Working groups addressing: – Urban consolidation centres – Loading/unloading provision – Out-of-hours deliveries – Vans, servicing and utilities
South	● Freight industry stakeholder surveys ● Feasibility studies for urban consolidation centres ● Reviewing loading/unloading provision on high streets ● Identify Penalty Charge Notice hotspots ● Setting up a trial of night-time deliveries ● Organizing seminars

TABLE 14.3 *continued*

London sub-regional FQP	Work carried out
West	• Providing an information system for deliveries • Improved signage for drivers in several locations • Improved loading provision in Ealing Town Centre • Producing Delivery and Servicing Plans • Reviewing overnight parking provision • Carrying out delivery and servicing studies in Brent and Harrow • Review of fly-tipping
East (Thames Gateway)	• Urban freight study in Bexleyheath resulting in hotspot identification • Freight study in Belvedere industrial estates resulting in hotspot identification, lorry map and improved signing • Mapping expected construction projects • Mapping existing lorry parking facilities and determining demand for these in the medium to long term • Developing pilot project for River Thames

Environmental zones

Several terms are often used interchangeably when referring to this topic: these are 'environmental zones' (EZs), 'low emissions zones' (LEZs), 'Umweltzonen', 'Milieuzones', 'Lavutslippssone', 'Miljozone' and 'Miljözon'.

An environmental zone (EZ) is a defined geographical area that can only be entered by vehicles meeting certain emissions criteria. The purpose of an EZ is to either restrict or charge the most polluting vehicles if they enter the EZ when their emissions are over the set level. In this way, an EZ can lead to air quality improvements because it capitalizes on recent EU legislation for road vehicles, which has set progressively tighter emission limits on new vehicles manufactured over the past decade. EZs are implemented in locations in which air pollution has reached levels that are dangerous to public health. By introducing the EZ it is hoped that air quality will improve and that this will reduce the health problems and fatalities associated with poor air quality.

As noted by the Low Emission Zone in Europe Network (LEEZEN):

> air pollution is responsible for 310,000 premature deaths in Europe each year… more than caused by road accidents. Air pollution particularly affects the very young and the old and those with heart and lung diseases – both common causes of death in Europe. It also triggers health problems like asthma attacks and increases hospital admissions and days off sick. The human health damage that air pollution causes is estimated to cost the European economy between €427 and €790 billion per year. Because of this danger to health, many countries around the world, as well as the European Union (EU), have set air quality targets to be met. In the EU, it is in order to meet these targets that LEZs are being implemented.
>
> CLARS, 2014

Particulate matter (PM), nitrous oxides (NOx) (notably including nitrogen dioxide – NO_2), carbon monoxide (CO) and ground-level ozone (O_3) are all significant air pollution issues in Europe today. Road traffic is a significant source of both PM and NO_2.The Framework Directive 1996/62/EC describes the legal framework for the assessment and control of air pollution in the EU. Directive 1999/30/EC sets the limit values for PM and NO_2. If the limit values are exceeded, the air quality framework directive requires member states to develop 'plans or programmes' designed to ensure that the limit values are met. An EZ offers one approach by which emissions of these pollutants can be reduced in areas where road traffic makes a significant contribution to air concentrations and thereby (together with other actions) can help authorities to meet the European air quality standards. The EU noise directive will also require development of action plans in some areas, and EZs may be used to address traffic noise problems in affected areas in future (Joint Expert Group on Transport and Environment, 2005).

As mentioned above, an EZ can only be entered by vehicles that meet specified emissions criteria. This can be applied to just goods vehicles, a selection of motor vehicles or all motor vehicles. An EZ therefore differs from the following types of access restrictions that can be placed on goods vehicles in urban areas:

- weight restrictions;
- length restrictions;
- restrictions based on utilization of loading capacity;
- time restrictions;
- permanent street closures and pedestrianization schemes;
- road user charging.

However, the above types of access restrictions can be implemented in addition to an EZ. EZ schemes can take many forms based on their objectives, the geographical area they cover, the times at which the EZ is in force, the vehicle emissions standards required for vehicles to enter the zone, the types of vehicles that need to comply with the EZ, and the implementation and enforcement approaches used. EZs are seen as one of the options for helping to improve urban air quality. Table 14.4 summarizes the key features of EZs already implemented in Europe.

TABLE 14.4 Key aspects of current Environmental Zones in Europe

Key aspects of EZs	Practice in current EZs in Europe
Objectives of the EZ	The objective of an EZ is to improve environmental standards in the area in which the EZ is implemented. The main environmental goal is to reduce vehicle pollutant emissions and thereby improve air quality (helping to reduce fatalities and health problems caused by poor air quality). In addition EZs can also help to improve other environmental standards by reducing traffic noise, and improving road safety.
Geographical area covered by the EZ	Range from small, historic city centres (eg the city centre of Bologna which is 3.2 km^2) to entire cities (eg virtually all of Greater London – which is approximately 1580 km^2). The vast majority of existing EZs are located in urban areas (as this is where air quality levels tend to be worst), but there are examples of EZs on motorways in Italy and Austria.
Times at which the EZ is in force	Of the EZs already implemented all, with the exception of some of the Italian schemes, operate 24 hours a day, 365 days a year. Some of the Italian schemes are only in force for certain hours per day during winter months.
Vehicles included in the EZ restrictions	All current EZ schemes cover heavy goods vehicles over 3.5 tonnes. All EZs, with the exception of the Dutch schemes, also include buses and coaches. The London EZ also includes vans over 1,205 tonnes (unladen) and minibuses with over 8 seats. The German EZs cover all vehicles except motorcycles. Many of the Italian schemes include all vehicles. The inclusion of vans is currently being considered in some other existing EZs.
Emissions standards required by the EZ	Goods vehicle emissions standards required by EZs are based on Euro engine standards. Some EZs require heavy goods vehicles to meet Euro 1 and 2 standards, while others require Euro 3 or Euro 4 standards. Some schemes permit older vehicles to be retrofitted in order to meet the required emissions standards, while others do not.

TABLE 14.4 *continued*

Key aspects of EZs	Practice in current EZs in Europe
Enforcement approaches used in the EZ	Some current EZs use manual enforcement, while others use automated systems. Manual systems typically involve vehicles having to register and then stickers having to be displayed on windscreens which are manually checked by police. Automated systems make use of fixed and mobile camera-based ANPR (automatic number plate recognition) and number plate checking with the relevant national vehicle registration body.
Fines imposed on non-compliant vehicles entering the EZ	Range from €40 (and one point in the national traffic penalty register) in Germany to £500–1,000 in London (approximately €600–1,200).

Table 14.5 summarizes the EZs that have already been implemented or that are planned to be implemented soon in European countries, based on information currently available.

An assessment of the air quality benefits of the Stockholm scheme in 2000 found that emissions of nitrous oxides (NOx) from heavy vehicles within the zone were reduced by 10 per cent and emissions of particulates by 40 per cent. The corresponding reductions in air pollution concentrations were estimated at 1.3 per cent reduction for NOx (with a range of 0.5–2 per cent) and 3 per cent for particulates (with a range of 0.5–9 per cent), compared with the predicted concentrations without the zone. The air pollution reductions are much lower than vehicle emission reductions because of the relative importance of goods vehicles to total air quality concentrations. The analysis also concluded that the effect of the EZs was large when compared with other actions that it was possible for the local city administration to implement (Johansson and Burman, nd).

The Gothenburg EZ has produced the following reductions in vehicle emissions: 3.6 per cent reduction of carbon monoxide (CO), 6.1 per cent reduction of hydrocarbons (HC), 7.8 per cent reduction of NOx and 33.2 per cent reduction of PM (Roth, 2007; Schoemaker, Dasburg and Allen, 2008).

Evaluation of the EZ schemes in the Lombardy region of Italy has shown daily mean emission reductions of 7 per cent for PM10 and NOx, and 11 per cent for CO (Joint Expert Group on Transport and Environment, 2005).

Monitoring work on the London LEZ has noted some small improvements in air quality since its introduction (Transport for London, 2008).

TABLE 14.5 Planned and existing Environmental Zones in European cities and regions (as at May 2012)

Country	Existing and Planned EZs
Austria	One scheme on the A12 motorway started in 2007. There is also a scheme in Graz and many other larger towns in the Steiermark area.
Czech Republic	An EZ exists in Prague.
Denmark	EZs have been operating in centre of Copenhagen and in Frederiksberg since 2008 and in Aalborg since 2009. EZs also started in Arhus and Odense in 2010.
Germany	EZs have been operating since 2008 and are currently in force in approximately 70 towns and cities.
Hungary	An EZ started in Budapest in 2011.
Italy	EZs operate on the A22 motorway, in Bologna, Brescia, Florence, Milan, Napoli, Palermo, Parma, Rome, Torino and Verona as well as in towns and cities in the following regions (during winter months and specified hours per day): Emilia-Romagna, Lombardy, Piedmont, Venetia, Bolzano-Bozen, Valle d'Aosta, Toscana, Trentino and Umbria.
The Netherlands	EZs have been operating in 7 cities since 2007, another 2 cities since 2008 and further 4 cities since 2010. Arnhem is also introducing an EZ in 2014.
Norway	EZs are planned in Bergen, Oslo and Trondheim for 2015.
Portugal	One EZ has been operating in Lisbon since 2011.
Sweden	EZs have been implemented in Stockholm, Gothenburg, Lund, Malmo, Helsingborg, Uppsala and Molndal. An EZ is starting in Umea in 2014.
UK	An EZ was implemented in London in 2008. It covers virtually the whole of Greater London and is the largest EZ in Europe. A small EZ operates in Norwich city centre and Oxford is also planning to start an EZ by 2014 but these two schemes are only intended for buses.

SOURCE: Based on information in CLARS, 2014; Tuero, 2008; and the authors' own knowledge

Conclusions

There are no standard, easily applicable solutions to the problems caused and experienced by freight transport in urban areas. However, the goal ought to be to identify public policy measures and initiatives that ensure safe vehicle operation, promote economic vitality and lead to environmental improvement.

Policy makers will probably need to adopt a range of policy approaches to address urban freight transport and its relationship with sustainable development. They should make use of both encouragement and compulsion in their efforts. In some cases it will be necessary to impose restrictions on certain aspects of goods vehicle operation and to enforce these restrictions so as to meet safety and environmental objectives. LEZs are an example of this type of approach. In other cases, more progress is likely to be made by working closely with the private sector to improve the efficiency and reduce the negative impacts of urban freight. The FQP approach is achieving some success in raising the level of dialogue between all the parties involved, identifying the key issues and problems, and implementing solutions. Whether the FQP approach can achieve sustained progress in the implementation of economic and environmentally sustainable urban freight solutions across all urban areas remains to be seen.

Strategies designed by the public and private sectors to increase load consolidation and/or reduce delivery frequency (such as the use of UCCs, fiscal measures to encourage improved lading factor, or company-led supply chain innovations to improve the efficiency of distribution) have the potential to reduce the number of goods vehicle rounds quite considerably. To achieve increased levels of load consolidation, public policy makers should avoid the unnecessary use of weight and time restrictions on goods vehicle operations, confining such restrictions to specific local situations as required.

Notes

1 FQPs are an approach to achieving closer working relationships between freight stakeholders in the public and private sectors in order to identify and resolve local or regional freight transport problems and difficulties. Members of FQPs typically include representatives from freight operators, freight receivers, local government, trade associations, enforcement agencies and local interest groups.

2 Delivery and Servicing Plans (DSPs) were introduced by Transport for London in 2008 to help receivers of goods to make deliveries to their buildings more efficient and mitigate the traffic and environmental impacts. DSPs are intended to provide a framework to better manage all types of freight vehicle movement to and from individual buildings of all types (including shops, offices, factories, and depots).

3 Out-of-hours deliveries (OHDs) refer to those deliveries that take place outside normal working hours to avoid traffic peaks (which are sometimes also known as night deliveries). In the US this is referred to as off-hours deliveries. The term is abbreviated to OHD in the rest of this chapter.

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15

E-business, e-logistics and the environment

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Introduction

The term 'e-business' was coined by Lou Gerstner, CEO of IBM to describe the transformation of key business processes through the use of the internet (IBM, 1997). E-business (or e-commerce) refers to the online buying and selling of goods and services, collaboration among external business partners and the handling of electronic transactions within an organization (Turban *et al*, 2008). A distinction is often made between business-to-business (B2B), business-to-consumer (B2C) and consumer-to-consumer (C2C) e-commerce (the focus of this chapter being B2B and B2C). It is estimated that by the end of 2014, 3 billion people will be connected to the internet, representing roughly 40 per cent of the world's population (www.internetlivestats.com). In recent years, the development of mobile technology has significantly increased the reach and capability of internet-based services and trading.

The development of e-business has transformed the way in which supply chains are structured and managed at both the B2B and B2C levels. In some sectors it has permitted disintermediation, allowing intermediaries (such as wholesalers and retailers) to be bypassed and promoting more direct distribution from producers to customers. In the B2C market, many supply chains that used to end at the shop now extend to the home. The internet has facilitated the search for suppliers of industrial and consumer goods, promoting the sourcing of goods over much wider areas. The online trading of logistical services, through so-called 'freight exchanges', has helped carriers to obtain backloads and bundle freight flows into more economically sized loads. All of these developments have affected the environmental footprint of logistics operations at different geographical scales. Early research by Crowley (1998) and Hesse (2002) anticipated some of these environmental impacts. The aim of this chapter is to consider whether over the past 20 years e-commerce has helped or hindered efforts to green companies' logistics operations. The B2B and B2C impacts will be considered separately.

Business-to-business (B2B)

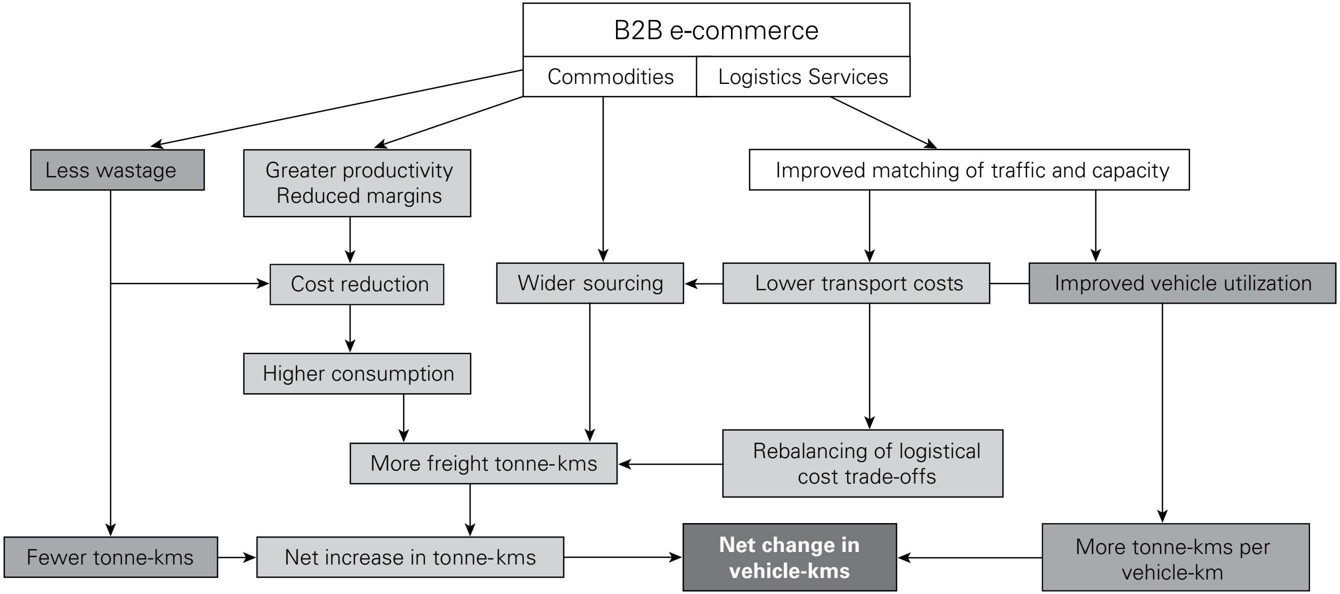
Figure 15.1 maps the complex interrelationship between the growth of B2B e-commerce and the amount of freight movement. It highlights the difficulty of assessing the net impact of e-commerce on the greening of logistics.

In Figure 15.1, a distinction is made between the online trading of commodities and logistical services. The trading of commodities through e-marketplaces reduces prices partly as a result of an intensification of competitive pressures but also through productivity improvements. These price reductions are likely to stimulate a growth in demand and hence an increase in the quantity of freight to be transported. E-commerce also makes it easier for companies to trade with more distant suppliers and customers. This will have the effect of lengthening supply chains and reinforcing the growth of tonne-km. These trends may be partly offset by a reduction in the wastage of product and unnecessary movement of inventory. This is based on the reasoning that online trading and improved supply chain 'visibility' should improve the coordination of supply and demand. Overall, this is likely to moderate the increase in tonne-kms.

The growth of online freight exchanges and web-enabled tendering for logistics services helps companies match traffic flows more closely to the available transport capacity (Rowlands, 2003). Vehicle load factors then rise and the greater efficiency is often reflected in a reduction in haulage rates. This reduction in rates is reinforced by a strengthening of competitive pressures within the e-market and some narrowing of margins. The decline in transport costs indirectly encourages the trend to wider sourcing of products. It also causes companies to rebalance their logistical cost trade-offs between transport, inventory, warehousing and production, promoting a shift to more centralized systems which generate more tonne-km per tonne distributed. This reinforces the tonne-km growth associated with online commodity trading. The resulting increase in tonne-kms, however, does not necessarily translate into a proportional increase in vehicle-kms on the ground. This is because the improved utilization of vehicle capacity reduces the ratio of vehicle-km to tonne-km, mitigating the net effect on traffic levels. It is largely through these traffic levels that the environmental effects of e-commerce are mediated within the logistics sector.

This model illustrates the critical role of e-marketplaces (EMs), both for commodities and logistics services, in influencing environmental outcomes. Definitions of an EM are diverse. One of the earliest and broadest definitions is offered by Bakos (1991: 2), who referred to an EM as 'an inter-organizational system that allows the participating buyers and sellers to exchange information about price and product offerings'. Daniel *et al* (2004: 279) narrowed the definition and described EMs as 'web-based systems

FIGURE 15.1 Interrelationships between B2B e-commerce and freight traffic levels



which enable automated transaction, trading or collaboration between business partners'. Utilizing the web has considerably reduced the complexity and cost of implementation, and integration with other systems. In the context of logistics, EMs can be termed electronic logistics marketplaces (ELMs).

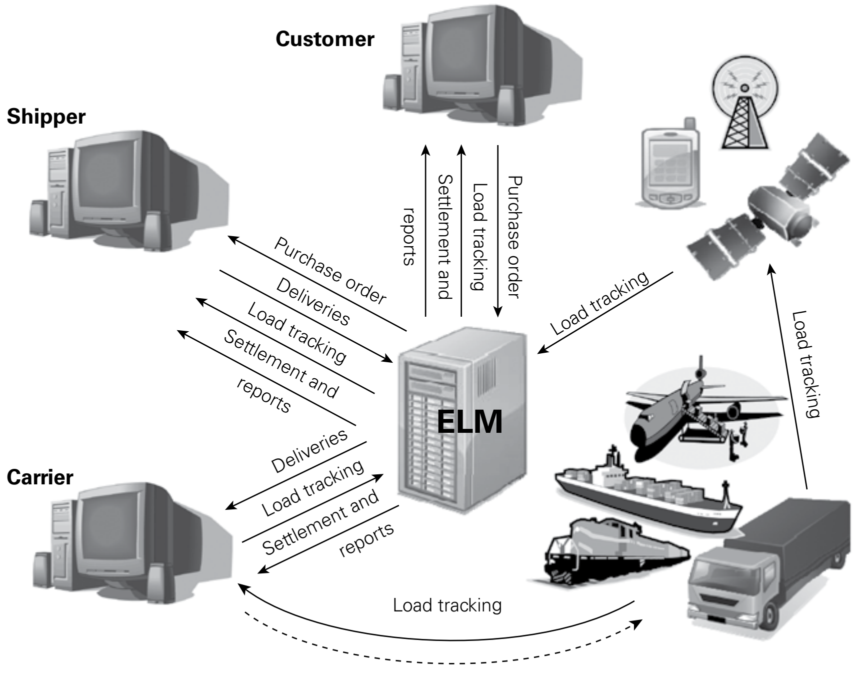
ELMs have grown quickly as viable alternatives to large scale client-server solutions, especially where they take advantage of the development of 'cloud computing' (IBM, 2009). This has involved data being stored by the technology provider and accessed through the internet, providing lower-cost access to ICT services. Combined with the fast pace of development in mobile technology, this means that logistics operations can be controlled from almost anywhere in the world at any point in time. Figure 15.2 provides a generic overview of ELM operations, although the exact functionality varies across the different types of marketplace.

ELMs and the freight modal split

Figure 15.1 models the B2B impact of e-commerce on freight traffic levels. It sheds no light on the allocation of freight volumes between transport modes. Environmental impacts, however, will be very sensitive to this modal split, as discussed in Chapter 7.

The adoption of a multi-modal transport strategy helps companies to green their logistics and ELMs can assist this process. Traditionally multi-modal

FIGURE 15.2 Overview of an ELM



transport has either been directly managed by a shipper or indirectly sourced via an intermediary such as a freight forwarder. Under both scenarios, the complexities of dyadic information exchange between organizations often lead to longer lead times, increased landed cost (the total delivery cost of a product) and more goods-in-transit inventory. This in turn has posed significant challenges to companies in gaining the necessary degree of supply chain visibility to respond quickly to disruptions as well as find ways to cut cost. Lack of visibility has dampened interest in using multi-modal transport, especially for short- and medium-distance movements. Many ICT visibility tools have been developed in recent years in an attempt to address the multi-enterprise visibility issue. This has led to a concept of e-multi-modal connectivity.

E-multi-modal connectivity is facilitated by web-based inter-organizational information systems which can be either open or closed. The closed system is usually initiated by a leading supply chain player, for instance a shipper or a carrier, focusing on the planning and management of an individual supply chain. The open initiative is usually led by a port or airport authority, using their terminal as the central point of coordination and control through which multiple supply chains are routed. By tracking each individual consignment in real time, such systems give organizations a digital footprint of their freight transport operations and thus support the smooth planning and execution of freight movements across various transport modes.

