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The use of ICT in road freight transport for CO_2 reduction – an exploratory study of UK's grocery retail industry

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Abstract

Purpose – The purpose of this paper is to investigate empirically how information and communication technologies (ICT) can contribute to reduction of CO_2 emissions in road freight transport and to identify opportunities for further improvements.
Design/methodology/approach – This research adopts a multiple case study approach with three leading UK grocery retailers as exemplars of fast-moving consumer goods retailers, conducted using multiple data collection techniques including interviews, system demonstrations, onsite observations and the use of archive information.
Findings – ICT solutions have a direct positive impact on CO_2 emissions reduction but opportunities to further reduce CO_2 emissions are perceived as lying beyond retailers' own distribution networks. These opportunities are not fully utilised due to the complexities of collaborative ICT provisions and retailers' reluctance to share information with competitors.
Research limitations/implications – A limitation of the study is that it is exploratory and only three cases were examined. Even though these three retailers represent over 60 per cent of the UK grocery retail sector, other retailers may deploy significantly different ICT applications.
Practical implications – The research provides an overarching insight for businesses on how to leverage the existing and emerging information technologies for environmental and economic benefits.
Originality/value – While sustainability issues have received increasing attention recently, the role of ICT in freight transport for CO_2 emissions reduction has not been investigated in depth and its impact is largely unknown. This research advances understanding about how ICT contributes CO_2 emissions reductions and provides a framework for further investigation.

Keywords Case study, ICT, Road freight transport, CO_2 reduction, Grocery retailing
Paper type Research paper

1. Introduction

Road transport currently dominates freight movements in the UK, accounting for around 83 per cent of tonnes-lifted and 64 per cent of tonne-kilometres (km) (Department for Transport (DfT), 2012). Subsequently, road transport contributes 92 per cent of total CO_2 emissions for domestic freight transport among various modes, and roughly 6 per cent of total domestic CO_2 emissions in the UK (Piecyk and McKinnon, 2010). Given the rising

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cost of energy plus increasing concerns on environment sustainability, both the users and providers of road transport services have been actively exploring ways to reduce energy use and carbon emissions. Common practices include, for instance transport collaboration, the use of alternative fuels and less carbon-intensive road vehicles (Fernie and Sparks, 2009). There are different ways to measure carbon emissions from vehicles, but a common approach is to calculate total fuel consumption. This is then converted to CO_2 using the standard conversion ratio recommended by Defra (2013), which varies depending on the type of vehicle. Total fuel consumption can be measured based on the exact fuel consumption of the vehicle or by using: the vehicle-km multiplying fleet average fuel consumption per vehicle or the tonne-km multiplying fuel average consumption per tonne-km (McKinnon and Piecyk, 2009).

More recently, with rapid advances in information and communication technologies (ICT), companies have also started to explore the potential benefits of using either on-vehicle (such as telematics systems fitted to a tractor), or in-house systems (such as Computerised Vehicle Scheduling System – CVSR) to reduce the CO_2 and cost impacts of their road freight transport networks (Baumgartner *et al.*, 2008). The use of internet-based applications, e.g. electronic marketplaces, to identify backhaul opportunities is also gaining popularity (Wang *et al.*, 2011; So and Sun, 2010). Evangelista and Sweeney (2006) undertook a research project to investigate the role of ICT in the operations of logistics service providers. Furthermore, Wang and Lalwani (2007) found that e-business can improve the performance of customised logistics networks.

Recently, several authors have undertaken research on environmental sustainability in the context of supply chains (Abbasi and Nilsson, 2012; Cucchiella and Koh, 2012; Green *et al.*, 2012; Tacken *et al.*, 2013) and road freight transport (McKinnon, 2011). Nevertheless, despite the potential role of ICT as a key enabler for increasing cost efficiency and simultaneously reducing CO_2 emissions, there has been limited attention from both practitioners and academics to fully explore potentials in CO_2 reductions through utilising ICT. This gap is evidenced, for instance, by the work of Perego *et al.* (2011) who conducted a literature review on the use of ICT for logistics and freight transportation. Out of 44 papers they have closely examined, only one paper (Button *et al.*, 2001) discussed the environmental benefits of using freight transport-related technology. McKinnon (2011) developed eight carbon-saving measures for logistics which briefly mentioned using technologies as a CO_2 reduction solution. McKinnon argued that using telematics in association with CVRS could help organisations to determine the most fuel efficient route and encourage good driving behaviour for better fuel efficiency. However, no empirical evidence is provided to support this argument.