A typical example of a closed initiative is an ELM in which shippers (consignors), carriers and customers (consignees) use the single platform to manage the order-to-delivery process. GT Nexus (http://www.gtnexus.com) is a neutral platform used by around 25,000 businesses. Removing the dyadic B2B connections, this e-platform allows multiple supply chain partners to form a closed community and collaborate with each other simultaneously. The system offers modular choices of function, from freight tendering and contract management, to shipment planning and execution including cross-border customer clearance, financial settlement and performance management. The system is capable of providing visibility down to individual item level, though for many organizations visibility at consignment level is sufficient. The on-demand pricing model eases the heavy financial burden of infrastructure and software deployment, making this type of ELM an attractive choice for small and medium-sized companies. It can also provide real-time information about product positioning.

The open initiative is often known as a ‘single window system’ which interconnects various members from both the private (such as freight forwarders, shipping lines, carriers) and public sectors, focusing on cross-border transactions and information exchange. Hence the role of shippers, who are often the most powerful players in the supply chain and often the leaders of the closed community in the private e-multi-modal system, is less significant in an open ELM. Portbase (http://www.portbase.com) is a port community system jointly initiated and funded by the ports of Rotterdam and Amsterdam. It is an independent and not-for-profit organization and has around 2,300 registered business users. It also deploys a 'pay as you go' pricing model in which users pay per transaction. The primary purpose of this system is to establish a hub through which port-related companies can efficiently exchange data, both with each other and with the authorities, such as the port operators and Customs.

In the case of import processes, individual companies are able to perform certain online actions such as submitting a cargo declaration report to Customs, and monitor each status via the use of a self-managed account. Once the cargo is released and off-loaded from the vessel, road hauliers or rail operators will pick up the cargo and deliver to its next or final destination. These single-mode freight operators benefit from a road/rail planning module within the system which automatically generates pre-arrival notices and provides a detailed status update on each individual container. This port community system plays a crucial role in ensuring a smooth transit of cargo from water to either road or rail and can offer environmental benefits. The nature of the benefits arising from B2B logistics marketplaces are discussed in the next section.

Environmental impact of B2B marketplaces

Many of the environmental benefits from using an ELM are closely associated with economic benefits. A key feature of ELMs is the ability to use triangulation to reduce transport demand. Triangulation occurs where two separate return journeys (A–B and B–C) are replaced by a single triangular route (A–B–C). This improves the backloading of vehicles and helps to reduce the amount of empty running. Within open systems, carriers can bid for return loads where the vehicle would otherwise be returning empty. This ad hoc system will not necessarily generate an optimum solution but will reduce the level of empty running. With a closed system, triangulation can be managed more effectively as account is taken of the opportunities when the transport system is being planned. This improves the degree of optimization and can be enhanced when triangulation not only occurs within networks but also across them.

In the case of closed ELMs participation is restricted to a particular set of carriers and shippers though this can result in greater functionality, particularly in the area of load planning. Shippers can impose constraints on which carriers they use. Nowadays the opportunity exists also to impose environmental criteria, such as compliance with environmental quality assurance standards (such as ISO 14000) or the use of vehicles meeting certain emission standards.

In terms of shipment planning, some closed ELMs allow carriers to input the availability of vehicles on a daily basis. From this, the system can then optimize deliveries so as to make the best use of each vehicle's capacity as well as maximizing the opportunities for backloading. The system will also identify opportunities for consolidation, either within a single network or across different networks, depending upon the type of ELM used. If demand exceeds supply, there may also be the chance to delay deliveries to avoid the spot hire of vehicles, which may then result in an empty return journey.

Finally, many closed ELMs offer the opportunity for tracking and tracing loads. Where this occurs on a real-time basis, it may be possible to identify opportunities to re-route vehicles away from areas of congestion. This may mean that the vehicle needs to travel further. From an environmental perspective, the emissions from these extra miles need to be balanced against those arising from the vehicle whose fuel efficiency is impaired by traffic congestion. In the context of road haulage, this information is increasingly being integrated with telematics information from on-board computers. Similar management approaches are also being adopted in the rail freight industry.

Examples of how the principles and processes of ELMs have brought environmental benefits can be found in Freight Best Practice (2007, 2008 and 2011).

Business-to-consumer (B2C)

B2C e-commerce is simply online retailing using the internet as a medium for placing orders, through which the consumer interacts directly with the supplier. With the advent of internet shopping, the 'store-reach' boundaries of the retailer have been geographically extended to offering goods to the final consumers who, given the distances involved, cannot physically 'shop' for them in the conventional sense. The combination of convenience, product diversity and, often, discounted price, has made this 'e-tailing' very attractive to the expanding population of consumers with internet access – hence the phenomenal growth of this form of e-commerce. Global B2C online sales exceeded $1.0 trillion for the first time in 2012 and are expected to be around $2.4 trillion by 2017, with almost 60 per cent of this growth predicted to occur in the Asia-Pacific region (eMarketer, 2014).

The UK is firmly established as a highly developed online retail market, with online B2C purchases representing 13.5 per cent of total retail sales in 2011 and expected to rise to 23 per cent by 2016 (Boston Consulting Group, 2012). According to the OECD, the percentage of the population shopping online in the UK is the highest in the world (*Daily Telegraph*, 1 Feb 2012).

Types of online retail operation

- *Multi-channel retailers (bricks and clicks)*: many traditional shop-based retail companies have successfully reinvented themselves as multi-channel retailers, retaining a physical presence (in *bricks*) while establishing an online platform (*clicks*), running both 'fulfilment' channels in parallel. Some retailers exploit synergies between the 'bricks' and 'clicks' sides of the business by using the same logistics assets for supplies bound for shops and homes (Agatz *et al*, 2008). Some hold a common inventory in upstream distribution centres and decouple the two fulfilment channels close to the customer. For example, most of the UK supermarket chains pick most or all of online grocery orders in their shops. Other retailers, particularly in the non-food sectors, operate different logistical systems for their online and store-based offerings. The presence of physical stores, nevertheless, makes it easier for online customers to return unwanted or damaged products. Established retailers can also gain from their existing brand identity and attract customers outside their shop catchment areas.

In recent years, many large brick-and-click retailers have deployed 'omni-channel' logistics strategies to enable them to supply products quickly and efficiently to consumers in many possible locations with products purchased in many different ways (Carroll and Guzman, 2013).

Many multi-channel retailers now offer a *click-and-collect* option, allowing consumers to purchase goods online and collect them from a store of the customer's choice in as little as 30 minutes after the original order was placed. Once in-store, customers can be encouraged to make supplementary offline purchases. IMRG (2014) estimates that click-and-collect accounts for a quarter of the sales of multi-channel retailers in the UK, showing how successful this combination of online ordering and customer collection has become.

- *Pure-player retailers (e-tailers)*: e-tailers are dedicated online retailers, who use the internet as their only means of trading. In Germany, pure-players held 35 per cent of the online retail market in 2013 and were enjoying faster sales growth than their multi-channel competitors. These retailers have had to set up distribution (or 'fulfilment') centres for storage and order picking, though rely heavily on existing parcel delivery networks to get orders to customers.
- *Mail-order companies*: catalogue and mail-order companies have diversified into the online market, seeing the potential of the internet to lure additional younger and wealthier clientele to those who traditionally bought from catalogues. Online orders now represent a large share of mail-order companies' sales. In the US the number of mail-order catalogues distributed to consumers dropped 42 per cent from 19.6 billion to 11.4 billion between 2007 and 2012, though research suggests that the use of catalogues will retain an important role in the retail market (Kurt Salmon, 2013).
- *E-auction companies*: some companies sell through e-auction sites such as eBay in addition to other media. Many sell their left-over stock, returns and slightly defective products on such sites, but increasingly companies are viewing this as just another medium through which to sell their normal goods.

The huge growth of online retailing has caused a major restructuring of supply chains. The traditional retail logistics model comprising bulk deliveries from distribution centres to shops and customer collections from these outlets has declined in importance. Online non-food orders are typically picked at an item level in large e-fulfilment centres and channelled through the hub-and-spoke networks of parcel carriers to consumers' homes. Van deliveries have been substituted for personal shopping trips mainly by car or public transport. The logistics of online grocery retailing has been less transformational as much of the order picking is done is supermarkets and all that has changed is the replacement of a customer collection by a van delivery. Once the volume of online grocery business exceeds a threshold level, however, it is advantageous for supermarket chains, in operational and financial terms, to move the order picking to dedicated fulfilment centres (or 'dark stores'), as Tesco has done in the south-east of England (Fernie *et al*, 2014).

In the next section, we examine the environmental implications of adaptation of retail logistics operations to the steep growth in internet shopping.

The environmental impact of B2C e-commerce

Online retailing can have wide-ranging environmental effects not just through the physical distribution of products, but as a consequence of increased IT usage, the redesign of packaging and changing patterns of consumption (Fichter, 2003; Abukhader and Jönson, 2003). In this section, however, we will focus on the impact of online retailing on transport-related externalities.

In many countries, vans (or light goods vehicles) are the fastest-growing category of traffic, and some of this growth is being driven by the huge expansion of online retailing and home delivery. In the UK, however, the Commission for Integrated Transport (2010), noted that 'we must not get this out of perspective as home deliveries are only a small proportion of van use' (p ii). On the other hand, vans are second only to aircraft in the amount of energy they consume per tonne-km of freight movement (McKinnon, 2007). In 2003, the average small van (of 1.5 tonnes gross weight) generated around 4.6 times more CO_2 per tonne-km than the average 44-tonne truck (Department for Transport, 2004). When assessing the relative environmental impact of B2C e-commerce though, the main comparison is not between vans and trucks, but rather between vans and cars, as van deliveries can replace car-borne shopping trips. This substitution of vans for cars on the so-called 'last mile' to the home is by far the most critical element in this environmental comparison. Several e-retailers have been claiming in their advertising that shopping online, rather than by conventional means, yields an environmental benefit (Smithers, 2007). Several studies have tried to test the validity of this claim, including Matthews *et al* (2001), Rotem-Mindali (2010), Edwards *et al* (2010), Weber *et al* (2011), Rizet *et al* (2012) and van Loon *et al* (2014).

Edwards *et al* (2010) reported the results of a UK comparison of carbon emissions from the distribution of books bought online and delivered to the home or purchased from a book store on a personal shopping trip. Although the study was concerned with books, these were representative of a range of small, non-food consumer goods. In conducting a comparison of this type a series of methodological issues have to be resolved, particularly as the relative carbon footprints of the two types of order fulfilment depend on numerous operational, geographical and behavioural factors which can be highly variable (Edwards *et al*, 2011). In the case of conventional, shop-based retailing, key parameters include the fuel efficiency of the cars and buses, their occupancy levels, the number of items purchased per trip and the degree of trip-chaining (ie the linking of different visits and activities on a single trip). On the online/home delivery side, the main parameters include the loading and fuel efficiency of the vans, the types of van used, the drop densities, the probability of a successful first-time delivery and the likelihood of the goods being returned. To keep the degree of variability manageable the researchers made simplifying assumptions and based their comparison on mid-range values.

Carbon emissions were measured from the point upstream in the supply chain at which the online and conventional retail channels diverge, to the final destination at the consumer's home. Emissions from transport, warehousing, materials handling and shop-based retailing operations were included in the calculation. Personal travel to the shops could either be by car or bus. When compared on a supply chain basis (from the point of divergence), online fulfilment emitted approximately 8.3 times less CO_2 per book than conventional retail when the consumer travelled to the shop by car and 2.8 times less when their trip was by bus. When the comparison was confined to the last link to the home, home delivery by van commanded a 24-times carbon advantage over a car-based shopping trip and a 7-times advantage over a trip by bus. This amplification of the relative carbon savings from home delivery reflected the fact that, respectively, 87 per cent, 75 per cent and 30 per cent of the supply chain CO_2 was emitted from the car trip, bus journey and van delivery at the last-mile level.

This comparison rested on a number of critical assumptions: for example, that the personal trip was made solely for shopping purposes, the book ordered online was successfully delivered first time and not returned, and that average UK travel distances, drop densities and vehicle fuel efficiencies applied. The research also assessed the sensitivity of these CO_2 estimates to the various assumptions (Edwards and McKinnon, 2009). The results of this UK research broadly confirmed the earlier findings of Matthews *et al* (2001) in the United States, that online retailing has an environmental advantage over conventional retailing, particularly where the latter involves a car trip. Weltevreden and Rotem-Mindali (2009) found that, in the Netherlands, B2C e-commerce slightly reduced the amount of personal travel and slightly increased the amount of freight transport, with the 'net mobility effect' being a marginal reduction in transport overall.

Key parameters in the online vs conventional retailing comparison

- *Delivery time windows*: home deliveries are either 'attended' when someone needs to be there to receive the order or 'unattended'. For attended delivery, the width of the 'delivery window' and its scheduling are crucial. For the supplier/carrier, the wider the delivery window the lower the delivery cost, whereas for the customer, the narrower the delivery window the less time is spent waiting. At the heart of online retail logistics is this conflict between delivery efficiency and customer convenience. Carriers also find that the wider delivery window, the greater the probability of no one being at home and hence a failed delivery.
- *Failed delivery*: estimations of first-time delivery failure rates vary considerably. For instance, in the UK, figures range from almost a quarter (McLeod *et al*, 2006) to one in every eight attempts (IMRG, 2012). Such delivery failures lead to increased costs on the part of carriers as packages need to be redelivered at a later date. Ultimately, after several failed attempts at delivery, a very small percentage of parcels are returned to sender, or, being undeliverable, are disposed of by the carrier. Edwards *et al* (2010) found that the additional CO_2 from a second delivery attempt increases the emissions per drop by between 9 and 75 per cent (depending on the delivery failure rate). The vast majority (85–95 per cent) of emissions emanating from traditional failed delivery arise, not from the repeat van delivery, but from the customer travelling to the carrier's depot to collect the order. This study showed how the use of a collection point, such as a small shop or post office, could substantially reduce the CO_2 penalty associated with a failed home delivery.
- *Returned products*: online retailers experience far higher product returns than conventional retailers (Park and Regan, 2004), although the return rates depend largely on the type of product. Fashion clothing, for instance, has some of the highest return rates at between 20 and 50 per cent. To minimize the impact of returns on their operations, a parcel carrier may choose to collect returned items as part of their usual outbound delivery round. When dedicated pick-up runs are deployed for returns, additional mileage and emissions result. Many customers favour returning items via the postal services, in which case, the addition of returned items within the usual postal network will have a negligible environmental impact.
- *Degree of vehicle substitution*: environmental comparisons of online and conventional retailing typically assume van deliveries will replace a large proportion of the car and bus trips that consumers would have otherwise made to the shops. This is unlikely to be the case, however, as some consumers will use the shopping time saved to

make other types of trip, often by car and sometimes to more distant locations. Any net reduction in total travel and related emissions may therefore be quite small, as Weltevreden and Rotem-Mindali (2009) found in the Netherlands. Research has also shown that even when consumers order the bulk of their weekly groceries online and have them delivered, they still make trips for interim 'top-up' purchases. Environmental modelling by van Loon *et al* (2014) found that these 'complementary' trips could add between 7 and 29 per cent to carbon emissions from the online retailing of fast-moving consumer goods. This further reduces the net environmental benefit from online retailing.

Opportunities for improving the relative environmental performance of B2C e-commerce

The environmental footprint of online retailing can be reduced in relative and absolute terms in several ways:

- *Wider adoption of unattended delivery systems*: the ability to deliver products to the home or a local collection point on an unattended basis virtually eliminates the risk of a delivery failure, removes the need to redeliver the order and allows carriers to route and schedule vehicles much more efficiently. Modelling by Nockhold (2001) in London found that, by comparison with having attended delivery time windows of three hours, unattended delivery reduced transport costs by one-third. Fuel consumption and emissions would be likely to drop by a similar margin.

  Unattended delivery can take various forms both at the home and at communal collection points (McKinnon and Tallam, 2003). Very few homes, even in countries with well-established online retail markets, have reception boxes, despite the efforts of numerous companies to promote boxes of various sizes and designs. As the average frequency of online purchases increases and the unit cost of installing boxes declines, more households may invest in unattended delivery systems. It is also possible that e-retailers will subsidize their installation, although the experience of Streamline, one of the first pure-players in the US online grocery market may deter this. It went out of business in late 2000, unable to recoup its investments in providing customers with refrigerated reception boxes (Agatz *et al*, 2008).

  In the absence of unattended reception facilities at the home, networks of communal collection (or 'pick-up') points (sometimes called, rather misleadingly, 'collection and delivery points' (CDPs)) have been developed by companies such as DHL in Germany (Packstation network) and ByBox in the UK, which has essentially adapted left-luggage lockers for the collection of B2B and B2C orders. In May 2014, DHL Parcels operated 2,650 automated Packstations in 1,600 towns and cities in Germany, comprising 250,000 individual lockers. Roughly 90 per cent of the German population is within 10 minutes' walking or driving time from a Packstation. It was estimated in the Netherlands that 'a five minutes' driving distance by car seems the critical accessibility value for the success of this concept' (ie the use of a pick-up point/CDP) (Weltevreden, 2008: 257).

In addition to automated, web-enabled collection facilities, networks of 'attended' pick-up points have been established using existing shops, petrol stations, post offices etc, the largest of which in Europe are operated by companies such as Kiala and Collect+. In France, 20 per cent of online orders are now delivered to a pick-up point/locker bank rather than to the consumer's home (Morganti *et al*, 2014). As the density of pick-up points increases, the average distance from home to pick-up point diminishes, increasing convenience, reducing the need for consumers to invest in dedicated reception boxes at their homes and making it more likely that they will walk or cycle to collect their order than drive. Such a modal shift to non-motorized transport at the 'last mile' can dramatically reduce the level of externalities per online order and should be strongly encouraged by planners and public policy-makers.

- *Continued growth of online retailing*: the volume growth which justifies the extension of pick-up point networks is also increasing the utilization of logistics assets across the online retail supply chain. As the throughput at parcel sortation centres increases and vehicle load factors rise, emissions per order are likely to decline. There is a danger, however, that the diversion of sales from conventional retail channels will impair their level of capacity utilization, offsetting some of the environmental gains from e-fulfilment operations.
- *Enhanced environmental performance of vans*: the van (or light goods vehicle) is the workhorse of B2C e-commerce and responsible for much of its environmental impact. Advances in van technology were reviewed in Chapter 8. This suggested that the potential exists to cut the emission-intensity of local deliveries by a substantial margin, mainly by improving the energy efficiency of vans, making greater use of biofuels and hybrid technology, and 'repowering' the vehicles with batteries charged with low-carbon electricity. The introduction of fuel economy/carbon standards for new vans in the EU in 2016 (at 175 g CO_2/km) and their subsequent tightening (to 135 g CO_2/km by 2020) will help to reinforce the 'greening' of local deliveries to homes and local pick-up points.

  It has been suggested that vans may be replaced by drones in some sectors of the online retail market. The prospects of this happening and the possible environmental impacts are discussed in Postscript 1 to this book.

- *Use of couriers and 'crowd-shipping'*: a significant proportion of online orders are not actually delivered by van to their final destination, but instead by citizens engaged by carriers on a part-time basis to act as 'couriers'. They receive bundles of parcels for last-mile delivery within their neighbourhood in their private cars, by bike or on foot. They typically make these deliveries in the evenings or at weekends when people are more likely to be at home and can often combine the parcel delivery with a trip that they were making anyway. This is a form of 'trip-chaining' (Primerano *et al*, 2008). Opportunities for integrating personal and freight movement in this way have recently been expanded by the 'crowd-sourcing' of parcel deliveries (also known as 'crowd-shipping') made possible by online platforms such as Zipments (www.zipments.com). Some of these platforms:

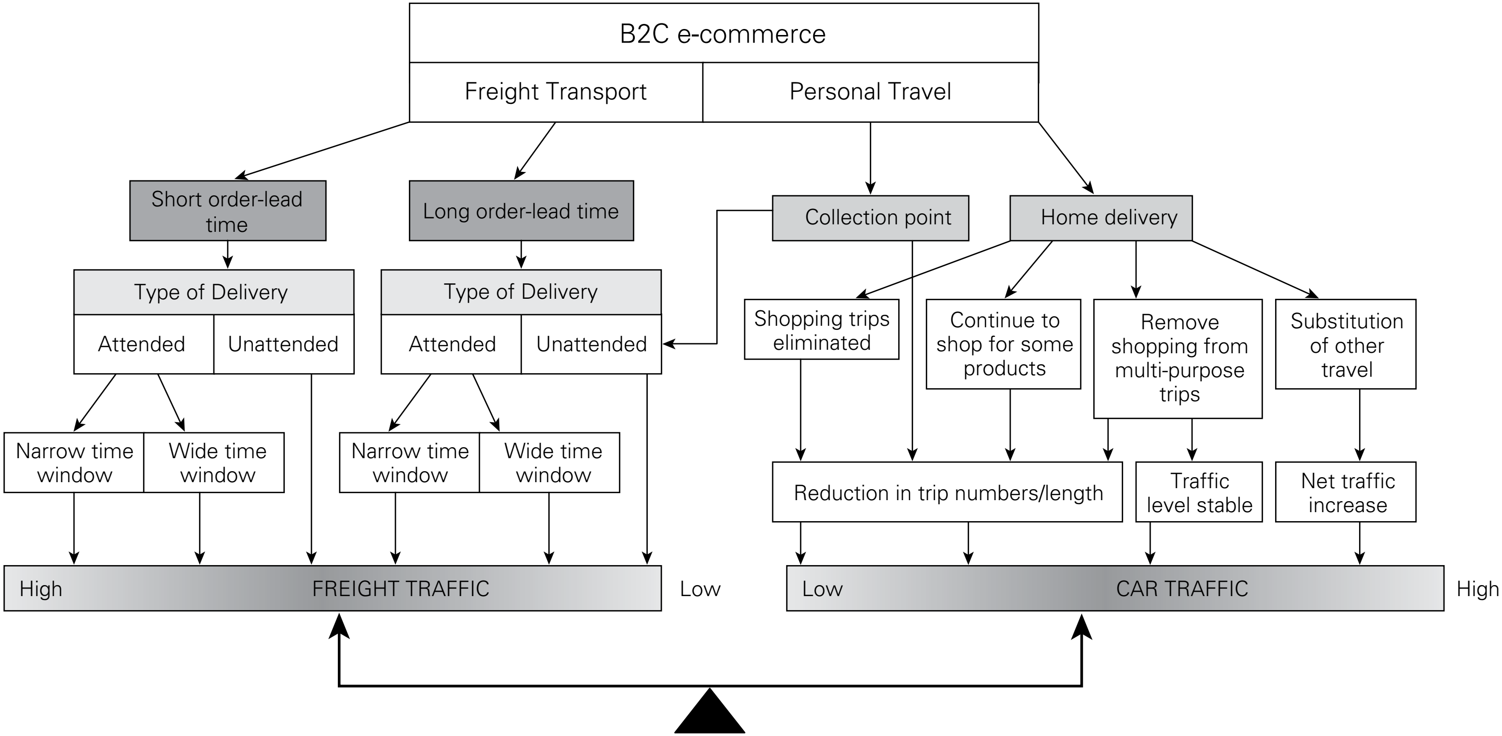
  > have truly transformative models, enlisting people who are already travelling from points A to B to take a package along with them, making a stop along the way to drop it off. Others are incremental innovators who employ technology and social media elements to steer deliveries to a bunch of independent deliverers. They're not all that different from traditional courier services, which have been around forever.
  >
  > (US Postal Service, 2014, p1)

  These collaborative delivery systems raise issues of security and liability, though if they were to prove viable and robust they could yield environmental benefits by reducing traffic levels, particularly within local neighbourhoods.

While these developments offer the prospect of online retailing strengthening its relative environmental advantage over conventional retailing, they could be partly counter-acted by other trends. For example, a new generation of rapid home delivery services are emerging such as Shutl in London (now owned by eBay) which offer a 90-minute delivery service for online orders. It is not known how the environmental impact of these services compares with the standard services which take 1–3 days, though there is a risk that lower delivery efficiency and higher emissions will be traded for greater speed. The 'Internet of Things' (IoT) could also have an adverse effect on the environmental performance of B2C logistics. IoT is the term used to describe the linking of equipment and appliances to the internet. Once people's fridges and kitchen cabinets are equipped with web-enabled sensors, it will be possible for them to constantly monitor home inventory levels and automatically order fresh supplies when stocks fall below a prescribed level. This type of automatic replenishment could be detrimental in environmental terms if it resulted in a form of domestic 'just-in-time' comprising frequent deliveries of small quantities. To avoid this situation, replenishment protocols could be devised to ensure that the flow of goods to the home met certain efficiency and environmental standards.

Overall assessments of the transport-related environmental impacts of B2C e-commerce must distinguish between changes in the volumes of freight and personal movement. Figure 15.3 maps the interrelationships between

FIGURE 15.3 The effects of B2C e-commerce on levels of freight and car traffic



the key parameters that influence the overall traffic impact of online retailing. The amount of freight traffic is strongly influenced by the order lead time, the nature of the home reception operation (attended or unattended) and the width of the delivery time window. The volume of personal movement is determined by the relative reliance on pick-up points and direct delivery to the home, the degree of trip substitution and changes in consumer shopping behaviour. The factors affecting freight and personal transport are clearly interrelated and illustrated in Figure 15.3 by a 'seesaw' effect in which a balance is struck between the relative amounts of car and freight traffic. The relative strength of the various relationships exhibited in Figure 15.3 is difficult to quantify and vary by market sector and geographical area. The available empirical research, however, suggests that, under certain circumstances, online retailing can generate less traffic and emissions per customer order than traditional forms of shopping.

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16

Reverse logistics for the management of waste

TOM CHERRETT, SARAH MAYNARD, FRASER MCLEOD and ADRIAN HICKFORD

Introduction

Research into sustainable distribution has largely focused on improving the delivery of products through the supply chain from manufacturer to end customer by developing fundamental understanding of the various supply chain operations at local, regional and global levels. The logistics activities associated with the return of damaged, unsold or returned consumer products back up the supply chain, and the consolidation, handling and treatment or disposal of waste products that may result, is becoming of increasing interest in the drive to reduce costs and maximize efficiency within the distribution sector.

Through the challenging targets set by 'producer responsibility' legislation in a range of waste-stream-specific European Directives, the onus is on retailers and manufacturers to reduce their waste output and better manage their respective logistics operations by participating in specific waste take-back schemes. Waste Electrical and Electronic Equipment (WEEE) is managed through the recast WEEE Directive (2012/19/EU), with current EU-wide collection targets of 4 kg per capita increasing to approximately 20 kg per capita from 2019 (Europa, 2014a). Manufacturer and retailer packaging waste is managed through the Packaging and Packaging Waste Directive (94/62/EC, as amended by Directive 2004/12/EC) with a forthcoming 2014 revision likely to focus on minimization and recovery as part of the overall European Commission Review of Waste Policy and Legislation (Europa, 2014b).

The need to effectively manage product returns as part of the supply chain process has become more pronounced since the introduction of the Directive on Distance Contracts (97/7/EC), implemented in the UK through the Consumer Protection (Distance Selling) Regulations 2000 (referred to as the Distance Selling Regulations), which stipulates that people who make a purchase via the internet, telephone, fax or mail order can change their minds during a 'cooling-off' period of seven working days after the goods have been received, with no explanation for their return being required.

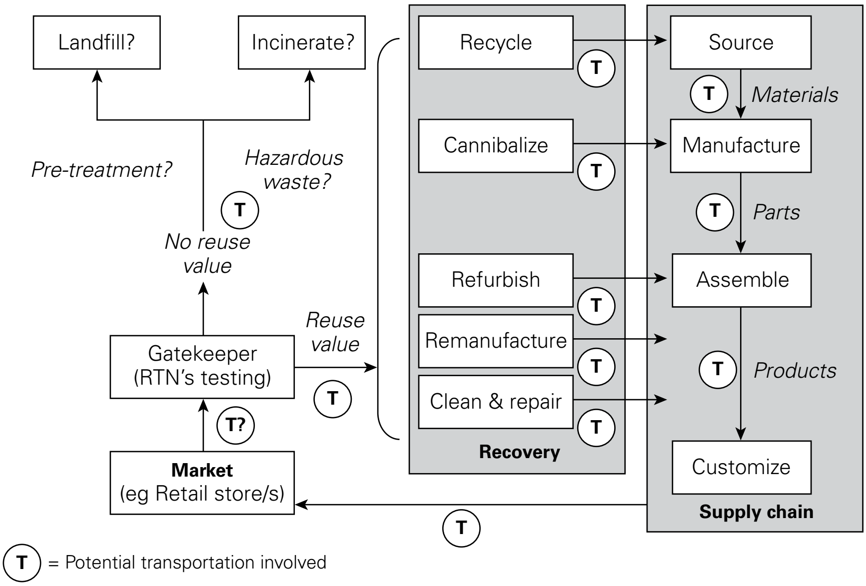
Under this backdrop of increasingly liberal returns policies, coupled with a 'throw away' consumer culture, the extent to which product returns contribute to increasing waste and recyclate generation needs to be explored. With a variety of centralized and decentralized supply chain mechanisms being employed to service retailers, there is potential scope for coordinating reverse processes to both reduce collective transport impacts and maximize reuse value from the recyclate generated.

Waste management in the context of reverse logistics

'Reverse logistics' has been defined as 'the process of planning, implementing, and controlling the efficient, cost-effective flow of raw materials, in-process inventory, finished goods, and related information from the point of consumption to the point of origin, for the purpose of recapturing value or proper disposal' (Rogers and Tibben-Lembke, 1999). Reverse logistics differs from waste management as the latter is mainly concerned with the efficient and effective collection and processing of waste: that is, products for which there is no longer any reuse potential (De Brito and Dekker, 2003). The definition of 'waste' in this context is important from a legal perspective as the act of 'importing' waste is often forbidden (Fleischmann, 2001). However, there are similarities between some of the processes used by product recovery networks and waste disposal networks, especially in an urban setting (Shakantu, Tookey and Bowen, 2002). These are most evident in the 'supply' side where used products are collected from many, possibly widespread, sources and need to be consolidated for further processing and transportation. Major differences do exist between these network types on the 'demand' side however. While a flow of recovered products would historically be directed towards a reuse market, waste streams would eventually end at landfill sites or incineration plants (Figure 16.1) after various treatment processes (Fleischmann *et al*, 2000). However, the increased emphasis on producer responsibility and the policy focus on waste minimization and recovery as a result of the EU Waste Framework Directive (2008/98/EC) have led to the distribution and return networks being modified.

Depending on the type of reverse process employed, products may not necessarily be returned to their point of origin, but to a different point for recovery (De Brito and Dekker, 2003), and as the level of complexity in reverse logistics operations has increased, there is an increasing need to address issues of sustainability and integration within the overall supply chain (DfT, 2004). The shipment of materials back to recovery sites and treatment

FIGURE 16.1 Recovery processes incorporated in the supply chain



SOURCE: Adapted from Hillegersberg *et al* (2001)

centres is a natural extension of reverse logistics, and better integrating waste management processes within the overall reverse process could help reduce the negative transport impacts.

Within the retail sector, two main mechanisms of returns management have been identified (Halldórsson and Skjøtt-Larsen, 2007). In the centralized reverse supply chain, one organization has responsibility for the collection, inspection, disposition and redistribution of returned items that could originate from many different retailers. In the decentralized reverse supply chain, multiple organizations could be involved in this process, where individual sales outlets act as their own 'gatekeepers', checking returned product and deciding which reuse/disposition paths items should take. Where the gatekeeping function is taken on at the individual store level, local skills will be needed in product inspection and testing. This is not a trivial undertaking and is a process that could lead to increased waste generation if not tightly managed and coordinated. Four physical network structures for handling retail returns have been identified (DfT, 2004), and are outlined below.

Type A: Integrated outbound and returns network

Using a company's own fleet or its logistics providers' vehicles, returns are 'backhauled' from the retail outlets to a regional distribution centre (RDC).

The gatekeeper function associated with sorting, checking and deciding the ultimate fate of the returned items (potentially including certain refurbishment processes) is carried out at the RDC. This system works well in a supply chain where the frequency of delivery to stores is high, and the volume of returns is also high.

Type B: Non-integrated outbound and returns network

In this case, a separate network is used for managing returns, typically operated by a third-party logistics provider (3PL) that takes returns (on an 'as and when required' basis) from stores to a separate location where the gatekeeper activities are undertaken by the retail organization. This system works well if the level of returns varies in volume but is generally low.

Type C: Third-party returns management

Where the total management of product returns is outsourced to a third-party contractor, the retailer benefits in that no gatekeeping expertise is required at the individual store level. The 3PL provides this functionality along with a complete returns management process, including supporting technologies, refurbishment and disposition programmes. Centralized gatekeeping processes have the potential to better manage the waste generated during the returns process and maximize reuse potential, as they have greater visibility of the various refurbishment options. This has seen the emergence of 4PLs that undertake 'business process outsourcing' to deliver fully comprehensive forward and reverse supply chain solutions, including refurbishment and disposition management (Mukhopadhyay and Setaputra, 2006).

Type D: Return to suppliers

In this case, goods are returned direct to the suppliers and exchanged for credit. Under these circumstances, retailers may have no gatekeeping responsibilities and little responsibility for returns. Such systems may have additional transport cost implications as the goods have to return to the individual supplier for the gatekeeping function before potential further travel related to refurbishment or disposition.

Waste and recyclate management should be seen as a key component in all reverse logistics processes but should be considered in the context of initial source reduction strategies to minimize waste production (Wu and Dunn, 1994; Marien, 1998). Carter and Ellram (1998) proposed a hierarchy of disposition that suggested that resource reduction (minimizing the amount of materials used in a product, and reducing the waste produced and energy spent through designing more environmentally efficient products) ought to be the ultimate goal of the reverse logistics process. Building on this concept, the introduction of the waste hierarchy of 'prevent, prepare for reuse, recycle, other recovery, disposal', legally required by the EU Waste Framework Directive (2008/98/EC) (Europa, 2014c) coupled to the Waste Regulations (SI 2011/988) are the models most suited to minimizing the environmental impact of product returns.

Reduction of returns can be attained through better management of the supply chain, particularly where closer collaboration between gatekeeping processes can be realized. Reuse of returns will maximize their asset value through the utilization of effective refurbishment programmes, and where reuse is no longer an option, recycling refers to the best route for material recovery of products that cannot be resold. Returns that cannot be managed through these three elements will enter the waste stream (Figure 16.1).

To effectively utilize this hierarchy of disposition, businesses need to integrate their current supply chain and process management strategies, and consider collaborating with potential rivals to better utilize existing assets and generate critical mass to make use of specialist service providers. As legislation such as the WEEE Directive and the Directive on Distance Contracts continues to impact on retailers by increasing the volumes and variety of returns, so opportunities increase for the small to medium-sized enterprise (SME) to cooperate with other organizations in collaborative 'reduce, reuse and recycle' initiatives in areas such as WEEE management (Ongondo *et al*, 2011).

The impact of waste treatment legislation

The Producer Pre-Treatment Requirement of the Landfill Directive was implemented in October 2007, prohibiting businesses from sending non-hazardous waste that had not been pre-treated to landfill and this has been strengthened by the legal obligation imposed on all businesses to consider the waste hierarchy when managing their waste (Waste (England and Wales) Regulations, 2011). The responsibility for pre-treatment rests with the waste producer and the overall aim of the directive is to reduce the impact of landfill and increase material recovery through recycling. Under the directive, 'pre-treatment' is deemed to have been undertaken when the waste has been through a 'three-point test' in which all three points have been satisfied:

1. It must be a physical, thermal or chemical, or biological process, including sorting.
2. It must change the characteristics of the waste.
3. It must do so in order to:
   - reduce its volume, or
   - reduce its hazardous nature, or
   - facilitate its handling, or enhance its recovery.

In the case of a high-street retailer, pre-treatment can usually be achieved by separating out recyclable material from the general waste stream using different containers, or by sending mixed waste (where separation at-store is not possible) to a sortation facility where recyclate can be recovered. This then meets the obligation to work 'up' the waste hierarchy and attempt to prevent disposal to landfill. There is no clear guidance as to the proportion of waste that would need to be recovered, only that it is 'significant' and 'consistent'. For waste that is not destined for landfill, the treatment requirements are not applicable.

An online survey of over 600 SMEs and 200 larger corporate businesses (with over 250 employees) looked at the extent of recycling amongst UK businesses and the extent to which SMEs were aware of the pre-treatment requirements (Taylor Intelligence, 2007). The results suggested that there was a general lack of awareness amongst SMEs of the producer pre-treatment requirements and many did not have the facilities or contracts in place to separate out and recover recyclate from the general waste stream. There is clearly a market for both private contractors and local authorities to provide commercial recycling collections to SMEs, as highlighted in the UK Government Review of Waste Policy in England (Defra, 2011) which encourages local authorities to assist SMEs to recycle. Given the requirements of the producer pre-treatment legislation, SMEs would do well to coordinate their recycling activities with their neighbours to reduce costs and meet their obligations under the Waste (England and Wales) Regulations (2011) and Waste Framework Directive (2008/98/EC).

The end of 'co-disposal' brought about through the Landfill Regulations 2002 (Landfill Directive 99/31/EC) has seen the number of sites permitted to take hazardous waste in England drop from around 240 (2001) to 72 (2014) (Environment Agency, 2014). The longer-term impact of this is likely to be an increase in average length of haul and the trans-boundary movement of waste as authorities seek alternative means of waste management. Approximately 10 per cent of the UK's hazardous waste is generated in London; however, only 15 per cent of this is actually managed within the city itself (Greater London Authority, 2014).

The EC Directive on Packaging and Packaging Waste (94/62/EC) seeks to reduce the impact of packaging on the environment by introducing specific recovery and recycling targets, and by encouraging more minimization and reuse in this area. Under the 2012 targets, the UK was obliged to recover 74 per cent and recycle 68.1 per cent of packaging waste, with individual targets set for specific waste streams (eg glass, paper/card, plastic, wood, aluminium and steel). As published online on the Environment Agency's National Packaging Waste Database, the targets were met by the end of the compliance period although there was evidence that both recovery and recycling were slightly down on the 2011 figures especially for paper, glass, aluminium and plastic. Further UK targets have been introduced for 2013–17 which include annual incremental rises of 1 per cent, 3 per cent and 5 per cent for steel, aluminium and plastic respectively, with split targets for glass (Defra, 2014). For 2017, the targets are that 79 per cent of packaging is to be recovered of which 72.7 per cent is to be recycled. The Packaging Regulations work on the principles of shared producer responsibility affecting any business within the packaging chain handling more than 50 tonnes of packaging per annum and with an annual turnover of more than £2 million. These targets affect businesses that put goods or products into packaging as well as those that sell already packaged goods to final users.

Under the regulations, obligated businesses must provide evidence of payment for the recovery and recycling of a specified proportion of their packaging waste (including wood, aluminium, steel, cardboard and plastic). This is done through electronic Packaging Recovery Notes (PRNs) and Packaging Export Recovery Notes (PERNs) issued by the accredited reprocessor to indicate how much packaging has been recovered or recycled. As in the 3PL returns management model, businesses have the option to join a packaging compliance scheme that manages the individual company's recovery and recycling obligations (eg purchase of PRNs/PERNs and reporting on compliance to the regulator). The government has acknowledged that the increased recovery of packaging waste is integral to meeting its landfill diversion targets and improving recycling and recovery from waste.

Using a common type of reusable packaging that complies with an agreed standard (Golding, 1999) and could be exchanged between companies (Kroon and Vrijens, 1995; DfT, 2005) is one way that businesses could reduce such costs. Reusable packaging may not be universally attractive as logistics costs might be adversely affected by additional handling, retrieval and storage requirements. Since manufacturers typically factor the costs of packaging into their prices to customers, the total cost of supply would probably reduce where packaging could be reused, along with end disposal costs (Wu and Dunn, 1994). It is however important to clarify whether the collective processes associated with managing the production, take-back and final disposal of returnable packaging is not more detrimental to the environment than the use of one-way packaging material (Kroon and Vrijens, 1995). While large retail chains often maximize vehicle utilization through backhauling reusable packaging (trays, dollies etc) and other recyclable material (DfT, 2005), wholesalers have to deliver small loads to many small businesses and for hygiene and cost considerations, it is sometimes impractical to recover packaging waste (Fernie and Hart, 2001).

The EC directives on WEEE (2012/19/EU) and on the Restriction of the Use of Certain Hazardous Substances (RoHS) in Electrical and Electronic Equipment (2002/95/EC) aim to reduce the environmental impact of waste from electrical and electronic equipment (EEE) and increase its recovery, recycling and reuse. The directives affect producers, distributors and recyclers of EEE, including household appliances, IT and telecommunications equipment, audiovisual equipment (TV, video, hi-fi), lighting, electrical and electronic tools, toys, leisure and sports equipment. Increased recycling of EEE will reduce the total quantity of waste going to final disposal with producers having the responsibility for taking back and recycling items.

Under the WEEE Regulations, producers and distributors are required to finance the recovery, processing, recycling and reuse of electrical and electronic waste. There are three ways that they can comply with the regulations: i) by retailers offering an in-store take-back service or via 'collection on delivery' which is done on a 'like-for-like' basis; ii) joining the Distributor Take-back Scheme (DTS); or iii) providing an alternative free take-back service which is available to all customers. The latter would be expected to accept all WEEE and not just on a like-for-like basis, and would therefore have greater implications in terms of transport. Businesses that collect and transport WEEE (eg at the same time as making a delivery) need to be registered with the Environment Agency as waste carriers under the Waste (England and Wales) Regulations (2011). Coordinated compliance schemes ease the problems associated with handling and tracking the return of goods and the associated packaging back to manufacturers via retail outlets (Ongondo *et al*, 2011).

By joining the nationwide DTS, distributors discharge any take-back obligations that they may have over to the Valpak Retail WEEE Services Ltd, who are the current operators of the scheme (Valpak, 2014). Members of the DTS are charged a fee based on their total sales value for electrical products. By the end of 2012, 1,861 members had joined the scheme, generating over £12 million (*Retail Environment*, 2014) which has been used by local authorities to operate designated collection facilities (DCFs) for the collection of domestic WEEE through the upgrade of Household Waste Recycling Centres (HWRC) (Ongondo *et al*, 2011). HWRCs that are permitted to receive commercial waste can theoretically facilitate the collection of non-household sources of WEEE (WRAP, 2010a). However, there are a range of operational issues that may deter sites from collecting (eg lack of space). If HWRCs were to play a more significant role in reverse logistics processes, then some of their existing functionality may need to be outsourced to more localized collection systems (eg kerbside/bring-site green waste collections) to free up space for WEEE consolidation (Cherrett and Hickford, 2006).

A producer of EEE may register as a member of a Producer Compliance Scheme (PCS) who will then take on their legal obligations for the collection and treatment of their WEEE at the end of life of the product. Through registration payments made by the producer, the PCS will finance the collection of WEEE from areas such as DCFs and transfer it to an Approved Authorised Treatment Facility (AATF) for safe and registered recovery. Upon completion of the recycling, the AATF will then provide the PCS with Recycling Evidence Notes (RENs) that are then passed onto the producer of the EEE as evidence of meeting their legal obligation under the WEEE Regulations.

The gatekeeping function within a reverse supply chain (the point at which returned items are checked to establish whether they can be resold, repaired, refurbished, cannibalized or disposed) can also play an important role in managing the movement of potentially hazardous waste products back up the system. Under the EU Waste Framework Directive (2008/98/EC) and the

Hazardous Waste (Amendment) Regulations 2009, any organization that produces over 500 kg of hazardous waste per annum (as identified in the List of Waste (Decision 2001/573/EC)) is required to register their premises as a producer of hazardous waste with the Environment Agency in England (or equivalent regulatory body in other countries) before they can move hazardous waste materials from their premises.

The mixing of hazardous and non-hazardous waste is strictly prohibited and reverse logistics operations where the gatekeeping process leads to significant deconstruction and cannibalization need to carefully consider waste separation and segregation. Both of these outcomes can lead to additional transport and handling costs. A waste carrier's permit is needed and drivers require special training in order to carry hazardous waste consignments. The consignee is also required to keep detailed records of waste disposition and provide quarterly reports to the Environment Agency detailing the quantities and origins of wastes. Such documentation enables the movement of hazardous waste to be tracked and managed responsibly until it reaches authorized disposal or recovery facilities.

Reuse, refurbishment markets and take-back schemes

Of key importance to reverse logistics networks handling recyclate are the end markets for the retrieved materials. The lack of available markets has long been identified as a barrier that restricts recycling performance, and the Waste and Resources Action Plan (WRAP) was established in 2001 with a view to creating stable markets for recyclables with a specific focus on aggregates, glass, organics, paper, plastics and wood (WRAP, 2014a).

Material markets are found on a local, national and global level, and commodity pricing structures can be complex, dependent on a range of factors including the supply of and demand for the recyclate, transportation and handling costs, market competition and overheads (APSRG, 2013). The UK recyclate market is influenced by its foreign counterparts (through which exports and imports of materials are exchanged), the virgin commodity market and the PERN market (packaging waste recovery notes as part of the Packaging and Packaging Waste Regulations). Due to the lack of domestic recyclate markets for the volumes generated in the UK, there is a reliance on exporting materials to achieve higher rates of recycling.