At a macro level, the European Commission recently commissioned a study on the impact of ICT on energy efficiency in road transport (Klunder *et al.*, 2009), which examined three types of ICT-based solutions: eco-solutions, Advanced Driver Assistance Systems and traffic management solutions. Though the findings highlight the importance of ICT in aiding the reduction of energy consumption and subsequently CO_2 emissions, this study did not focus on freight-specific ICT systems and is generic in nature. Other FP7 projects in transport logistics tend to focus on the development of ICT solutions to enable co-modality (such as Integrity and CO_3) in global supply chains or seek smart solutions for traffic management (such as Smartfreight) (CORDIS, 2013). Though most of such projects exploit environment-friendly practices, evidences collected from these projects regarding CO_2 emission reduction are rather implicit, due to the fact many ICT solutions developed are yet to be fully taken up by industry.

Therefore, the primary aim of this research is to evaluate empirically the impact that currently deployed ICT solutions have had on environmental sustainability (with regards to CO_2 emissions reduction) and to identify opportunities for further improvements. We use the UK food and grocery sector as an exemplar sector that is dependent upon road freight for its operational efficacy. Our contributions are threefold: from a theoretical perspective, it advances our understanding about the role of ICT in CO_2 reduction and provides a basis for further investigation and develops a hierarchical conceptual framework for the classification of ICT used in supply chains for the reduction of CO_2; meanwhile from a practice perspective, the research provides an overarching insight on how to leverage the existing and emerging information technologies for environmental and economic benefits. Consequently our proposed research questions are as follows:

RQ1. What is the current status of ICT deployment for road freight transport in reducing CO_2 emissions?

RQ2. What are opportunities for further improvements in carbon savings?

The paper is organised as follows. The next section provides a review of freight transport-related CO_2 reduction initiatives, recent developments of ICT in freight transport and a background of the UK's food and grocery sector as an exemplar of fast moving consumer goods (FMCG) logistics. It is followed by the introduction of the research method for this research. Research findings are then discussed highlighting recent developments and potential areas for further carbon saving. The final section draws conclusions, and outlines limitations of this research and future research directions.

2. Literature review: freight transport-related CO_2 reduction solutions and ICT systems

In order to improve the environmental sustainability of supply chains, logistics operations need to be managed in an environmentally sustainable way since 6 per cent of the global CO_2 emissions are derived from freight transport (Kahn *et al.*, 2007; McKinnon, 2010). A major cause of concern is that in road freight transport, the growth in the amount of energy consumed is increasing at a faster rate than the energy consumed by cars and buses. The road freight transport industry is predicted to account for more energy consumption than cars and buses by the early 2020s (World Business Council for Sustainable Development & World Resources Institute, 2004). In Europe, considerable government focus is being put on decoupling this growth in CO_2 emissions from increases in gross domestic product (McKinnon, 2007a). In order to support this endeavour, it is essential to explore management initiatives and practices to reduce CO_2 emissions in road freight transport operations.

McKinnon (2007a, 2008) and Tacken *et al.* (2013) have developed frameworks to guide CO_2 reduction in road freight transport sectors. The framework developed by McKinnon (2007a) has been applied in previous research at the macro level and consists of seven ratios: modal split, average handling factor, average length of haul, average load on laden trips, average empty running, vehicle fuel efficiency and carbon intensity of fuel used. Tacken *et al.* (2013) extended McKinnon's (2007a) to identify road freight transport-related CO_2 reduction initiatives adopted by German logistics service providers: modal shift, logistics network optimisation and consolidation, improvements to the vehicle and reduction in the CO_2 content per litre of fuel.

Building from the early works of both McKinnon (2007a) and Tacken *et al.* (2013), initiatives adopted by companies to reduce CO_2 emissions generated from road freight transport sectors can be clustered into four main CO_2 reduction elements: modal split, vehicle fuel efficiency, carbon intensity of fuel used and road freight transport network optimisation and consolidation. It is important to discuss the CO_2 reduction effectiveness and economic feasibility (payback period) of initiatives classified under each of these four elements, since there are a wide range of initiatives which are recommended in the literature and from industry.

Modal split-based initiatives in recent literature focus on the shift from either road to rail (McKinnon, 2007a; Woodburn and Whiteing, 2010) or from road to water (Wee *et al.*, 2005; Boege, 1995). However, it is recognised that multimodal transport is only suitable for certain logistics operations where the volumes justify it, and less carbon-intensive transport modes, such as rail, do not provide the flexibility and transit time reliability required in the modern FMCG supply chain (Woodburn, 2007). Transferring freight to less carbon-intensive modes can generate considerable levels of uncertainty within the delivery process, which could ultimately increase CO_2 emissions in other supply chain elements, such as warehousing (Sanchez-Rodrigues *et al.*, 2008).