China is a key end market for recyclate emanating from the UK, with exports of recovered paper and plastics standing at 4.3 million and 285,000 tonnes respectively in 2012. This accounted for 80 per cent and 90 per cent respectively of the UK exports of these two materials (APSRG, 2013). Such a reliance on exports makes the UK vulnerable to changing economic situations and also policy changes affecting key end-market destinations (APSRG, 2013). In February 2013, the Chinese government introduced

Operation Green Fence, a policy instrument designed to reduce and prevent the import of contaminated waste shipments. The policy, which was enforced over a 10-month period, set a limit of 1.5 per cent allowable contaminant for each bale of imported recyclables. In the first three months of enforcement, there was a backlog of containers as 55 shipments were stopped and 7,600 tonnes of recyclable material was rejected (*Guardian*, 2013). In the early stages of implementation, some exports from the UK were rejected due to contamination from food waste and packaging labelling which caused a shortfall in PRNs (especially for plastic) and increased the PRN base prices (Comply Direct, 2013). Operation Green Fence has had a significant impact on the global recycling trade and has improved the quality of waste as indicated by the acceptance levels for global recycling.

Community and charity groups also generate a reuse market for recovered material. Organizations such as the Furniture Reuse Network (FRN, formerly known as Furniture Recycling Network), Community Resource Network UK, CREATE (Community Recycling and Training), CRISP, Community RePaint, Lighthouse Furniture Project and the SOFA project play an integral role in local and national sustainable waste management. Through local community schemes and social enterprises, materials such as EEE (computers, TVs etc) can be refurbished and reused within the community. There are also established charity markets that export materials to developing countries (eg Computers for Africa, which collects and exports computers).

There are a number of businesses that are now targeting the different types of waste/recyclate generated by the retail and business sectors, many providing dedicated services that can be easily integrated into existing reverse networks. Some examples are:

- FareShare (www.fareshare.org.uk). FareShare is a national organization that works with over 100 food businesses, wholesalers and retailers (including three major supermarket chains) to reduce the amount of food waste sent to landfill by redistributing surplus fresh food to day centres and night shelters for homeless people. The scheme has been in operation since 2004 and has 17 centres around the UK. FareShare helps around 43,700 people daily by collecting food from businesses and redistributing it through their network to disadvantaged people in the community. In 2012–13, the food collected contributed to more than 10 million meals.
- RASCAL (http://www.rascalsystems.com). The RASCAL system provides a comprehensive in-store newspaper and magazine returns-processing system designed to reduce unidentified loss, which is significant due to the short shelf-life of newspapers. Retail outlets routinely store product information, including magazine titles, on-and-off sale dates and wholesaler details through their stock management systems. Titles that are due for return are scanned and matched to the details of the relevant receiving wholesaler, which are then transmitted to the RASCAL database. Once a product has been returned, the wholesaler transmits a credit from its system to the

consignee. The system, which is used by a range of high-street retailers, provides an effective tool to track all returned stock.

- Furniture Reuse Network (FRN) (http://www.frn.org.uk/). The Furniture Reuse Network is the national coordinating body supporting 300 furniture and appliance reuse and recycling organizations across the UK. The FRN promotes the reuse of unwanted furniture and electrical equipment, with around 2.7 million items per year being reused and passed on to 950,000 low-income families saving them £350 million. Approximately 110,000 tonnes of waste is diverted from landfill through the FRN network as a result. FRN employs around 4,000 people to collect and deliver furniture and appliances around the UK and has over 160 organizations within its network that refurbish and reuse domestic appliances, with over 300,000 fridges alone being collected annually. The FRN is able to reprocess electrical items and is currently developing a network of over 35 treatment centres for WEEE and is entering into partnerships with local authorities to collect bulky waste.
- Regenersis (www.regenersis.com/). It is estimated that over 15 million mobile phones are replaced each year in the UK. The main channels for their disposition are through the retail outlets that sell them, and linked to those are a number of WEEE-compliant schemes offering a specific recycling service. Fonebak, an online operation, now part of the Regenersis brand (one of the largest phone refurbishers and end-of-life processors in Europe) have over 1,000 clients representing every network operator in the UK and many major networks, retailers, manufacturers and charities across Europe. With around 10,000 phone collection points across Europe, it has handled over 25 million phones for reuse and recycling since 2002. It also offers a reverse logistics service, which manages the collection of mobile phones and accessories from over 2,000 outlets throughout the UK.
- Computer Aid International (www.computeraid.org). With around 3 million PCs decommissioned in the UK every year, Computer Aid International is a charitable organization that provides high-quality, professionally refurbished computers for reuse in education, health and not-for-profit organizations in developing countries. In 2010–11 the organization shipped over 220,000 refurbished PCs and laptops to over 100 developing countries.

Managing waste as part of a sustainable reverse process

Under Section 34 of the Environmental Protection Act 1990 and The Waste (England and Wales) Regulations (2011), commercial premises have a 'duty of care' to make satisfactory arrangements for their waste collection (Bell *et al*, 2013). Generally, businesses will arrange a collection contract with a private waste management company but, increasingly, authorities also offer rival 'trade waste' services under the Controlled Waste Regulations (2012).

The Environment Agency has suggested that approximately half of all commercial and industrial waste in England and Wales is produced by SMEs, making up around a third of industrial wastes and two-thirds of commercial wastes (EA, 2005). Data produced from the commercial and industrial waste survey indicated that a 52 per cent recycling rate was being achieved by SMEs, highlighting that there is demand for recycling services within this sector (WRAP, 2011a). However, recycling performance amongst SMEs can be restricted due to a number of barriers that businesses face (WRAP, 2014b) and an overall lack of understanding regarding legislative responsibilities (Wilson *et al*, 2010). SMEs frequently face problems obtaining affordable recycling and recovery services as they find it difficult to meet the minimum volume requirements set out by some service providers (WRAP, 2011b). The Review of Waste Policy in England (2011) outlines the government's commitment to improving access to cost-effective recycling services for businesses, in particular SMEs, through engaging both the private sector and local authorities. This is supported by WRAP's Business Waste and Recycling Service Commitment which provides local authorities with a 12-step programme on how to provide services that break down many of the identified barriers (WRAP, 2014c).

Schemes to aid SMEs

There are many examples of collection schemes that have been specifically aimed at helping SMEs handle their waste and recyclate and therefore encourage sustainable take-back.

Dove Recycling (now part of TJ Waste & Recycling Limited) based in Hampshire (www.doverecycling.co.uk) was formed in July 2005, and provides a tailored collection system to allow businesses to better manage their recyclable waste. Cardboard, paper, cans, plastic bottles, glass, WEEE, fluorescent tubes and confidential waste can all be sent back through its system. An electric-powered collection vehicle was supplied by Hampshire County Council as part of the EC-funded MIRACLES project and was used to transport the collected cardboard and paper.

Local authorities can set up their own trade waste collections for business customers, and under the Controlled Waste Regulations (2012) they can charge businesses for these services. In 2005, the Landfill Allowance Trading Scheme (LATS) was launched in England to help waste disposal authorities reduce the amount of biodegradable municipal waste (BMW) sent to landfill as part of the UK targets under the Landfill Directive (Defra, 2005). Any waste collected by local authorities from small businesses was classed as BMW and therefore counted towards the LATS allowance, which, if exceeded would be met with costly financial penalties. The LATS therefore deterred local authorities from operating trade collections while the SME market for waste collections was distorted by the high prices that private waste contractors were able to charge. In 2013, the LATS was abolished (Defra, 2011) as increases in landfill tax were now regarded as the predominant policy driver in diverting biodegradable waste from landfill. This move was much welcomed by local authorities as it meant that they could invest in trade collections whilst generating income.

Co-collection of domestic and commercial waste

Local authorities that offer trade waste collections often do so as a separate entity, using a fleet of dedicated vehicles and hiring out bins to businesses as part of the overall service contract. Within the UK there are examples of waste-collection authorities facilitating the co-collection of domestic and commercial waste as part of the same collection round (WRAP, 2011b). For recyclate collection, this appears to be a much more efficient way of utilizing transport and staff resources, as residential areas encompassing areas of retail/business can be covered using the same vehicle fleet as part of the same round. The potential to generate income from service charges and material sales, coupled with increased opportunities for businesses to recycle, make co-collections an appealing proposition for local authorities (WRAP, 2011b).

New Forest District Council (NFDC) is one such authority that has implemented co-collection of commercial and domestic waste. In their operating model, commercial waste is collected from SMEs that have pre-registered with the council under the Waste (England and Wales) Regulations 2011 and the Controlled Waste Regulations (2012). This waste is collected on the same rounds as the domestic recyclate collection. All commercial waste collected as part of a joint collection would have to be separated out prior to weighing to meet legal requirements.

In research undertaken by McLeod and Cherrett (2006), 13 weekly residual-waste rounds were operated by NFDC, with the proportion of commercial waste collected ranging from 0.1 per cent to 3.2 per cent (97.5 tonnes collected during 2005/06 through the domestic rounds). Such a system is ideally suited to small businesses that may be producing small quantities of waste and do not want to sign up to a large-scale commercial collection service.

The ability of an existing domestic round to collect additional SME waste is dependent on the spare capacity in the refuse collection vehicle (RCV). Spare capacity is needed in terms of both physical space and also in the amount of time available for collecting due to the time constraints associated with crew shift patterns and the operating hours of waste treatment/disposal facilities. A number of other practical considerations will also need to be taken into account before exploring the viability of co-collections, eg geographical distribution of premises, volumes and types of waste generated (WRAP, 2011b)

A theoretical study, modelling the impacts of incorporating SME commercial waste collections into certain domestic rounds across Winchester in

Hampshire, was undertaken (McLeod *et al*, 2011). The modelled waste-collection rounds used in the research represented approximately one-half (the 'northern sector') of all domestic and trade collections undertaken by a waste contractor on behalf of Winchester City Council (WCC). This collection area covered the city of Winchester and the surrounding areas, including Alresford, Kings Worthy, Otterbourne and Hursley. Mixed recyclable and residual waste was collected from 577 different trade customers, separately from the domestic collections using an RCV with a carrying capacity of approximately 8.9 tonnes. A separate fleet of vehicles serviced around 25,000 households on an alternate weekly basis.

Modelled joint collections reduced vehicle mileage by up to 9.8 per cent, equating to an annual saving of around £36,800, although the levels of benefit fell to 4.7 per cent when the base case scenario was fully optimized. The modelled benefits were greatest when a common starting time (6 am) was adopted for the trade and domestic collections. The modelled rounds were estimated to have sufficient time and vehicle capacity available to allow an additional 50 per cent of trade waste to be collected, equating to 35.8 tonnes per week.

There may be wider environmental benefits to be gained through the introduction of joint domestic/commercial collections. Recycling performance amongst SMEs should improve whilst the volume of waste taken to landfill would reduce. Total vehicle mileage, traffic congestion and CO_2 may decrease, particularly in shopping areas, if the number of visits by waste-collection vehicles could be reduced. The current fragmented situation, where some areas can be serviced by many different collection companies, could be improved if the WCA offered a commercial waste-collection service of this type.

Commercial bring sites and HWRCs

Historically, local authorities have implemented measures to prevent commercial waste being disposed of at HWRCs (eg banning trade vehicles, vehicle recognition systems, height barriers). However, it is now considered that utilizing existing HWRCs and bring sites (eg in public car parks) can provide the business community (especially SMEs) with an opportunity to manage their recyclate in a cost-effective manner that meets legislative requirements. A survey conducted by Defra (2010) highlighted that 41 per cent of micro-businesses in England already use household services, informally, to dispose of their waste and recyclate (Defra, 2010). To manage commercial waste streams on a more regulated basis, investment and improvements in existing site infrastructure would be essential to cope with additional throughput. In the Review of Waste Policy (Defra, 2011), the government outlined their desire to encourage local authorities to adapt bring sites and/or HWRCs to accept business waste at an affordable price to businesses. It is thought this could be mutually beneficial for SMEs and the local authorities themselves as the revenues generated could be used to keep open some existing sites that are on the brink of closure. For those businesses that generate low volumes of recyclate and are not willing to commit themselves to contracted collection, the development of HWRCs could provide an effective solution.

Networks for return management

Take-back opportunities for SMEs, particularly in the area of small parts returns, could be achieved through utilizing the networks of attended and unattended collection–delivery points (CDPs) (Cherrett and McLeod, 2005). The use of attended premises, typically convenience stores, petrol stations and post offices (eg Kiala, Royal Mail, Parcel Force, Redpack Network, UPS Access Point) or unattended locker banks or boxes (eg ByBox) for returning products back up the supply chain are already well established in the service industry. Such concepts could provide alternative, more effective methods for consolidating small items for take-back.

Conclusions

Managing recyclate, in terms of minimizing the costs associated with its separation and transport whilst maximizing any value that can be gained through its recovery, is becoming of increasing interest as part of integrated supply chain management strategies. As a result, many innovative take-back systems have been developed, catering for a wide variety of materials, targeted often at small to medium-sized businesses that often do not generate significant volumes of recyclate to warrant a contract with a major waste contractor, but nevertheless have to comply with their obligations under waste management legislation.

In terms of the options that would have the greatest impact for 'greening' the waste take-back systems, supplying the various treatment/processing facilities, combined domestic and commercial waste collections, particularly for SME recyclate management, have considerable potential. Coordinated through the local collection authority, these types of combined collection could effectively cater for additional small-volume recyclate consignments on top of the domestic set out, and potentially encourage SMEs to recycle more material.

Utilizing the existing delivery mechanisms serving a retail sector to take back recyclate ('backloading') is the other option for reducing the transport footprint associated with waste management in urban centres. If the combined transport resources across different supply chains could be pooled in some way to create shared take-back schemes, then considerable environmental and financial savings could be gained. There are some fundamental barriers to this, not least the requirement that transport companies seeking to take back waste on behalf of other businesses register their intent with the Environment Agency and obtain a Waste Carrier Licence. Other issues relate to whether retailers would be happy with the image of waste and recyclate from a potential rival business being loaded into their liveried vehicles. This aside, the customer-focused operating characteristics of logistics suppliers mean that many are ill-equipped to handle reverse flows, as the methods of transportation, goods storage and handling are often very different from those used in the forward flow (Halldórsson and Skjøtt-Larsen, 2007).

Some of the key issues that would have to be considered with regard to using existing delivery fleets for take-back are:

- *Is there spare capacity on the existing delivery rounds?* In the case of centralized distribution systems, where single-drop delivery rounds are more prevalent, there may be more potential to take back recyclate as well as returns, depending on any collections that have to be scheduled as part of the return journey. Multi-drop delivery rounds may be problematic as stowage space may be at a premium with multiple delivery calls to make, but there could also be more serious issues relating to the cross-contamination of grade A stock by recyclate or returns. There could also be time conflicts on a multi-drop round with having to collect, consolidate and store recyclate/returns at each delivery point.
- *Do the delivery vehicles visit frequently enough to service the waste-collection/return goods demands?* External storage and groupage areas are often at a premium for businesses operating in historic city centres. If a retail store only has a small area set aside for waste and recyclate storage, then it might require a more frequent waste-collection service than can be offered through backloading opportunities. The available backloading capacity may vary considerably depending on day-to-day occurrences in the supply chain (eg rejected deliveries, inter-store transfers, promotional stock etc).
- *Which materials may be collected?* In reality, only 'clean' recyclate such as uncontaminated paper, cardboard and plastics would be suitable for take-back using delivery vehicles. Depending on the requirements of the end-processor, there may be limited opportunities further up the reverse supply chain to separate out recyclate, and therefore mixed collections, although desirable, may not be achievable in practice. This could increase handling costs and lead to small, sub-optimal volumes of recyclate passing back up the system.
- *What equipment is needed?* Waste collection typically involves a range of bins, sacks, compacting and baling equipment, lifting mechanisms and specialist waste-collection vehicles. If special equipment is required to consolidate the recyclate or lift it on to the vehicle then this might preclude the use of backloading as a realistic option. The existing equipment used in deliveries (eg roll cages, pallets, dollies) may limit what items can be returned in the vehicle.

- *Where does the waste/recyclate have to be delivered to?* In centralized distribution systems, recyclate and returned products may simply go back to the regional distribution centre. The situation could be more complex if a delivery vehicle being used for backloading has to divert from its schedule to drop recyclate at a specific processing or sortation facility. There may be vehicle–facility compatibility issues where re-processing facilities are not geared up to receive articulated delivery vehicles. Given the fluctuation in recyclate values, end markets may frequently change as retailers try to maximize the financial return for the material carried. In such instances, the additional mileage travelled to a facility might outweigh the financial returns from the load. In this case, out-of-town groupage facilities might be a viable option to enable delivery vehicles to backload out of the centre to a managed facility from where recyclate is grouped for onward movement by a waste contractor. This facility in effect would be acting as a traditional 'consolidation centre' in reverse.
- *How stable/regular is the demand for waste and return goods collection?* Ideally, there should be a regular and stable flow of returns and recyclate in a backloading operation to allow effective scheduling of the delivery vehicles. If the demand is highly variable, particularly in cases where seasonal fluctuations are pronounced, then it may be difficult to accommodate effective backloading as part of the delivery structure, as accurately forecasting demand may prove difficult.

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The food miles debate

Is shorter better?

17

TARA GARNETT

Introduction

The concept of 'food miles' first entered public consciousness in the mid-1990s, following the publication of a ground-breaking report by the SAFE Alliance, an environmental organization now known as Sustain. The phrase was originally coined to encapsulate a broad range of environmental, social and economic problems resulting from the globalizing of food supply systems. Since the report's initial publication, however, the phrase's broader, more holistic intent has been superseded by a narrow focus on the environmental (and specifically CO_2) impacts of transporting food over long distances. The basic, simplified message that the food miles label now carries in the public consciousness is that food transport today is excessive and unnecessary, and that, essentially, further is worse and nearer is better.

While this may be the public view, a considerable and growing body of research has sought to take a closer look at this assumption (Foster *et al*, 2006; Edwards-Jones *et al*, 2008). Initial research highlighted the need to consider the importance of mode (sea vs air, for example) and of efficiency (of vehicle, of loading, of route) before making conclusions about the merits of one supply chain over the other. Increasingly, however, food researchers have been adopting a life cycle analysis (LCA) approach; this considers transport within the context of food's environmental impacts at all stages in the supply chain, from agricultural production through to storage and cooking in the home and final disposal. Transport is just one element requiring consideration, and with this whole-cycle approach its importance, relative to other stages, can be gauged. Importantly, the LCA approach not only sheds light on the relative importance of different stages in the supply chain, but also allows us to explore what effect a change in one part of the system (say, a shorter transport leg) may have on emissions from other parts.

The purpose of this chapter is to examine what the LCA approach reveals about the importance of food-transport-related CO_2 emissions. We then consider whether the LCA is itself a sufficient analytic tool – whether it is able to capture the broader, more systemic impacts of globalized food provisioning systems and their contribution to climate-changing emissions. Finally, since they are at the core of many discussions around food miles, we consider the issue of self-sufficiency and food security; we ask whether a national policy of maximizing the former enhances the likelihood of achieving the latter.

Transport and GHGs: Is further worse?

Several studies have sought to investigate the correlation between distance and environmental impact. An early example is the *Wise Moves* report (Garnett, 2003) published by the environmental organization Campaign for Better Transport (at that time Transport 2000). This found that food transport accounts for around 3.5 per cent of the UK's GHG emissions. It concluded that there was some correlation between shorter journey distance and lower emissions, but that there were many exceptions, owing to differences in the efficiency of production systems as well as in the mode of travel and logistics. It suggested that the elements of a lower-carbon food system included the following:

- Seasonal and indigenous: fresh produce grown during its natural growing season and well adapted to UK growing conditions will be less transport intensive and produce fewer overall CO_2 emissions than non-indigenous foods or those imported out of season.
- Efficient manufacturing: the processing plant needs to be efficiently operated and managed.
- Minimal use of temperature-controlled storage: this should not, in the process, compromise safety standards or generate waste through spoilage.
- Local clustering: the inputs to the product in question must be situated near to the site of production.
- Journey distance: the distance from point of production to point of retail to point of consumption should be minimized.
- Logistical efficiency: the fuel efficiency of a vehicle and the way it is managed and operated are very important. In addition loads must be consolidated and vehicles as full as possible while they are in use.

It also recommended that a life-cycle approach to investigating and tackling food-related emissions be adopted.

At around this time, Defra (2005) commissioned a study to assess whether food miles might be a valid indicator of sustainable development, to be added to its suite of other indicators (Defra, 2008). It put greenhouse gas

(GHG) emissions associated with food distribution (including from overseas) at approximately 3 per cent of the emissions produced within UK borders – transport's share would be lower, at 2.25 per cent, if the embedded emissions of all goods and services imported from overseas were included (Garnett, 2008) – and concluded that distance per se was not an adequate gauge of environmental impact. It highlighted too the need to distinguish between different modes of transport, with the hierarchy of emission intensity running from sea, to rail, to road to air – this last being by far and away the most GHG-intensive mode of travel.

Following the publication of these two reports, many others have been completed. For example, one New Zealand study (Saunders and Barber, 2007) compared the GHG footprint of the British and New Zealand dairy industries and found that per kg of milk solids, the UK's emissions were 34 per cent higher (and 30 per cent more on a per hectare basis) than New Zealand's, even allowing for shipping emissions. Note that there has also been strong criticism of the authors' core assumptions, which have been articulated elsewhere in some detail (Murphy-Bokern, 2007). However, the important point to note here is that the magnitude of emissions from other stages in the life cycle (and hence differences between the same key stages of two comparable products) can outweigh the environmental impacts of the transport element. In the case of livestock products, the main impacts lie at the agricultural stage and the differences in agricultural production are more significant than the differences in transport impacts.

Perhaps most significantly, one observes that a focus on 'food miles' alone can distract from the real issue, the main one in this case being that livestock production is inherently GHG-intensive, wherever it occurs. Our consumption of livestock products in the UK has been estimated to account for around 8 per cent of the UK's total emissions – a figure that takes into account the livestock rearing stage only, and not emissions arising from slaughter, processing, transport and so forth (Garnett, 2008). Globally, livestock production accounts for around 18 per cent of world GHG emissions (FAO, 2006). The key concern, then, is not where the animals are reared but how much meat and how many dairy products we consume in our diets.

The relative importance of transport will not be consistent across food types. For meat and dairy products, the agricultural stage contributes overwhelmingly to GHG emissions associated with these foods, and the impact of transport is less significant. For other kinds of foods, however, such as field-grown fruits and vegetables, transport can be important. Sim *et al* (2007) look at sourcing options for three kinds of field-grown fresh produce – Gala apples, runner beans and watercress – and assess their global warming and other environmental impacts. They find that the transport stage of the life cycle does indeed make an important contribution to the environmental impact of these products and generally speaking, the further these products travel, the greater their GHG emissions. For these field-grown fruit and vegetables, Sim *et al* conclude that when in season it is generally environmentally preferable (from a GHG perspective) for UK consumers to buy

British produce rather than produce imported from overseas – although of course we import many foods that cannot be grown here in the UK.

A combination of seasonality and transport distance distinguished by mode may perhaps be a more effective measure of GHG impact than either of these elements alone. It has been argued by many environmental groups that a combination of eating locally and seasonally is a key element (and indicator) of sustainable food consumption (Sim *et al*, 2007; Soil Association, 2008).

One paper, for example, found that during the UK apple season, indigenously grown apples are clearly less GHG-intensive than imports. During the summer months, however, the localness of the product is not enough, environmentally speaking. Before the UK growing season starts, apples imported from the southern hemisphere have the edge over UK apples from the previous year that have been stored under energy-intensive refrigerated conditions (Milà i Canals *et al*, 2007).

What is more, when fresh produce is grown outside its natural growing season with the aid of heating and lighting, the 'local is good' assumption receives another blow. One study (Milà i Canals *et al*, 2007) found that the GHG emissions resulting from the production of Spanish tomatoes, which are grown with little or no heating and lighting, are lower than those of British tomatoes since the latter require considerable inputs of light and heat. Complicating the issue further, a tomato grower might need heat at the beginning and end of the season and not in the middle – the 'seasonal' tomatoes in the late summer months will have a lower GHG footprint but this is only made possible because of the heating boost that was given at the beginning. One might also add that to justify the investment in the glasshouses, the plants and all the inputs, growers of horticultural products need to extend the season beyond the 'natural' growing season itself.

Resource utilization also affects the balance. The fish-processing company Young's Seafood took the cost-based decision to export its prawn de-shelling operations to Thailand. In anticipation of environmental criticisms it also commissioned a study to assess the GHG emissions arising from transporting the product to Thailand, de-shelling it there and transporting it back again, taking into account all emission sources, and comparing this with emissions from UK operations. The study in fact concluded that no net increase in emissions had occurred, the reason being that the efficiency of the de-shelling operation in Thailand was greater than in the UK (Young's Seafood Company, 2009).

It is vital to note that the food miles question is about more than GHG emissions; analysis of the merits of production in country X vs country Y needs to consider much more than the notion of GHG efficiency, with water use being a case in point. For example, the Almeria region of Spain, where much of its horticultural production is located, suffers from water shortages due in part to unsustainable rates of water extraction by the horticultural sector. According to current climate models, these areas are set to become more arid still as the effects of climate change intensify. One might question the wisdom of continuing to grow horticultural products in highly water-stressed areas, and of making simplistic 'single-issue' decisions. In Spain, for example, some Spanish production systems do worse in other non-GHG environmental respects, such as pesticide use. What is more, there can be huge variability between production methods even within the same region, as Milà i Canals has shown for apples. In the case of tomatoes, some growers in Spain now use heating to boost production (López *et al*, 2006), in which case the GHG benefits of importing them into the UK are contestable (Milà i Canals, 2003).

It is important to note too (Garnett, 2003), that while there may be trade-offs between measures to reduce transport emissions vs those to minimize production-stage impacts, there can also be correlations between transport energy use and other forms of energy use, including for refrigeration. Food transported over long distances also needs to be refrigerated for lengthy periods; many handling stages in the supply chain increase the possibility of waste occurring. What is more, apples from New Zealand may first be stored there before being shipped into the UK, or shipped here and then stored here[1] – a double whammy. There are after all only two main global harvests (northern and southern hemispheres) and so storage will always be needed at some point in the year if we are to maintain year-round supplies.

So far the discussion has focused on transport in general but the air freight issue merits particular attention. Notwithstanding heavy media focus (Blythman, 2007) on air-freighted food, the vast majority is actually carried by ship and road. In absolute terms, emissions from air freight as compared with those from shipping and trucks are considerably lower. This said, per unit of food transported, air freight is by far and away the most GHG-intensive mode. Less than 1 per cent of all food is carried by air but it accounts for 11 per cent of all food transport CO_2, including customer car travel to and from the store (AEA, 2005).

Hence, during the UK growing season, air-freighted Kenyan green beans are 20–26 times more GHG-intensive than seasonal UK beans (Sim *et al*, 2007). Of course, people also eat green beans out of season and a non-seasonal analysis would give different results, since heating would be needed to produce the crop in the winter (this is a hypothetical example since beans are not, in fact, grown out of season in this country). For comparison, a relative environmental assessment of rose production in Kenya and Holland found that during the UK winter months, roses imported to the UK from Holland have a GHG burden nearly six times greater than those air-freighted in from Kenya (Williams, 2007). This reflects the very high energy requirements of Dutch greenhouses; Kenyan roses, by contrast, are grown using 'free' sunlight.

It is important, however, to emphasize that both have a high footprint. One of the psychological traps of the life-cycle approach is that it can prompt dualistic conclusions. The product that has a lower GHG impact becomes 'good' while the other is 'bad', when in fact both have very high impacts – half a dozen Dutch roses contributes around 17.5 kg of CO_2 and even the less GHG-intensive Kenyan ones are responsible for the emission of 2.9 kg CO_2 per half dozen.

For comparison, 2.9 kg would 'buy' nearly 6 kg of sugar or 38 packets of crisps or 5 kg of raw broccoli (British Sugar, 2009; Walkers, 2009; Muñoz, Milà i Canals and Clift, 2008). Clearly no self-respecting lover is going to turn up on the doorstep bearing broccoli, but the point is that either/or comparisons can be misleading. There are, moreover, potentially acceptable alternatives: British daffodils for example. This would, of course, involve cultural changes – among other things, in what we define as being 'romantic'.

Evidently, the GHG emissions arising from our food system are not sustainable, and while some of the alternatives suggested (eat local – without regard to season or type of food being consumed) may not necessarily improve on the current situation (or may have unintended consequences in terms of water, diets/health, landscape or biodiversity), this emphatically does not mean that all is for the best in the best of all possible worlds. The findings of LCA need framing within wider perspectives on absolute impacts and on need and consumer behaviour (Milà i Canals *et al*, 2008).

Of course, the environmental impacts of air freight cannot be considered in isolation from other social and economic concerns. It has been estimated that between 1 and 1.5 million people in sub-Saharan Africa depend in one way or another upon export horticulture, with 120,000 people directly employed (MacGregor and Vorley, 2006). The contribution overall that flown-in fruit and vegetables make to the UK's GHG emissions is actually very small at around 0.2 per cent; why, one might ask, should poor Africans have to suffer on account of our tender consciences, particularly since we could easily compensate for these emissions by, for example, walking, rather than driving, to the supermarket, or opting-out of a few pints down at the pub?

On the other hand, forms of economic development that are environmentally unsustainable are effectively sawing off the branch they are sitting on, particularly since climate models suggest that sub-Saharan Africa will be particularly affected by the negative impacts of climate change (Boko *et al*, 2007). There is clearly a development-vs-environment dilemma that many organizations are seeking to explore from a diversity of perspectives (Soil Association, 2007; UNCTAD/WHO, 2007; DfI, 2008; Food Ethics Council, 2008), although at this stage there does not appear to be much by way of resolution.

To conclude this sub-section, the evidence seems to be pointing towards the view that while the transport stage is environmentally significant for some products, particularly for field-grown fruit and vegetables, and more particularly still for those that are air-freighted, a focus on food miles alone can distract both from the important variables of mode and efficiency and, more importantly still, from the often heftier impacts at other stages in the supply chain. Moreover, some foods, wherever they are grown and however they travel, are inherently more GHG-intensive than others.

However, while life cycle analysis usefully helps dismantle 'common-sense' assumptions that shorter is better, the approach itself has its limitations. As we discuss in the next section, it is important, with food miles, not to throw the baby out with the bathwater.

Transport, the second-order impacts and the implications for GHGs

There is a view, among some LCA practitioners that the 'concept of food miles is unhelpful and stupid. It doesn't inform about anything except the distance travelled'.[2] This, we argue, is itself a somewhat unhelpful view, for two reasons.

First, transport creates a wide range of social and environmental problems that, albeit not climate related, are nevertheless significant. These include transport's contribution to accidents, noise, air pollution and congestion (Woodcock *et al*, 2007; AEA, 2005), and the concreting over of natural landscapes. Long-distance food transport also raises major socio-economic questions concerning globalization, the inequality and concentrated nature of power structures, and the merits or otherwise, for developing-world countries, of developing export-oriented monoculture in preference to building up national self-sufficiency. One needs also to consider the broader role that transport plays in fostering obesogenic environments (Hinde and Dixon, 2005), the homogenization of food culture and the loss of local identity (Lang and Heasman, 2004). These very important issues are the subject of campaigns by a number of non-governmental organizations[3] (Lake, and Townshend, 2006) and consideration by policy makers and researchers alike, and should be included in any thorough analysis of transport's impacts on society and the environment.

Second, the life cycle analysis approach tends to present an a-temporal, 'snapshot' picture of transport and its contribution to GHG emissions. It assesses the impacts now; it has little to say about the way in which transport indirectly contributes to greenhouse gas emissions and does so over time. A different perspective is needed to assess broader trends in transport emissions, or the way in which long-distance transport can contribute to emission-intensive structural 'lock-in', or the way different policy decisions can alter both the emissions picture and transport's relative prominence in it. We discuss these issues in the paragraphs that follow and argue that, using this more dynamic, systemic approach, food miles once more become relevant.

The first systemic issue concerns transport trends and investment decisions. Clearly, as supply chains globalize, there will be more transport. More transport, in the absence of a clean fuels revolution, means that emissions will grow in absolute terms. This is obvious; however – and this is where the second-order, indirect impacts start to emerge – these growth patterns have gone hand-in-hand with infrastructural, systemic changes that bring with them their own impacts. As supermarkets and manufacturers commit to securing supplies or locating their manufacturing plants far from home, their decisions give impetus to further investment in new or expanded infrastructure – roads, ports, runways, air freight handling facilities, as is clearly being seen in the emerging economies (India Aviation, 2008). While these construction activities will produce their own direct environmental (including

GHG) impacts, more importantly, they foster a situation where supply chains become committed to, and predicated on, long-distance sourcing and distribution. The presence of new infrastructure makes it easier and cheaper to source from further afield, and of course the cost of investment needs to be recouped. This fosters the continuation of, and increase in, long-distance sourcing. By contrast, sources closer to home may be less economically attractive because labour costs are higher. As a result, local enterprises go out of business, leaving no closer-to-home choice available – even where they may be environmentally preferable. This is what we mean by structural 'lock-in'.

Swings in the price of oil and the health of national economies will have a major influence on these trends. One might speculate that in an economically constrained world, long-distance sourcing may start to look less attractive. It is important to bear in mind, however, that all stages in the supply chain are oil dependent and that economic savings are being sought in all areas, including labour. The cost of transport (and hence the argument that local sourcing may be more cost-effective) needs to be balanced against cost elsewhere in the supply chain; it is still entirely possible that for many commodities the more distant source will remain the most economical one.

A further reason why the 'food miles' concern should not be dismissed as unimportant is this: while other industry sectors are beginning, slowly, to clean up their act and even achieve absolute reductions in emissions, green transport fuels are either a long way down the line (hydrogen for example), or environmentally and socially questionable (biofuels) (Searchinger *et al*, 2008). The growth in transport has so far been the great intractable, unbudgeable problem, with its importance, relative to those of other life-cycle stages, growing. This is perhaps an overly pessimistic view, given the scope for making more use of alternative modes of transport such as rail and short-sea shipping – and for improving the efficiency of these modes, where there is still considerable scope for improvement. This said, as ever, a combination of political will and economic feasibility is needed.

Finally, for transport and its second-order impacts, there is the 'what if?' question to consider. We have already highlighted the fact that products such as tomatoes may be more GHG-intensive to produce in a greenhouse here in the UK than their sunnier-climed counterparts. But while this may be the 'correct' life-cycle answer today, what if, over the next few years, the UK protected horticulture sector were to invest heavily in cleaner or renewable heating and lighting technologies? There is more immediate technical scope for applying clean fuel sources (biomass, trigeneration, wind and solar) to stationary infrastructure such as commercial greenhouses than there is to moving infrastructure – transport vehicles. Indeed one study found that technically there is potential for UK horticulture to be carbon neutral (Warwick HRI, 2007).

What if, coupled with this, increased desertification in Spain (Chapagain and Orr, 2008) forced its horticulture industry to increase its use of energy-using irrigation (a likely scenario)? In these circumstances the UK tomato may become the less GHG-intensive choice. Alternatively, tomato production in Spain may become totally uneconomic and retailers may turn to regions further afield, where the GHG balance may be less favourable. Of course, what is true of the UK policy could equally be true of Spain. The Spanish horticulture sector could make concerted efforts to apply renewable technologies to its enterprises, and indeed the use of renewable energy is higher in Spain than it is here (PROGRESS, 2008). The point is that the answers given to particular life-cycle questions can change, depending on what policy makers actually decide to do and, relative to other life-cycle impacts, the prominence of transport may or may not increase.

A final point to note for transport is that in future years, as the impacts of climate change start to hit home in the developing world and agricultural production becomes increasingly vulnerable to climate-induced shocks, we may see a growth in imports from rich northern-latitude countries to the developing world. How this affects transport-related emissions remains to be seen but perhaps merits further investigation.

Local vs global and the self-sufficiency question

This brings us round to the question of self-sufficiency. It is worth bearing in mind that the UK has not been self-sufficient in food for hundreds of years. In the 1840s, around 40 per cent of domestic demand was being supplied by imports (Davis, 1979). In the 1890s a third of the meat consumed in Britain was imported (University of Guelph, 2009), and indeed in London most of the meat consumed came from overseas (Oddy, 2006).

For many environmentalists and development groups there is a link between a more sustainable, equitable and secure food system and one that is more self-sufficient (Oddy, 2006; Sustain, 2008; Fife Diet, 2009). This view is based partly on the view that food miles are a bad thing (with the sophistication of the argument varying), and partly on a sense that one can have more control over the way indigenous goods are produced than those grown on unknown terrain. Growing your own, it is argued, can protect a nation from the vagaries of economic and climatic conditions overseas.

There are several underlying assumptions here, and the security and environmental issues perhaps need to be treated separately. Taking the security question first, is there a specific risk-avoidance argument for shortening the supply chain? This is a difficult question to answer. All supply chains are exposed to risk of one kind or another, and although a shorter supply chain will not be vulnerable to some of the risks threatening a global one, the reverse is also true. The risks may be different but not necessarily of less magnitude. Various food safety crises such as BSE, avian influenza and Sudan red are all examples of security risks associated with long-distance sourcing and potentially affecting a large number of people. On the other hand, if we base our food security on the availability of food grown within, say, a 100-mile radius, then we may be at risk of hunger during poor growing seasons, or during a localized outbreak of listeria. Others elsewhere might not be affected, but the health and food security of local people could suffer greatly. Arguably, therefore, a well-prepared business is a flexible one – one that develops as broad a supply and market base as possible in order to spread its risks and respond to events with agility (Garnett, 2003). In short, it can be dangerous to put all one's eggs in one basket.

On the other hand this 'flexible' approach can make life very difficult for suppliers. Without secure long-term contracts and a sense of the volumes they need to produce they cannot plan ahead or indeed invest in some of the cleaner technologies and systems that need to be put in place. Insecure, short-term contracts can undermine food production and thereby reduce food security. More secure, stable arrangements, on the other hand, allow farmers to invest, to plan ahead and indeed to work towards long-term environmental sustainability.

Importantly, we cannot talk about food security without considering our energy security (Food Chain Analysis Group, 2006). As we increase our reliance on energy imports (DTI, 2007), so food grown or manufactured in this country will, relying as it does on energy inputs, be inherently import dependent. It has been argued that we should perhaps be aspiring to achieve food security at the European level, since at this scale energy security is a more achievable goal (Defra, 2006). It is also important to point out that measures to reduce the dependence of the food sector on energy inputs will, by this measure, also increase food security.

The environmental arguments are perhaps harder to answer. As highlighted above, the relationship between transport and environmental impact is not always clear, although we have argued that there are additional important, and damaging, second-order consequences of basing economic structures upon globalized provisioning systems. It may also be the case that sourcing more from the UK enables greater control over the quality (and environmental sustainability) of production, although many overseas production systems are in fact highly regulated and controlled by UK retailers.

It is also important to explore self-sufficiency from the perspective of long-term changes in the global climate. While all regions of the world will ultimately suffer from the consequences of a warming climate, agricultural production in northern latitudes (including the UK) may initially benefit. Countries in the southern hemisphere, on the other hand, and particularly those that are already agriculturally vulnerable, are already beginning to suffer the negative consequences of a warmer, more volatile climate. They will not be able to grow as much or as predictably, and so the number of people at even greater risk of hunger will grow (Easterling *et al*, 2007). There is therefore a strong moral case for the UK and other wealthy northern countries to ensure that their farming sector is robust enough to grow enough food not just for their own populations but for people overseas. There is of course a danger that this point may be used as an argument for maintaining high levels of EU subsidy for EU agriculture – a situation that would be damaging to developing-world growers.

Perhaps the key point with respect to food security is that strong local, regional and national supply networks are important, as are global ones, but in all cases they will be strong only if the agricultural base is environmentally sustainable (Barling, Sharpe and Lang, 2008), which in most geographical regions worldwide, is not the case (IAAK, 2008; Food Matters, 2008; Smith *et al*, 2007). Food security, then, is as much about the 'repeatability' of food production in the long run as the geographical origin of the product, and repeatability requires the maintenance of soil and water quality and of biodiversity, and the reduction of farming-related GHG emissions. The questions of food miles and self-sufficiency are important, but need to be considered as part of the broader challenge of improving the sustainability of the food system as a whole.

Notes

1 In the latter case the situation is worse since the UK's electricity mix is more carbon intensive than that of New Zealand, which is based largely on hydroelectricity.

2 Dr Adrian Williams quoted in: How the myth of food miles hurts the planet, *Observer*, Sunday 23 March 2008.

3 For example the Campaign for Better Transport, the Council for the Protection of Rural England, Friends of the Earth, Sustain, Oxfam and others.

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PART FIVE

Implications for public policy and the future of supply chains

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The role of government in promoting green logistics

18

ALAN McKINNON

Introduction

This book contains many examples of companies reducing the environmental impact of their logistics operations. While these corporate initiatives are gathering momentum, it is unlikely that the free market on its own will deliver an environmentally sustainable logistics system, particularly within the required time frame. A key attribute of such a system will be carbon emissions per unit of product delivered that are well below the current level. Logistics will be expected to make a large contribution to the drastic reductions in CO_2 emissions that will be required by 2050 to contain the global temperature increase within 2°C by 2100. Industry cannot be expected to achieve this on its own. It will require concerted action by companies, citizens and government to reach the necessary carbon reduction targets. Governments also have a strong interest in ‘greening’ other aspects of logistics to improve the general quality of the environment. While great progress has been made over the past 20 years in cleaning exhaust emissions, cutting vehicle noise levels and reducing the involvement of freight vehicles in accidents, the potential exists to attain significantly higher environmental standards.

There has been a long history of government intervention in the freight transport sector. This was traditionally motivated by a desire to correct market anomalies, particularly in the competition between transport modes. In most developed countries, regulatory frameworks were established to control the supply of freight transport capacity, impose obligations on carriers and/or influence the tariffs that they could charge. Over the past 30 years most of these quantitative regulations on freight transport have been removed as part of a general process of market liberalization, to be replaced by qualitative controls designed to maintain operating standards and professionalism in the freight industry (McKinnon, 1998). It is over this period that environmental concerns have begun to play an increasingly important role in the formulation of freight transport policy. It is ironic that while liberalization measures have been facilitating the growth of freight movement, governments have been intensifying their efforts to reduce its impact on the environment.

As explained in Chapter 1, official definitions of sustainability used in the context of freight transport/logistics generally encapsulate the concept of the triple bottom line (Savitz, 2006). This aims to reconcile economic, environmental and social objectives in a fair and balanced manner. Building on the Brundtland Commission's definition of sustainable development, the UK government defined the 'aim of its sustainable distribution strategy' as being 'to ensure that the future development of the distribution industry does not compromise the future needs of our society, economy and environment' (DETR, 1999). As the growth, efficiency and reliability of freight transport are seen as being intimately linked to economic development, governments are naturally reluctant to impose environmental constraints on the movement of goods that would be damaging to the economy. The updated version of the UK government's sustainable logistics strategy, published nine years later, continues to adopt this broad definition of sustainability, aiming to reconcile climate change, competitiveness/productivity, equal opportunities, quality of life, safety, security and health objectives (DfT, 2008). In this respect they are applying what Whitelegg (1995) calls the 'weak' form of sustainability, in which environmental objectives are traded off against social and economic objectives. The 'strong' form, which involves the imposition of environmental controls regardless of their economic and social consequences, may have to be more widely applied in the future to address the problem of climate change.

Since the 1980s, environmental policies on freight transport have evolved in several respects. First, their emphasis on particular externalities has shifted, partly because of the success of earlier policy initiatives but mainly because of a general reordering of environmental priorities at national and international levels.

Second, policy objectives have become more wide-ranging and specific, with clearer definition of targets and timescales. For example, the latest EU Transport White Paper sets a target of having '30 per cent of road freight over 300 km... shift to other modes such as rail and waterborne transport by 2030, and more than 50 per cent by 2050'. It also aims to achieve 'near zero-emission urban logistics' by 2030 (European Commission, 2011).

Third, the policy 'toolkit' has been expanded to include a broader range of measures. Some national governments, such as those of the Netherlands, the UK, the United States and France, have been more innovative than others in devising new methods of greening the freight transport system. The more progressive ones have also recognized the need to make freight transport policies sensitive to wider logistical and supply chain trends. As companies now manage transport as an integral part of a logistics strategy, governments must understand the interrelationship between transport and other logistical activities if they are to be able to influence corporate behaviour. For example, in the late 1990s the UK government acknowledged that 'a sustainable distribution strategy should consider more than just the transport of goods from A to B'. It should also 'encompass supply chain management or "logistics" as well as all modes of transport' (DETR, 1999).

Fourth, knowledge has accumulated in government circles of the relative cost-effectiveness of different sustainable logistics strategies. International networking through organizations like the International Transport Forum,[1] the EU and UN Centre for Regional Development (UNCRD) has helped to disseminate this information and identify the most promising measures. There nevertheless remain wide international differences in the nature, scale and resourcing of government programmes designed to improve the environmental performance of logistics.

Although formal policy statements on sustainable freight/distribution/logistics usually emerge from national transport ministries, the environmental impact of freight transport is influenced by a broad spectrum of governmental decisions at central and local levels. The demand for freight movement is affected by government policies on the economy, industry, regional development, the environment, energy, land-use planning and recycling, which are the responsibility of several departments. It is interesting to note that the review of US Federal freight policy by Frittelli (2013) does not even mention the environment, despite the pioneering work on sustainable distribution undertaken by the US Environmental Protection Agency, an agency of the federal government, in its SmartWay programme.

The goals of logistics sustainability are sometimes in conflict with other government policy objectives. For example, efforts to promote industrial development (or 'social cohesion') in peripheral regions typically generate more freight movement per tonne of product produced, while, by inflating the real cost of holding inventory, monetary policy can cause companies to tighten just-in-time regimes, often at the expense of poorer vehicle utilization. Differences in the level of tax imposed on different transport modes are often determined more by budgetary requirements than by an assessment of their relative environmental impacts. Although politicians frequently espouse the virtues of 'joined-up' government, in practice there is often little cross-ministry coordination of all the government decisions affecting the freight transport system.

This chapter will focus on the green logistics initiatives of central governments and multinational organizations. Earlier chapters, particularly Chapter 14 on city logistics, have examined the efforts of local government to reduce the environmental impact of logistics. In some countries, it is at the local or state levels that the development of public policy on freight sustainability is most active.

Objectives of public policy on sustainable logistics

Few national governments have so far articulated a clear set of sustainable freight or logistics objectives. The UK government (DETR, 1999) declared a fairly comprehensive set of 'sustainable distribution' objectives (which embraced the triple bottom line principle). It aimed to:

- improve the efficiency of distribution;
- minimize congestion;
- make better use of transport infrastructure;
- minimize pollution and reduce greenhouse gas (GHG) emissions;
- manage development pressures on the landscape – both natural and anthropogenic;
- reduce noise and disturbance from freight movements;
- reduce the number of accidents, injuries and cases of ill-health associated with freight movement.

This addressed all the main externalities associated with logistics, though it excluded visual intrusion (Baugham, 1979), where people object to the appearance of freight vehicles and warehouses in 'sensitive' environments, and community severance, where a transport link carrying large amounts of freight traffic acts as a barrier to social interaction. Several of the objectives were mutually reinforcing. Improving the efficiency of distribution, for example, can reduce freight traffic levels, thus easing congestion and mitigating a range of environmental effects, as well as saving money.

In contrast, the German government's sustainable freight transport strategy has a narrower environmental focus, aligning the development of freight transport with the country's five overriding environmental goals of climate protection, air pollution control, noise control, nature conservation and landscape preservation (Erdmenger *et al*, 2009). This translated into two more specific targets: to reduce the freight transport intensity of the German economy by 5 per cent between 1999 and 2020 and to increase the share of tonne-kms moved by rail and inland waterway to, respectively, 25 per cent and 17 per cent by 2015.

Policy measures

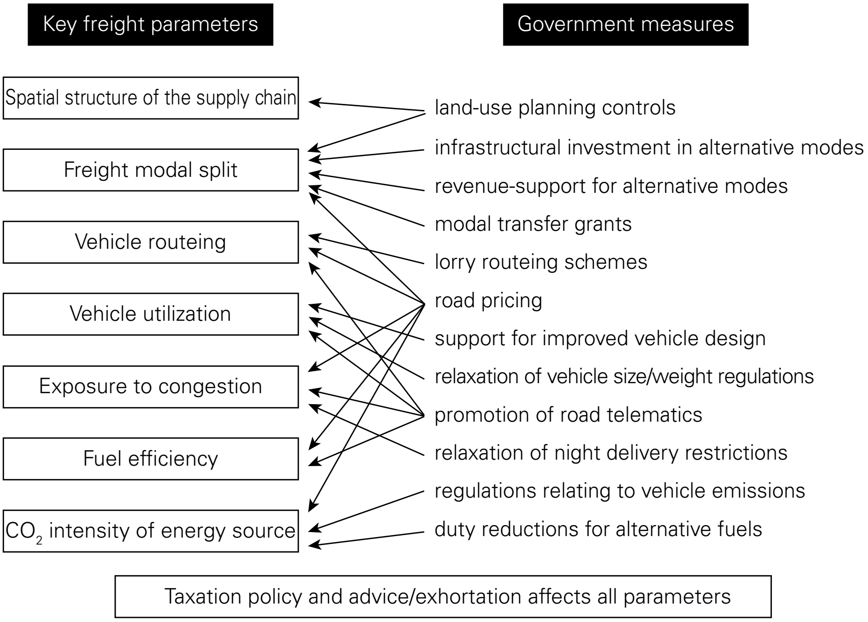
Governments have a range of policy instruments that they can deploy to reduce the environmental impact of freight transport/logistics. Lists of these policy measures can be found in reports by Faber Maunsell (2008) for the European Commission and the International Energy Agency (2009). They can be divided into seven broad categories:

1. Taxation: this comprises mainly fuel taxes, vehicle excise duty (VED) and road-user charges.
2. Financial incentives: these can take various forms. For example, they can support capital investment by companies in new equipment or infrastructure, or subsidize the use of greener freight modes or urban consolidation depots.
3. Regulation: this can be applied to vehicle design and operation, the status of the freight operators, the tariffs they charge and even the capacity of the freight sector.
4. Liberalization: the liberalization, and privatization, of freight markets can also have environmentally beneficial effects by, for example, enabling rail companies to compete more effectively for traffic or giving own-account truck operators permission to backload their vehicles with other firms' traffic.
5. Management of nationalized enterprises: in many countries freight businesses are state owned, often giving governments a direct influence over their environmental performance.
6. Infrastructure and land-use planning: this includes the construction and management of network infrastructure and terminals, controls on vehicle access to infrastructure and the zoning of land uses for logistics-related activity.
7. Advice and exhortation: governments have a role in identifying and promoting best environmental practice in freight transport, often working closely with trade associations.

Under each of these headings, there are many specific measures that can be applied, giving government considerable flexibility in the way it influences the behaviour of organizations involved in logistics. The policy maker must exercise considerable skill, however, in designing a package of measures that in combination achieves the declared objectives. This can be difficult in the field of sustainable logistics because many of the measures are relatively new and their longer-term impact and relative cost-effectiveness are still uncertain. Nor is there a single optimum policy mix for all countries and regions. The package of measures will always need to be tailored to the particular circumstances of a country's geography, freight market, infrastructure and industrial strategy, as well as the weighting attached by politicians and the public to different environmental effects.

Figure 18.1 shows the interrelationship between some of the more important sustainable logistics measures and the key freight parameters identified in Chapter 1 that link freight-related externalities to economic growth. By modifying these parameters, public policy interventions can reduce the environmental impact of freight transport even within an expanding economy. Figure 18.1 shows that some of the measures are likely to have targeted impact on specific parameters and objectives, while others can exert a wider influence on the freight transport system and simultaneously address several policy objectives.

FIGURE 18.1 Relationship between key freight transport parameters and government transport policy measures



In designing a package of sustainable logistics measures, policy makers must take account of possible 'second-order effects'. There is always a risk that the application of a green measure in one area of logistics will have an offsetting effect elsewhere. The most prevalent second-order effect in this field results from those measures that cut cost in addition to reducing the burden on the environment. These measures are generally lauded for being self-financing and thus commercially attractive to businesses. By reducing the cost of transport per tonne-km, however, they can, perversely, cause a re-adjustment of logistical cost trade-offs and promote developments, such as wider sourcing or greater centralization, that actually generate more freight movement. Winebrake *et al* (2012) review the various methods that have been used to estimate the strength of this so-called 'rebound effect' in the road freight sector. An analysis of the Portuguese road freight sector has suggested that it might offset as much as 24 per cent of an improvement in fuel efficiency (Matos and Silva, 2011). In some cases it may be necessary to introduce additional taxes and/or regulations to suppress undesirable second-order effects.

The following review of public policy measures will focus on five aspects of sustainable logistics strategy:

- reducing freight transport intensity;
- shifting freight to greener transport modes;
- improving vehicle utilization;

- increasing energy efficiency;
- switching to less polluting energy sources.

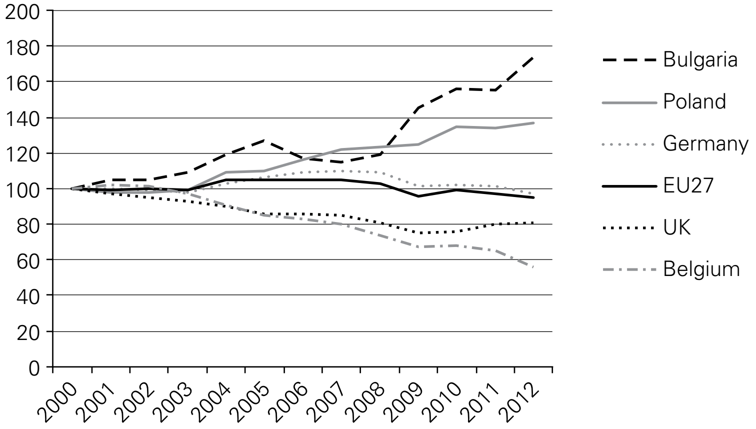
Reducing freight transport intensity

In its 2001 White Paper on Transport the European Commission (2001: 15) stated that 'We have to consider the option of gradually breaking the link between economic growth and transport growth'. This policy statement did not specifically mention freight, though as Meersman and van de Voorde (2002: 2) explain, 'the European Commission refers primarily to freight transport when it argues that transport growth should be gradually decoupled from economic growth'. This proposal was not officially adopted as an EU policy objective, however, and it did not appear in the mid-term review of the White Paper. This review document emphasized the need to divorce the growth in mobility from the related externalities rather than to cut mobility relative to GDP (European Commission, 2006: 5). The latest EU White Paper on Transport has gone further in stating unequivocally that 'curbing mobility is not an option' (European Commission, 2011).

The EU and national governments are committed to promoting economic growth and naturally fear that attempts to constrain increases in the amount of freight movement might adversely affect future growth prospects. Across the EU's 27 member states the ratio of freight tonne-kms to GDP was fairly stable between 2000 and 2012 (Figure 18.2), though individual member states have exhibited widely divergent trends in freight transport intensity (McKinnon *et al*, 2008). In the countries where this intensity is declining, the case for explicit transport-reduction strategies is weakening. This, for instance, will make it easier for them to meet climate change obligations (McKinnon, 2007). The UK DfT (2008: 19) argued that 'the decoupling demonstrates that the economic growth in UK GDP is not currently reliant on freight tonne-km growth and therefore economic growth is not directly linked to increased GHG emissions due to freight activity'. At least some of this freight–GDP decoupling, however, is likely to be the result of manufacturing operations being offshored to low-labour-cost countries, taking with them all the externalities associated with the inbound logistics operation. While national environmental footprints are then reduced, freight transport intensity and total freight-related externalities are increased at a global level. Statistical evidence of decoupling in one country should not, therefore, be taken as grounds for complacency on the part of freight transport policy makers. There is also evidence of manufacturing 'reshoring' from low-labour-cost countries to the US (Sirkin *et al*, 2011) and Europe (European Parliamentary Research Service, 2014) suggesting that some of the geographical displacement of freight externalities may have been temporary.

As the magnitude of the global warming challenge becomes more apparent, it may ultimately be necessary for governments to introduce explicit policies to curb the growth of tonne-kms. How then could this be achieved? It might

FIGURE 18.2 European trends in the ratio of freight tonne-kms to GDP ('freight transport intensity')



SOURCE: Eurostat

have to be done as part of a deliberate downsizing of national economies to bring the level of material consumption down to a more sustainable level. Alternatively, ways might have to be found of reducing freight tonne-kms within an expanding economy (McKinnon, 2008). This would require changes to the structure of supply chains, arresting and then reversing the geographical changes in production and distribution systems that have been key drivers of freight traffic growth for several decades. Promoting a return to more localized sourcing, greater vertical integration of production and more decentralized warehousing could all reduce freight transport intensity, but would require a reversal of well-established business trends. A series of fairly draconian measures might have to be imposed to achieve this, including steep increases in taxation, the reintroduction of quantitative controls on capacity in the freight sector and a moratorium on infrastructural development to allow traffic congestion to worsen and act as a constraint on future traffic growth. Because freight transport tends to have a relatively low price elasticity, tax levels would have to rise steeply, especially in those countries where they are currently low, to achieve a significant traffic reduction. If oil prices were to rise sharply in the medium to long term, market forces could relieve governments of the need to raise transport taxes (Fiorella *et al*, 2008). It is worth noting, for example, that the increase in the world price of oil over nine months, between September 2007 and June 2008, inflated diesel fuel prices in the UK by a greater margin than five years of the government's radical 'fuel-duty escalator' policy, which increased fuel taxes by 5–6 per cent per annum in real terms between 1994 and 1999.

Much less controversial and more cost-effective are government initiatives that encourage companies to reduce the amount of freight movement within their existing logistical systems and pattern of trading links. This can be achieved by, for example, routeing vehicles more directly, probably with the support of computerized vehicle routeing and scheduling (CVRS) systems as discussed in Chapter 10, or establishing swap arrangements between producers, as currently happens in the petroleum sector. As part of the UK government's Freight Best Practice programme, for example, companies were given advice on the use of CVRS (DfT, 2007), while in the Netherlands the government operated for several years a 'transport prevention' programme that gave companies guidance on ways of reducing their demand for freight movement by rationalizing their logistics operations. The European Commission, as part of its Marco Polo programme, provides financial support for 'traffic avoidance actions' which:

> innovate by integrating transport into the production process. They make the whole supply chain more efficient. They can do this, for example, by cutting the journey distance, increasing loads, reducing the number of empty runs or reducing the amount of waste. These efficiency gains must not, however, be at the expense of jobs or total output.
>
> (European Commission, 2012)

There is no hint of transport avoidance principles being applied at a global level. On the contrary, it is forecast that the World Trade Organization's Bali Accord of December 2013 will increase international trade by around $1 trillion, mainly by facilitating the movement of freight across international frontiers and promoting the development of complex global value chains. 'The prospect of governments individually or collectively restraining the growth of trade for environmental reasons seems remote' (McKinnon, 2014: 2).

Shifting freight to greener transport modes

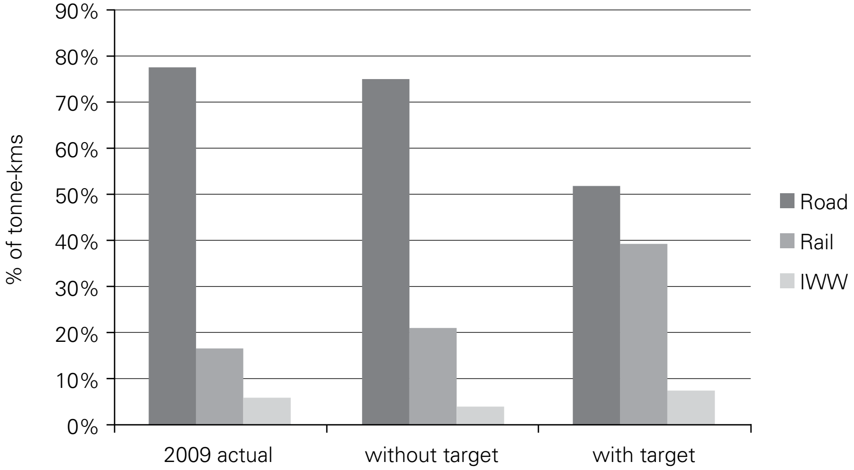
Getting freight off the road network and on to trains, barges and ships has traditionally been seen by policy makers and politicians as the most promising way of easing the environmental and congestion problems associated with goods movement. In most countries this would involve reversing a long-term modal shift to road. In Eastern Europe, for example, the shift from rail to road has been a much more recent and dramatic phenomenon that will be difficult to stop, let alone reverse, in the foreseeable future (International Energy Agency, 2009). Despite the efforts of governments around the world to stem the erosion of freight traffic from rail to road, in most countries this trend has continued. One of the few exceptions has been the UK where, partly as a result of the privatization of the state-owned rail freight company and the emergence of new operators, rail increased its share of the domestic surface freight market (ie road + rail) from 8.0 per cent in 1995 to 11.2 per cent in 2010 (DfT, 2011).

As mentioned earlier, in its 2011 Transport White Paper the European Commission sets a very ambitious freight modal shift target for the EU,

FIGURE 18.3 Effect of EU transport policy target on the freight modal split in 2030

Without target: Business-as-usual projection of modal split in 2030

With target: EC White Paper target for 30% of freight tonnes moving over 300 km to move by rail or inland waterway (IWW) by 2030



SOURCE: Tavasszy and van Meijeren (2011)

requiring, by 2030, 30 per cent of freight traffic travelling distances greater than 300 km to move by rail or water, and 50 per cent by 2050. Figure 18.3 shows how the freight modal split in the EU would change by 2030 both on a business-as-usual basis and if the White Paper target is reached. It is not clear, however, what range of public policy interventions will be required to induce such a dramatic modal shift. In a critique of this policy objective, Tavasszy and van Meijeren (2011: 18) conclude that 'even though there is a theoretical potential, the feasibility of shifting such volumes in the segment above 300 km seems low. The objective of reducing internal and external costs may be achieved more easily by other means...'.

All seven categories of policy measure listed earlier can be used to rebalance the modal split. As observed in Chapter 7, some measures can be used to make rail and waterborne transport more attractive, while others can deter companies from using more environmentally damaging modes. This combination can exert pull and push pressures on companies' modal split decisions. Some of the major measures are discussed below.

Taxation

Differential levels of duty can be imposed on fuel consumed by different modes. In the UK in April 2014, diesel fuel used in trucks was taxed at

58 pence per litre, while that consumed in diesel locomotives hauling freight trains attracts a tax of only 11 pence per litre. Not all fuel taxation is environmentally progressive, however. The most glaring anomaly is the exemption of aircraft kerosene from taxation, despite the fact that most of its pollutants and CO_2 are emitted high in the atmosphere where their damaging effect (or 'radiative forcing') is much greater than exhaust emissions from surface transport. Most air freight moves internationally and is bound by international treaties, mainly the Chicago Convention of 1944 and around 3,000 bilateral agreements between countries, which prohibit governments from taxing aviation fuel. It is likely to be only a matter of time before this historical legacy is corrected. In 2012, the European Commission started this process by incorporating air transport (of both passengers and freight) within the European Emission Trading Scheme.

The introduction of road-user charging for trucks can also favour a switch to rail and water. The German government, for example, estimated that its Toll Collect system would encourage a 6 per cent shift in long-distance freight tonne-kms to these alternative modes (McKinnon, 2006).

As discussed in Chapter 4, in an ideal world taxes on the various transport modes would be set at levels that internalized their marginal social/environmental costs. Within most countries, governments are still a long way from full application of the 'polluter pays' principle to the freight sector. The internalization of the environmental costs of freight transport is currently high on the transport policy agenda in the EU. In its White Paper on Transport the European Commission (2011: 29) states that it will 'proceed to the full and mandatory internalization of the external costs' of all transport modes by 2016–20. In preparation for implementation of this policy the Commission has recently published an updated set of external costs for transport (Ricardo/AEA, 2014).

Financial incentives

These can take various forms. The nature of government financial support for greener transport operations varies widely, reflecting differences in the ownership of the service and infrastructure, the nature of the freight market, competition policy and rules governing the award of state aid. Support typically comprises capital grants for rolling stock/vessels and terminal development, discounted infrastructure access payments or operating subsidies/revenue support grants. Such financial aid is usually conditional on the freight operator and/or client demonstrating that adequate environmental benefit accrues from the use of the alternative mode. For example, the Freight Facilities Grant Scheme, which operated in the UK between 1974 and 2011, provided capital support for rail freight investment where it could be demonstrated that environmental benefit resulted from the use of rail rather than road. This benefit was calculated financially by estimating the number of 'sensitive lorry-miles' (SLM) likely to be removed from different classes of road and multiplying them by appropriate monetary values for the environmental impact per mile. The grants awarded on the basis of this calculation effectively bought 'the removal of lorries from the road system' (DfT, 2009a: 55). Between 1997 and 2011, a total of 45 freight facilities grants (FFGs) were awarded in Scotland with a total value of £62 million, estimated to have removed 34.2 million lorry-miles per annum from Scottish roads and valuing the average SLM at £1.82 (Scottish Government, 2012). A similar set of Waterborne Freight Grants is still available to incentivize a shift of freight from road to inland waterways and coastal shipping. Since 2009 the UK government has also run a Mode Shift Revenue Support (MSRS) scheme which effectively subsidizes, again for environmental reasons, 'a service conveying deep-sea containers from a port to customers in an inland city' (DfT, 2009a). The maximum rate of MSRS support is calculated on a zonal basis, with the UK divided into 18 zones for this purpose. At the EU level, the Marco Polo programme has been promoting, mainly by means of financial incentives, the use of intermodal transport services incorporating trunk haulage by rail, inland waterway or sea. Between 2003 and the end of 2010, projects funded by this programme transferred just over 30 billion tonne-kms from road to rail or waterborne modes (European Economics, 2011).

Regulation

For much of the 20th century the governments of developed countries tried to use quantitative controls on the capacity and pricing of the road freight sector to protect rail freight operations against competition from road haulage. This strategy proved largely ineffective, however, and was abandoned with the deregulation of the trucking industry in most developed countries between 1970 and 2000 (McKinnon, 1998). The governments of these countries appear to have little interest in the re-imposition of quantitative licensing or tariff restrictions on road transport to engineer a modal shift by regulation. Instead, priority is being given to the liberalization of rail freight operations and the creation of commercial conditions in which rail can compete more effectively with road. Within Europe the EU and individual member states are also trying to improve the 'interoperability' of rail freight services among national rail networks to allow rail to exploit more effectively its comparative advantage in long-distance freight transport.

Infrastructural measures

In some countries, such as the UK, the growth of rail freight is constrained by inadequate track capacity, particularly at peak times in and around conurbations, a lack of network access points, and physical constraints on the size and weight of rolling stock (Railway Development Group, 2014). In European countries governments have been actively investing in the installation of rail sidings, lengthening of refuges/loops, strengthening of track to support heavier rolling stock, expansion of the loading gauge, construction of freight-only lines and the development of intermodal terminals. The EU's new TEN-T infrastructure plan, announced in 2013, will concentrate investment on nine European corridors, within which upgraded rail lines feature prominently.

Improving vehicle utilization

Despite the heavy emphasis that has been given to modal shift in government transport policies, in most countries road transport is going to remain by far the dominant mode of freight transport for the foreseeable future. Sustainable logistics policies must also therefore exploit the potential for improving the utilization of road freight capacity. For a given amount of freight movement, raising vehicle load factors reduces vehicle-kms, cutting transport costs, congestion levels, energy consumption and emissions. Chapter 11 examined the various methods that companies can use to improve vehicle fill. Here we will consider how much leverage government can exert on this critical parameter. Again, most of the categories of policy measure can be used, to a greater or lesser extent, to influence vehicle utilization.

Taxation

In theory, higher taxes on the ownership and/or operation of trucks will give companies an incentive to use them more efficiently. It has long been argued that the influence of taxes on vehicle load factors will be stronger and more targeted if they are related to the carrying capacity of the vehicle and the distance it travels. Over its first three years, for example, the Swiss Heavy Vehicle Fee (HVF), discussed in Chapter 4, is reckoned to have significantly improved truck loading, particularly on backhauls. It is claimed that 'the main reason for the more powerful effect of the HVF was its incentive for fully exploiting the logistic potential to optimize utilization of the vehicle fleet and especially avoiding empty runs' (Swiss Federal Office for Spatial Development, 2004: 22).

Financial incentives

As the vehicle operator gains a commercial benefit from improved loading, it should not be necessary for the government to provide an additional financial incentive. Governments at both central and national levels, however, have subsidized the development of urban consolidation schemes in an effort to rationalize the movement of freight in towns and cities. In a review of 114 urban consolidation centre (UCC) schemes in 17 countries, Allen *et al* (2012: 483) conclude that 'without some initial funding from the central or local government to pay for feasibility studies and trials, any form of UCC that is not related to a major new development is unlikely to proceed, let alone succeed'. They, nevertheless, observe a 'general consensus…

that UCCs must be financially viable in their own right in the medium to long term as public subsidies are not necessarily a desirable solution'.

Regulation

The loading of vehicles is partly a function of the size and weight limits imposed by government. As discussed in Chapter 11, vehicle utilization can be measured in terms of weight or volume. Many loads either weigh-out before they cube-out or vice versa, leaving some weight- or volume-carrying capacity unused. With higher maximum size and/or weight limits companies can consolidate loads, thus using some of this excess capacity. Economic, environmental and safety benefits can flow from such a measure, even after allowance has been made for any second-order modal shift or traffic-generating effects (McKinnon, 2005). Government decision making on the issue of vehicle sizes and weights has been influenced mainly by concerns about safety, public opinion and the competitiveness of rail freight services. In some countries, it has been conditioned more by lobbying and emotion than hard facts. A wide-ranging and authoritative report on the subject conducted by the OECD/International Transport Forum (2010) makes a fairly compelling case for the relaxation of truck size and weight limits. It concludes that 'Higher capacity vehicles have been operated extensively for a variety of freight tasks in some areas of the world without adverse impacts. The evidence available indicates significant safety, sustainability and productivity improvements' (p 10). A more recent report commissioned by the European Parliament to review all the main European studies on this controversial issue acknowledged that 'there are clear benefits associated with LHVs [longer and heavier vehicles], and the question for policy makers is whether the more uncertain disbenefits are likely to materialise, and if so whether they can be mitigated' (Steer Davies Gleave, 2013: 77).

Liberalization

Deregulation of the trucking sector has generally been accompanied by improvements in vehicle utilization (Cooper, 1991; McKinnon, 1998). When freed of operational constraints on backloading, vehicle movements and tariff levels, carriers can generally use their vehicle assets more intensively to the benefit of the economy and environment.

Advice, exhortation and accreditation

Several governments run advisory, benchmarking and promotional programmes to encourage companies, among other things, to improve the utilization of their vehicles. It may seem strange that governments feel the need to provide such support, given that efficient utilization of vehicle capacity is a core business skill and a key determinant of profitability. The advice is targeted as much at shippers as at carriers, however, and often publicizes new operational practices and technology in an effort to accelerate their uptake. A later section of this chapter gives examples of government advisory/accreditation schemes.

Increasing energy efficiency

Governments' efforts to raise the fuel efficiency of freight transport operations are often subsumed within general energy efficiency programmes spanning all sectors of the economy. These programmes usually comprise a combination of 'carrots and sticks', the carrots taking the form of advisory/auditing services and financial support for the implementation of energy-saving technology and the main stick being high fuel duty. They are motivated as much by a desire to cut total energy costs and reduce dependence on imported fossil fuels, as by environmental objectives. Again, a variety of policy measures can be deployed.

Raising fuel duty

The level of fuel consumption in the road freight sector is relatively sensitive to changes in fuel price (De Jong *et al*, 2011). During the period of the UK government's 'fuel-duty escalator' policy (1994–99), the fuel duty rose around 30 per cent in real terms and the average fuel efficiency of road haulage operations increased by approximately 9 per cent. It is not known how much of this efficiency gain was due to the tax policy.

Subsidizing driver training schemes

Such schemes offer a relatively cost-effective means of improving the fuel efficiency of trucks and vans and usually yield supplementary benefits in reduced accident involvement and lower insurance costs. The government-sponsored Safe and Fuel Efficient Driving (SAFED) programme in the UK, for example, has so far provided on-the-road training for over 13,500 truck drivers and 9,500 van drivers. As explained in Chapter 12, average 'on-the-day' improvements in fuel efficiency of just over 10 per cent have been recorded (DfT, 2009b). Regular training updates, incentive schemes and on-board monitoring equipment can help to ensure that improvements in driving behaviour are maintained.

Enforcing/reducing speed limits

As a rough average for heavy goods vehicles, every 1 mph reduction in speed saves approximately 0.8 per cent of fuel (Southwest Research Institute, 2008). Simply enforcing existing speed limits can thus significantly cut fuel consumption and emissions. Anable and Bristow (2007), for example, argue that effective enforcement of the 70 mph speed limit in the UK (for all road vehicles) would save roughly 1 million tonnes of road transport-related carbon emissions annually. Governments can go further and lower speed limits on particular classes of road for particular types of vehicles. They can also insist upon mandatory installation of speed governors to ensure that trucks adhere to speed limits, as is the case in the EU.

Imposing fuel economy standards for new vehicles

As noted in Chapter 8, the Japanese, Chinese and US governments have now imposed fuel economy standards on truck manufacturers, while the European Commission is planning to introduce similar standards for new trucks sold in the European market. Truck manufacturers would naturally prefer harmonization of these national and regional standards, though this seems a distant prospect at present.

Incentivizing scrappage of older vehicles

Evidence from Canada suggests that the average fuel efficiency of heavy trucks more than 10 years old is around 24 per cent lower than that of the average heavy truck (Transport Canada, 2005). Retiring elderly vehicles and replacing them with newer models can, therefore, effect substantial fuel savings. Some governments, most notably that of Spain, have used public funds to accelerate this process.

Advice and exhortation

Many of these advisory programmes, in countries such as the UK, the United States, Canada and Sweden, have been targeted on the fuel efficiency of trucking operations. Research has revealed that many operators underestimate the potential fuel savings that accrue from a broad range of technical and operational changes, many of which can be applied at minimal cost. This is viewed as a market failure that can be corrected by awareness-raising campaigns and the dissemination of information about fuel economy measures. As discussed later in the chapter, this form of government intervention can yield substantial environmental and economic benefits and represents a very cost-effective use of public funds.

Switching to less polluting energy sources

The externalities of freight transport can vary independently of vehicle utilization and energy efficiency. Those associated with air pollution have been separately controlled by the imposition of emission standards for vehicles and fuel (see Chapter 2). The reduction in pollutants such as nitrogen oxide (NOx) and particulate matter (PM10) has been achieved by making technical modifications to vehicles, while sulphur has had to be removed from the fuel during the refining process. In the case of trucks, separate though similar sets of emission standards have been devised by the EU, the United States and Japan and tightened at four- to six-year intervals. This has induced a dramatic decline in emissions from new trucks over the past 20 years. Countries in other parts of the world have tended to adopt the EU or US emission standards. As developing countries acquire many of their trucks on a second-hand basis from Western countries, they inherit vehicles meeting their emission standards, typically with a delay of five or six years.

Legislation and directives relating to emissions from diesel-powered non-road vehicles (eg locomotives, barges and domestic shipping) have lagged behind those of road vehicles by an average of five to seven years. This has partly eroded these modes' environmental advantage relative to road transport, especially as they continue to use cheaper fuels containing more impurities. EU directives on the control of emissions from 'non-road mobile machinery' are steadily reducing the permitted level of NOx, particulate matter and hydrocarbons from diesel locomotives and inland waterway vessels. Regulatory authorities in the EU, United States and Japan are also trying to harmonize worldwide emission standards for non-road diesel vehicles, partly to make it easier for manufacturers of these vehicles to standardize their production.

Much stricter government control has been imposed on exhaust fumes from land-based freight transport modes than on emissions from shipping. Although, globally, ships consume only around 2 per cent of fossil fuels, they are responsible for 14 per cent of NOx emissions and 16 per cent of sulphur emissions. They account for much higher proportions of sulphur dioxide emissions along shipping lanes and in the vicinity of major ports. The failure of the shipping industry to upgrade its environmental standards in line with those of land-based freight modes can be partly attributed to a lack of inter-governmental action and, until recently, the inability of the international organization responsible for shipping, the International Maritime Organization (IMO), to garner enough support from member countries for environmental measures. It illustrates how, in the absence of public intervention, environmental standards in a major industry can remain woefully inadequate.

Much of the initiative in the greening of shipping operations has been taken by port authorities, because emissions from ships can represent a large proportion of airborne pollutants in the surrounding area. The Port of Los Angeles, the largest port in the United States, has set particularly ambitious targets for cutting ship-related emissions, forcing vessels to burn low-sulphur fuels, reduce speeds in the vicinity of the harbour and use shore-side electricity as the power source when docked. The ports themselves, many of which are still in public ownership, are also trying to green their operations. The European Sea Port Organization (2012) has published a Green Guide for member ports which recommends a broad range of environmental measures, including a switch to renewable energy.

Government-supported advisory, best practice and accreditation programmes

Governments in several countries have established programmes that promote the adoption of good environmental practice in the logistics sector. One of the first and most extensive was the UK Freight Best Practice Programme (FBP). It unfortunately was a victim of the UK government's public expenditure cuts in March 2011, though continues to be operated, on a much smaller scale, by the devolved administration in Wales.

The FBP programme provides advice to companies about a broad range of measures that improve the efficiency and reduce the environmental impact of freight transport operations (www.freightbestpractice.org.uk). It has produced numerous reports and brochures, run workshops and established online tools for monitoring and benchmarking energy efficiency. The programme was concerned with the movement of freight by trucks. It was extended to cover van traffic and promote the use of alternative, more environmentally friendly transport modes. Market research established that companies obtaining advice from the FBP showed a significantly greater propensity to implement a range of fuel-saving measures (Lawson, Michaelis and Waldron, 2007). It also suggested that the FBP was a very cost-effective means of promoting the decarbonization of freight transport operations (at approximately £8 of public funds per tonne of CO_2 saved).

The US SmartWay programme was set up by the US Environmental Protection Agency (EPA) in 2004 to help shippers and carriers to 'reduce their transportation footprint'. It provides advice and management tools to companies, approves emission-reducing products and services that transport companies can use, offers financial support for green technologies such as anti-idling devices for trucks, and helps companies obtain loans from private sources for 'green' investments. By 2014 over 3,000 shippers, trucking and rail companies were registered with the programme, many of them Fortune 500 businesses. Carriers meeting specified environmental criteria can gain differing levels of accreditation. An increasing number of US shippers, such as Walmart, are insisting that their carriers are SmartWay-accredited. The EPA also advertises the SmartWay brand, thus helping participating companies to derive a marketing advantage from greening their freight transport operations. The environmental achievements of SmartWay over the past decade are impressive. The so-called 'SmartWay partners' have saved 121 million barrels of oil (valued at $16.8 billion) and cut emissions of CO_2, NOx and PM by, respectively, 51.6 million tons, 738,000 tons and 37,000 tons (US EPA, 2014).

SmartWay now serves as a model to the rest of the world. It has, for example, inspired Green Freight Europe (GFE), an industry-led initiative launched in 2012 with a mission to improve ‘the environmental performance of road freight transport in Europe’ and now with over 110 ‘multinational carriers, shippers and logistics service providers’ (www.greenfreighteurope.eu). Although GFE is an independent, voluntary initiative, it is strongly supported by the European Union. Similar green freight initiatives are now springing up elsewhere, with varying degrees of government involvement. The Green Freight China Initiative (GFCI) was set up in 2012 by the China Road Transport Association, the Chinese Ministry of Transport and Clean Air Asia to provide ‘a basis for nation-wide efforts to reduce fuel use and emissions from the freight sector’. This grew out of a World Bank sponsored green truck pilot project in Guangzhou in 2008 and Green Freight Demonstration Project in Guangdong which started in 2011. Clean Air Asia (2013) reviews the green practices being promoted by GFCI and shows how that are closely aligned with the transport and environmental targets set out in China’s 12th five-year plan (2011–2015).

Green freight initiatives are also underway in India, Korea and Mexico, while a new organization, the Smart Freight Centre has been set up ‘to provide strategic support to existing industry-led initiatives and incubate new ones in Latin America, Africa and Middle East’ (www.smartfreightcentre.org). The emergence of these industry initiatives is relieving governments of the need to run freight best practice programmes themselves, though they can still play a key role in assisting, sponsoring, endorsing and partnering the organizations that are promoting green freight transport.

Conclusions

Government policy towards freight transport has greatly evolved in recent decades, recognizing the need to see transport as part of a larger logistical system, to manage its environmental as well as economic impacts and to deploy a wider range of measures to achieve long-term sustainability. There are, nevertheless, wide international variations in the nature, extent and resourcing of government initiatives in the field of green freight/logistics. Countries that are still at an early stage in the development of sustainable logistics strategies can learn from those, such as the US, UK, Netherlands and France, that have longer experience. They can also take advantage of the proliferation of industry-led green freight initiatives and the growing involvement of the World Bank, UN agencies and international development banks in the promotion of sustainable logistics. Given the magnitude of the environmental challenges now facing us, particularly from climate change, all governments will have to give much greater priority to the greening of logistics in the years ahead.

Note

1 Formerly the European Conference of Ministers of Transport.

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Postscript 1
Distribution by drone

ALAN McKINNON

1 Introduction

Drones, or unmanned aerial vehicles (UAVs), have been in existence for many years and have been extensively used by the military for surveillance and offensive purposes. Over the past year there has been much discussion of the commercial application of this technology in the rapid delivery of small items over short distances. Interest was sparked by an announcement by Amazon, the world's second largest online retailer, that it planned to deliver a proportion of its orders by drone within four to five years. Government controls on domestic airspace currently prevent such deliveries in countries such as the US, the UK and Germany, though are much more lax in China. If the authorities refuse to grant permission for the use of delivery drones, then this form of aerial last-mile logistics may never materialize, at least in those countries with tight regulations. If these regulations are lifted, however, what is the likelihood of localized parcel delivery taking to the air and what could be the environmental consequences?

2 System specification

The Amazon 'Prime Air' drone would be an optocopter with eight battery-powered rotors, capable of carrying a payload of 2.3 kg (5 lb) up to 16 km (10 miles) from its base. DHL has trialled a four-rotor 'parcelcopter' with a lower payload limit of 1.2 kg (DHL, 2014). Generally speaking, the lighter the load the greater would be the distance range. Amazon estimates that 80 per cent of the online orders it supplies weigh less than 2.3 kg allowing it to transfer much of its current market to drone delivery – at least in terms of payload weight.

Like other types of 'autonomous' logistics, drones would be self-steering, navigating by means of GPS and reacting to other objects in the vicinity to avoid collision. They would be programmed to deliver a parcel to a specific location and use specialist routeing software to avoid private or controlled airspace.

Videos of the Amazon Prime Air service show the drones landing on consumers' driveways or patios. Other companies developing drone distribution systems, such as Matternet, envisage the use of a purpose-built 'landing station', in recognition of the fact that the landing is the most risky and vulnerable part of the operation. This would require consumers to invest in facilities for receiving the goods, presumably on an unattended basis to maximize convenience. It would probably be necessary for communal landing pads to be established for apartment dwellers.

3 Applications

Most of the publicity has focused on the distribution of online orders to consumers' homes in developed countries. This, however, is only one of many potential applications of this technology. It can be used in the developing world to deliver medicines and other essential items in areas where road infrastructure is poor or non-existent. It could play a vital role in providing emergency supplies in areas afflicted by disaster, transforming humanitarian logistics in the critical period when other forms of transport are severely disrupted. Businesses can also use drones to achieve a more rapid and reliable delivery of spare parts over short distances.

4 Operational feasibility

Since the Amazon announcement, many articles have appeared in the press and online questioning the feasibility of distribution by drone. Their criticisms have been directed mainly at its use in consumer markets for the mass delivery of parcels to the home. They fall mainly into three categories: logistics, economics and security.

Logistics

The Amazon distribution model, like that of many other large e-tailers, concentrates inventories of a huge range of products in a few massive logistics (or 'fulfilment' centres) which serve wide areas. This allows the retailer to exploit the so-called 'square root law' of inventory which states that the more you centralize inventory, the less you need to hold for a given level of customer service. They can also take advantage of economies of scale in warehousing.

Drones would be able to serve a circular zone around these logistics hubs with a maximum radius of 16 km. The vast majority of the population, however, would live outside these zones, beyond the reach of the drones.

E-tailers could maximize the population within these zones if the fulfilment centres were located within dense urban areas, but they are not. The large warehouses which feed the online retail market are typically found on lower-value land on the urban periphery or in rural areas. Wohlsen (2013) observes that:

> Amazon's entire warehouse-building strategy has been to put these 'fulfillment centers' in the hinterlands, close enough to make standard delivery quick and cheap, but also far enough away that the million square feet of land required for the warehouses is also cheap. Building distribution centers in dense urban areas to make drone delivery feasible would be a massive cost that would go entirely against Amazon's current business strategy.

A new, lower tier of smaller distribution depots would have to be constructed to bring more of the population within a drone catchment area. Such a decentralized system would not only be very expensive to construct and operate, it would also require much higher inventory levels. Indeed, in inventory terms, it would also be virtually impossible to replicate the product range currently found in the centralized logistics centres at the local level within a half-hour drone delivery of the majority of the population.

Economics

No data has yet been released on the comparative costs of drone and van delivery. The drone that DHL has trialled cost 40,000 euros, though the unit cost would reduce if they were mass produced. It has been suggested by the founder of Matternet that 'for Amazon's application to make sense, the vehicle cost should be below $20,000'. Trials by Matternet, admittedly in Lesotho, found that the cost of powering drones was relatively low. They also eliminate the costs of a driver. On the other hand, drones generally deliver one order at a time, as opposed to a home delivery van which in the UK and US would typically deliver around 120 non-food items on an eight-hour shift (Edwards *et al*, 2009; Wohlsen, 2013). Assuming one round trip per hour, including loading and unloading, a drone would distribute only 6 per cent of that number. If all the orders delivered by van were of a size, shape and weight that permitted their distribution by drone, it would take around 15 drones to replace one van. Even if drones cost only $10,000 each, a fleet of 15 would require a capital investment of $150,000 for which you could comfortably buy five or six vans. So the productivity of the delivery would be much lower than conventional road-based deliveries and fleet purchase and operating costs correspondingly higher. This would be reflected in a much higher cost per kilometre. If the density of drone-serviced distribution depots was low, the catchment areas would be wide and the number of kilometres travelled per parcel greater. This would magnify the transport cost penalty per kilometre relative to vans. Efforts to reduce this penalty by increasing the number of depots would merely increase warehousing and inventory costs, probably by a much greater margin. As Wohlsen (2013) explains, 'same-day delivery is expensive because it requires a fundamentally different logistics model'. Harford (2013) suggests that the additional costs of providing a localized infrastructure for drone delivery could be reduced by having 'high-street shops serving double-duty as traditional retailers and drone-dispatch hubs'. This would essentially reinvent the concept of 'brick-and-click' retailing but not be scalable in operational or environmental terms.

The question that then arises is how many people would attach enough value to a rapid, drone-based delivery to be willing to pay the premium rates required to make this form of last-mile distribution profitable. If capital investment were required in home-based reception facilities for drones, the service would be further restricted to an affluent market segment.

Security

There are a host of safety and security concerns. Malfunctioning drones can crash and cause injury or damage. The US military, for example, suffered 418 drone crashes in 11 years (Whitlock, 2014). They can collide with aircraft and power lines. As the US Department for Homeland Security has demonstrated, they can be hijacked and used for malicious purposes by terrorists or criminals. They can be intercepted and have their payload stolen. As the delivery is unsupervised, a dishonest consumer could deny that they actually received the order. Drones could also be the victims of vandalism and used as target practice by unscrupulous gun and air rifle users.

5 Environmental impact

If one assumes that these potential shortcomings could be overcome and an economically viable drone distribution system established, what would be the impact on the environment?

- *Emissions*: as drones are battery powered they do not emit any polluting or greenhouse gases at point of use. If their batteries are recharged with electricity generated by renewable or nuclear energy, the level of emissions at the power source will also be minimal. Drones can be equipped with solar panels to generate some of their own electricity, though the additional tare weight reduces the maximum payload. Special very thin solar panels have been developed for drones that are only 1 micron thick yet have a high capacity to transform sunlight into electrical energy (Wang, 2013). On the other hand, recharging drone batteries on the ground with electricity from fossil fuel sources can release, on a life-cycle basis, significantly more emissions per parcel than delivery by a well-filled van. It is difficult, therefore, to generalize about the net effect on emissions of a switch from surface distribution by van to aerial distribution by drone as this will depend on the energy source and relative utilization of the equipment. One can state with some confidence, however, that the delivery of a parcel by drone would have a much lower energy and emission intensity than a dedicated shopping trip by car to collect the item (Edwards *et al*, 2009; Walsh, 2013).

- *Noise*: The rotors on the types of drone being tested for parcel deliveries are quiet and when travelling at height would be almost inaudible from the ground. When taking off and landing in large numbers, however, in the vicinity of a distribution depot or communal landing pad, drones could create a noise problem. While an individual drone will be much quieter that a diesel-powered van, it could take, as mentioned earlier, around 17 drones to replace a single van. Any difference in the level of noise irritation would also be much narrower between drones and battery-powered surface vehicles.
- *Congestion*: Advocates of drones often argue that they will liberate last-mile deliveries from traffic congestion on urban roads and in the process help to ease that congestion. They would relieve congestion by replacing vans undertaking local deliveries. In the UK, vans represent roughly 14 per cent of the traffic on local authority roads, a large proportion of which are in urban areas (Department for Transport, 2014). Surveys suggest that 28 per cent of the distance vans travel in the UK is for the delivery and/or collection of goods (Department for Transport, 2008). Vans engaged in freight distribution therefore represent around 4 per cent of all the traffic on local roads. Even if drones were to assume responsibility for a quarter of all the deliveries currently made by van, this would only reduce traffic levels by 1 per cent. Given the ratio of drones to vans, however, this level of substitution, which would have a negligible effect on traffic congestion, could result in urban skies filling with parcel-carrying UAVs.
- *Visual intrusion*: many people would object to the appearance of large numbers of drones hovering over buildings, public spaces and especially their own homes and gardens. As with noise irritation, this visual intrusion problem would be particularly acute in the vicinity of key nodes in a drone distribution system. Mass use of drones, after all, would be an essentially urban phenomenon as the economics of aerial distribution would be at their most favourable in areas of high population density. This would also, however, maximize their visibility to the public and concerns about the invasion of people's privacy.
- *Accidents*: the average risk of a drone crash or collision per km travelled might be very low, but if UAVs were to be used intensively for last-mile delivery the incidence of accidents might still be considered too high. As 'autonomous vehicles' their level of risk would depend on the integrity, robustness and interactivity of the onboard computing equipment as well as the external communication network. Both could be compromised by bad weather, system failures or cyber crime, possibly presenting an unacceptable risk to the population.

In summary, any assessment of the net environmental impact of autonomous distribution by drones has to be made relative to that of alternative modes of delivery. If the baseline alternative is a personal shopping trip by car for a single item, the drone could offer a net environmental benefit, particularly if its batteries were recharged with non-fossil-fuel energy and the car journey was made on a congested road by a petrol-fuelled vehicle. If the baseline is a well-loaded van, powered by clean, low-carbon electricity, and operating predominantly during off-peak periods, distribution by drone is very unlikely to yield any environmental advantage. Mass use of drones, as would be required to achieve even marginal reductions in traffic congestion, could seriously impair the quality of the urban environment, especially around the logistical nodes at which they cluster like robotic wasps. If, as the CEO of Matternet believes, the drone is 'going to be the next big paradigm in transportation', it could pose green logistics challenges (Madrigal, 2013). If, on the other hand, the CEO of Deutsche Post DHL is right when he states that drones are 'not a mass phenomenon' (Vasagar, 2014), they will be confined to niche applications and have little environmental impact.

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Postscript 2
3D printing

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3D printing, also known as additive manufacturing, is a developing technology by which products can be manufactured essentially by printing layer on layer using a range of possible materials, such as metal or plastic powders, binders, resins and dyes. Early uses were primarily in the manufacture of prototypes and basic models, but over the past few years there has been a huge diversification in the range of products that can be produced by this means. This range includes components for the aerospace industry, artificial limbs, the chassis of a car and even a house. Much 3D printing, however, is still of relatively simple plastic components and confined to business applications. The global market for 3D printing products and services was, nevertheless, worth $2.2 billion in 2012 and has been predicted to expand to $10.8 billion by 2021 (Biederman, 2013). With future technological advances and the emergence of new business models, 3D printing could become an industrial 'game changer' with major implications for logistics operations and their associated environmental effects.

Berman (2012) compares 3D printing to previous 'disruptive technologies' such as digital books and online music downloading, sectors in which consumer buying behaviour has adapted at a very fast pace. In one of its scenarios for 2050, Deutsche Post/DHL (2012: 8) envisaged a 'mass customized' future in which 'individualization becomes pervasive and 3D printing dominates manufacturing and households'. On the other hand, the US consultancy company Gartner (2013) argues that expectations of 3D printing being extensively adopted in consumer markets are seriously 'over-inflated'. It sees this technology being widely deployed in the corporate world (so-called 'enterprise 3D printing'), but is doubtful that it will transform consumer markets for the foreseeable future. The *Washington Post* (13 March 2014), nevertheless, suggested recently that 'theoretically, one day Amazon might just sell the design file for a product, and the consumer would print the design file at home with a 3D printer in the comfort of his or her living room'. While 3D printing would appear to be a logical extension of internet shopping and the online retail industry, to date it is far from becoming an integral part of that industry's offering.

Several factors will constrain the proliferation of 3D printing in consumer markets. First, the unit costs of 3D printing an object are an order of magnitude higher than batch production in a factory and likely to remain so for many years. As Janssen *et al* (2014: 11) explain:

> One drawback of 3D printing […] is that production costs do not decrease significantly with an increase in scale. The costs for the first product are effectively the same as for the 10,000th product. Current 3D printing technologies are still relatively inefficient and time-consuming and we do not expect this to change within the next decade. Therefore, mass production with additive manufacturing is not profitable now, nor expected to be in the near future.

A consumer would therefore have to attach a very high monetary value to the customization that additive manufacturing makes possible to justify an investment in this technology and the high unit production costs. Even if articles are not customized to individual tastes and requirements, 3D printing could allow companies to greatly expand the number of product variants without having to incur all the costs of retooling, additional inventory and the inevitable errors in demand forecasting (Manners-Bell and Lyons, 2012). The relative economics of 3D printing could also be enhanced if local 'fab-shops' are able to exploit economies of scale by using large printers and bulk supplies of materials. The US parcel carrier UPS has set up such a fab-shop in San Diego. DHL (2014: 4) also sees an 'opportunity for logistics providers to extend their value chain by integrating new 3D-production capabilities into their end-to-end logistics services'.

Second, the functionality of the objects made by 3D printing is still very limited by comparison with the output of conventional processing and assembly plants. Third, the layering and bonding processes that are fundamental to 3D printing contain inherent weaknesses which impair the integrity of the finished products and limit their use. Birtchnell *et al* (2013) note that concerns about product quality and unreliability are inhibiting the development of this technology. Fourth, the size of individual parts that can be made by additive manufacturing is limited by the dimensions of the 3D printers, most of which are still relatively small (Janssen *et al*, 2014).

If, however, these economic and technical constraints can be overcome and the use of 3D printing becomes widespread, how will it be likely to affect logistics?

Berman (2012) argues that 3D printing may ultimately make locally distributed, highly automated manufacturing of small batches or individual orders economically viable, thus undermining the cost advantages of globally-sourced mass production in low-labour-cost countries. Using similar reasoning, Manners-Bell and Lyon (2012) speculate that the massive volumes of manufactured goods being shipped from low-cost locations may sooner or later start to decline. If this were to happen, the freight transport intensity of the global economy would decline, yielding environmental benefits.

Transport intensity would not only drop because of the localization of production. It would also be a consequence of the streamlining of supply chains. In a survey of 108 manufacturers, PwC (2014: 10) asked, ‘if and when 3D printing is adopted, what will be the most disruptive effect on US manufacturing?’ The largest proportion (29.6 per cent) identified ‘restructured supply chains’ as the most disruptive effect and another 9.3 per cent the ‘reduced need for transportation and logistics’. Complex supply chains comprising several production and storage points and several intervening links could be replaced by more simple, direct ones moving the bulk powders and resins used in the printing process. This would cut vehicle-kms and the associated externalities. There would be much less less inventory in the supply chain and hence less need for warehouse space (Waller and Fawcett, 2014). There would be less wastage of materials than one typically finds in production and warehousing operations and product packaging would be virtually eliminated (Reeves, 2008). There would be little need for product returns (Kewill, 2013). On-demand manufacturing at point of use to the customer’s specifications would remove the need to send products back up the chain because they were the wrong size, shape or type. Indeed there would not be any physical chain to reascend as only a design file would have been distributed – in digital form. All of this could shrink the environmental footprint of logistics in a world transformed by 3D printing.

The environmental impact of spare parts logistics could be dramatically reduced. Inventories of spare parts, many of them with low stock-turn rates and spending a long time in storage, could be cut to a small fraction of their current level. The main environmental benefit, however, would accrue from reduced demand for the express delivery of components, much of it by air and hence very carbon intensive. Several authors, such as Manners-Bell and Lyons (2012) and Birtchnell *et al* (2013), see 3D printing as posing a potential threat to express parcels carriers providing rapid delivery of spare parts.

Eventually, 3D printers may become technically and economically viable for installation and use in individual households. In the interim, however, high equipment and materials costs will make it much more economical for consumers and small businesses to outsource their 3D printing requirements to local fab-shops which may develop in the same way that internet cafés sprang up during the early days of the internet. Additive manufacturing would then localize production rather than locate it at the point of use. Its main impact on the freight transport system would then be to cut the volume of long-haul transport and the numerous intermediate links in supply chains. There would still be a need for freight deliveries and/or personal trips on the ‘last mile’ between the fab-shop and the home. As discussed in Chapters 14 and 15, these local deliveries or customer collections could use green modes of transport such as electric vans, public transport, bicycles and walking. Some of this 3D printing-related travel would also replace conventional shopping trips or home deliveries of online purchases and so not represent a net addition to local traffic levels. Outsourcing the 3D printing operation to a local fab-shop would also remove the need to distribute the printing materials to the home, a logistics operation that is sometimes underestimated in discussions of 3D printing’s environmental impact (Birtchnell and Urry, 2013). The distribution of these material inputs may be over long distances and will need to be made to a much wider spread of locations in much smaller batch sizes than is the case for the bulk flow of raw materials and components into conventional mass production operations in factories.

In summary, we may be on the eve of a new industrial revolution which could completely transform supply chains and drastically reduce the environmental costs of logistics. On the other hand, if the sceptics are right, 3D printing may not become a mass market phenomenon and remain confined to niche industrial applications. If this latter scenario proves the more accurate, the environmental impact of this technology will be much more limited. It is too early to tell how great this impact is likely to be.

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Postscript 3

Physical (logistics) internet (π)

MAJA PIECYK

At present, green logistics research and practice focus on fuel efficiency improvements. However, if the GHG reduction targets are to be achieved, revolutionary solutions and breakthrough innovations will be needed. Some foresee changes so dramatic, that a paradigm shift towards open, collaborative logistics rooted in the wider economic transformation will occur. 'Now, a new generation of academics and logistics professionals is looking to the distributed, collaborative, laterally scaled internet communication system, with its open-systems architecture and Commons-style management, as a model for radically transforming global logistics in the twenty-first century' (Rifkin, 2014, p 219).

The notion of the Physical (or Logistics) Internet (π or PI)[1] was first introduced by Benoit Montreuil, a professor at Laval University in Quebec City, Canada. The term exploits the digital internet metaphor to present a vision of how physical goods can be manufactured, stored and distributed in a more efficient and sustainable way. The information transmitted over the internet, eg an e-mail, is encapsulated in a packet containing all relevant data to identify and route it to its destination. Just as an e-mail can follow a circuitous route exploiting excess capacity across the internet, so the PI would enable consignments to do the same in a physical sense. Montreuil (2011) envisages transporting products in modular, standardized π-containers via universally interconnected, multi-segment, intermodal π-networks. The π-containers have smart tags to ensure their identification, monitoring, routeing, traceability and security, ie to exploit the Internet of Things[2] to enable interconnectivity of π-containers and π-networks. The concept is illustrated by an example of a container moved from Quebec to Los Angeles. In the current system, a single driver would travel over 10,000 kms round-trip for at least 240 hours, and the container would reach Los Angeles after around 120 hours. In the distributed π-network, 17 different drivers would each drive an average of about three hours between π-transit points, thus returning home within a single shift, yet collectively getting the container to its destination in about 60 hours, ie half the time of the traditional door-to-door delivery system. Internet tracking would ensure seamless handovers of the container (Montreuil, 2011).

In a π-network, logistics companies could exploit economies of scale from commonly shared resources. 'An open logistics infrastructure will give integrated transport service providers a universal playing field – made up of thousands of warehouses and distribution centres linked into a single cooperative network – that they can access to optimize each client's logistical requirements' (Rifkin, 2014, p 221). Freight transport and storage of goods within the π-framework could be more environmentally sustainable, economically efficient, and socially responsible. Expected benefits include, for instance, quick and inexpensive deliveries, lower energy consumption and associated GHG emissions, reduced congestion, and better working conditions in logistics industry (Lounès and Montreuil, 2011; Montreuil *et al*, 2012).

Whilst the idea of π is conceptually attractive, a number of serious obstacles would need to be overcome, if it is to become a mainstream logistics practice. Some of the key issues are briefly discussed below.

In π, all goods will be encapsulated and moved in 'world-standard, smart, eco-friendly and modular' π-containers, designed to be easily handled, sealed, interlocked with each other and transported. All existing handling and storage systems will be replaced with ones suitable for π-containers. Products will be designed and engineered with dimensions adapted to standard π-container sizes (Montreuil *et al*, 2013; Ballot *et al*, 2014). A move away from existing handling and storage equipment would incur a massive cost to the logistics industry, not to mention the amount of waste arising from the disposal of the existing handling systems and units, and the carbon footprint associated with production of the new ones. Incremental replacement of the equipment does not seem to be an option, as encapsulation of cargo in the standardized π-containers is a key requirement of seamless flows through the π-network. Also, π-containers should be standardized and interlockable, which implies a limited number of unit sizes. Even though products could be engineered to match π-container sizes (which is inherently difficult, and the current evidence suggests logistics requirements are hardly ever taken into account at the product design stage), there is still a risk of significant underutilization of the standardized units. As illustrated in the above example, many direct door-to-door movements will be replaced with network flows with numerous handling points. Multiple handling entails greater risk of accidental damage, theft and delays.

The idea of a π-network also raises questions of the ownership of π-transit points and π-hubs, pricing strategy for their use, as well as legal and insurance liability for the consignments flowing through the system.

A significant regulatory change would be required to enable the transformation towards the π. For instance, at present the EU completion laws can be a barrier to collaboration amongst businesses. However, perhaps the most difficult issue to overcome will be the need to change the strategic outlook of businesses. In recent years, the logistics market has witnessed development of vertical or horizontal collaboration initiatives aimed at improvements in logistics efficiency. Some of the companies experienced substantial benefits from participating in bi- or multi-lateral partnerships, gaining advantage over the non-collaborating businesses in the marketplace. However, the move towards π would require opening the network to other players, potentially strengthening their competitive position. This is similar to Oscar Lange's discourse on technological innovation referred to by Rifkin (2014). According to Lange, technological innovation allows businesses to lower the price of goods or services, thus gaining a competitive advantage in the market. The competitors respond to this by introducing their own technological innovations to increase productivity and reduce prices, and the cycle continues. However, in mature markets with a small number of large players (monopolies or oligopolies), businesses have every interest in hindering this economic cycle to maximize the gains from investment in already existing technologies. A dramatic change in the environment would be required to break the opportunistic behaviour of the dominant market players. It is possible that climate change mitigation with carbon prices set at a level that fully internalized the external costs of GHG emissions might help to trigger the necessary changes in organizational strategy and corporate behaviour.

Despite the above-mentioned issues, the π concept, or some of its elements, has recently gained attention from government bodies, industry and academia. The EU's European Technology Platform for Logistics, called ALICE (www.etp-alice.eu), set up to develop a long-term strategy for research and innovation in the European logistics industry, clearly states that 'future research should focus on new concepts in which increased collaboration and coordination will eventually result in the physical internet, where complete horizontal and vertical supply chain collaboration takes place' (ALICE, 2014). Various research projects are currently underway to operationalize the π concept. For instance, the EU-funded project MODULUSHCA: Modular Logistics Units in Shared Co-modal Networks (www.modulushca.eu) aims to develop standardized containers for multi-modal land-based transport incorporating building blocks of smaller units, and to establish digital interconnectivity of the units (Mervis, 2014). Whilst π still seems like a science fiction logistics fantasy, a number of enabling technologies are already in use. Greening (2014) gives the following examples: 3D printing (GE Aviation, Boeing, Ford); drones (DHL, Amazon); autonomous vehicles (Oshkosh TerraMax defence truck, Google driverless cars); robotic material handling systems (Kiva Mobile-robotic Fulfillment System, Autostore System); and platforms connecting objects into the Internet of Things (Samsung Smart Home). These applications are still at an early stage, but by 2050 they could be sufficiently mature and integrated to make the physical internet a reality. Montreuil certainly hopes the π-revolution in logistics can be achieved by then (Mervis, 2014).

Notes

1 The abbreviation PI corresponds to the Greek letter π.
2 'Internet of Things' is a concept where physical objects are connected to the internet, and can generate and transfer data without any human intervention.

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Postscript
Peak freight: could it ever happen?

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A topic that has received considerable attention within logistics concerns 'peak oil'. There is still some debate about the exact origin of the phrase, or at any rate its first use, but the originator of the concept is acknowledged to be Hubbert (1956) although he did not use the term itself, referring instead to 'peak production rate' and 'peak in the rate of discoveries'. Despite some interest during the period 1960 to 2000 the real rise in interest in the concept of peak oil has only occurred in this century when the term has become more widely used. In relation to logistics, Christopher (2011: 247) noted the possible importance of peak oil in determining logistics strategies and leading to changes in the organization of logistics and supply chain networks.

Now the word 'peak' is added to many phenomena and occurs frequently in the mass media, prompting the *Guardian* to ask the question: 'Have we reached peak peak?' before going on to a discussion about 'peak beard', 'peak Beyoncé' and even 'peak punctuation' among other 'peaks' (Cocozza, 2014).

While many of these 'peaks' are simply a clever use of a phrase, the question of peak oil has many implications for transport. But another peak related to transport has also been noted within the research community – namely 'peak car'. The peak car hypothesis is based on the observation that, since the 1950s, increasing wealth was accompanied by increases in the use of the car (usually expressed in terms of car mileage) but in the period since the mid-1990s the UK has seen a levelling off in car mileage per person despite a continuing upward trend in GDP per capita. Indeed for male drivers there has been a recorded decline in car use (expressed in mileage). This decline in mileage has led to much speculation about the possible causes and about whether they are likely to continue to depress the level of personal mobility in the longer term. Changes in telecommunications are held by some to be important contributors to this change in behaviour (Goodwin, 2012). People are now able to perform many activities remotely that would in the recent past have required them to travel. Although there are those who argue that the proponents of peak car use have exaggerated the trends and that it should be regarded as a development that only applies to a small number of economies (or even to certain cities and regions), it is nevertheless an interesting example of a change that many would have considered unthinkable a few years ago when ever-increasing use of the car was taken as an accepted trend.

So, if we have 'peak oil' and perhaps 'peak car', should we also be considering the possibility that we may be within sight of 'peak freight'? Or at any rate within sight of peak freight for certain locations and types of freight activity. Of course the factors influencing freight transport demand are very different from those that influence personal travel choices such as whether to use a car or public transport (or indeed walk or cycle). However, there are some interesting factors that have been discussed in earlier chapters of the book that we need to reflect upon.

As noted in Chapter 18, there was at one time a broad agreement that rises in GDP (the main measure of national wealth) would lead inexorably to increased flows of freight – often expressed in terms of tonne-kms. And yet in recent years this clear relationship has broken down for some countries, such as the UK, Denmark and Belgium. So is it possible that in more countries or regions we will see future patterns where GDP rises but freight either does not rise in proportion or perhaps even falls?

Of course, as Chapter 18 notes, the so-called 'decoupling', whereby freight and GDP trends diverge, is complicated and can be highly variable through time. But this in turn leads to an interesting question about whether we should only focus on tonne-kms and, in the case of road freight, only measure products transported in vehicles over 3.5 tonnes (ie in trucks) since it is only this element of goods movement that is identified in statistical terms as freight. Movements in vehicles below 3.5 tonnes are not widely recorded in official statistics and to find measures of these flows we need to rely on occasional surveys and industry information.

Analysis of freight flows in London illustrates that there has been very little increase in vehicle-kms by trucks (ie vehicles over 3.5 tonnes). The majority of the increase in vehicle movements has been by vans (below 3.5 tonnes). It is estimated that about one-third of these vans carry freight – the remainder are mainly involved in some sort of service activity or are used for personal transport.

It is evident that freight transport responses to changes in the level of economic activity are complicated. When freight volumes fall it can be difficult to reduce vehicle-kms to the same extent – so a fall of 5 per cent in freight tonnage does not lead to a fall of 5 per cent in freight vehicle movements. This is because for operators there are inflexibilities within their systems that mean this change cannot be reflected in a change in operating practices. In the same way, a rise in the tonnage that needs to be transported appears to lead to a less than proportional rise in vehicle-kms because transport companies are able to use their vehicles and fleets more efficiently. An exploratory analysis based on data from London has identified this pattern.[1]

In addition, there are wider factors that could significantly influence the future demand for freight transport:

- 3D printing;
- transforming products and their packaging to reduce their volume and/or weight – for example by producing more concentrated products where water is added at the point of use;
- postponement – postponing the final packaging and customization of products until they reach the end market can cut freight volumes;
- direct delivery to the final consumer without the need to pass through intermediate points;
- miniaturization has been observed in some industry sectors – for example computing, electrical equipment and telecommunications;
- dematerialization of products – already established for software, films, books etc;
- changes in lifestyles and aspirations (ie an increase in the consumption of services and a decline in material consumption).

The list could go on and these trends have been noted elsewhere in the book. Of course, in many cases it remains uncertain whether the impact of the above influences would lead to more or less freight demand. For example, it is often asserted that a rise in direct delivery to the consumer will increase freight demand but this may not necessarily be the case. If the product flow can be optimized to avoid unnecessary storage and unnecessary trips in trucks, then perhaps the use of a smaller vehicle (a van) for the final delivery to the consumer will result in a reduction in total freight demand. Indeed in a quirk caused by statistics, if a product moves in a van it does not officially count as 'freight' since 'freight' statistics deal only with products moved in heavier vehicles used solely for transporting goods. In the same way shopping carried in a car is not classified as freight.

It is evident that the impact of these trends on freight transport demand will be complicated and will not necessarily be equally important across various freight sectors. Nor will the impacts be uniform across different geographical areas; for example, the impact at a city level may be very different from that seen over longer distances in the maritime sector.

The processes which have driven freight traffic growth cannot continue indefinitely (eg wider sourcing of supplies, globalization in trade and the centralization of production and inventory). As noted elsewhere in the book, some of these past trends may already be changing – for example the re-shoring of some manufacturing activities. Information on the speed and scale of these changes is not readily available. However, it is clear that, although there may be significant increases in the global flow of products over the next 10 to 20 years, it is also possible that in more mature economies we will see innovations and developments that may lead to reductions in freight flows on certain parts of the network. Whether we will be able to refer to this as a period of 'peak freight' remains to be seen, but it is clearly a topic to consider.

Note

1 Note on freight data in London prepared by the University of Westminster, 2013

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