The literature also focuses on initiatives designed to increase vehicle fuel efficiency as a way of reducing CO_2 emissions (e.g. McKinnon, 2008; Wee *et al.*, 2005). There are a wide range of initiatives which can be implemented to improve the fuel efficiency of vehicles, for instance, by providing training and economic incentives to drivers to improve their driving behaviour (Shell Deutschland Oil GmbH, 2010; McKinnon, 2008; Wee *et al.*, 2005). This will then lead to the fuel consumption reduction of vehicles and ultimately reduce vehicle running cost and CO_2 emission. Furthermore, the literature suggests that vehicle fuel efficiency can be improved by adopting technological improvements to the vehicle, such as more efficient engines, reduced vehicle tare weight, increasing vehicle dimensions and improved vehicle aerodynamic profiling (McKinnon, 2008; Wee *et al.*, 2005; Klunder *et al.*, 2009). Nevertheless, this type of technological improvement requires significant investment which companies can only realise as an economic return in the long term and hence only companies in a strong economic position may be able to adopt them.

A more radical way to reduce the CO_2 emissions generated from road freight transport is to reduce the carbon content of fuel used, as recommended widely in recent literature works (Baker *et al.*, 2009; Woodburn and Whiteing, 2010; Wee *et al.*, 2005; Wu and Dunn, 1995). For example, some UK grocery retailers have made serious attempts to implement alternative fuels. However, there are a number of concerns such as land use change and food security attached to bio-fuels due to the social and environmental impacts of the production of bio-fuel feedstock, as suggested by German *et al.* (2011). According to the Marks & Spencer's (2012) Corporate Social Responsibility report , even though Marks & Spencer has run two successful trials to test the fuel efficiency of bio-diesel, the adoption of bio-fuels has been suspended until the suppliers mitigate considerably their negative social and environmental effects.

In this regard, Hoogma *et al.* (2002) stated that there is an insufficient investment in infrastructure in the supply of alternative fuels (Hoogma *et al.*, 2002). Hoogma *et al.*'s (2002) finding was confirmed by Tacken *et al.* (2013), who found in a multiple case study investigation run in the German logistics sector that there are two main barriers in the use of bio-fuels. First, there is a negative ethical debate around the social and environmental sustainability standards in the production of bio-fuel crops. Secondly, there is the fact those bio-fuels tend to diminish the efficiency and productive life of vehicle engines. Nevertheless, Tacken *et al.* (2013) also found evidence from a leading German logistics service provider of the successful adoption of second generation of bio-fuels. Furthermore, strong evidence on the usage of other alternative source of energies such as wind, solar, biomass and hydrogen can be found in the green warehousing literature rather than as a carbon efficiency measure used in road freight transport (Marchant and Baker, 2012). Alternatives to liquid biofuels such as biogas, electric vehicles and fuel cell vehicles have barely moved beyond pilot stages, hence indicating a low level of maturity in the marketplace (Karabektas *et al.*, 2013).

A strong focus has also been put on the adoption of improvements in network optimisation and consolidation through CO_2 reduction initiatives, e.g. increasing backhauling opportunities and improving the efficiency of network design and routing (Eglese and Black, 2010; Preuss, 2005; Wee *et al.*, 2005; Hoogma *et al.*, 2002; Wu and Dunn, 1995; Cucchiella and Koh, 2012). For instance, Harris *et al.* (2011) explored the relationship between total logistics cost and environment impact in terms of CO_2 emissions for strategic modelling in an automotive logistics network, and found that the optimum design of a distribution network is highly sensitive to the level of vehicle utilisation and the optimum design based on costs does not simultaneously generate an optimum solution for CO_2 emissions. Wu and Dunn (1995) pointed out that there is a need to integrate reverse logistics into the total logistics framework in order to design an environmentally responsible logistics system and Olorunniwo and Li (2010) identify that ICT has a major role to play in that integration.

In particular, in the case of reverse logistics practices in UK retail sector, in a study commission by the DfT (2004), it was found that UK retailers adopt different strategies in the running of their reverse logistics networks. These strategies are: integrated outbound and return network, non-integrated outbound and return network, third party logistics return management and return to suppliers. In their study, the DfT found that the approach UK retailers take in the management of their reverse logistics network depends on the characteristics of products being returns, and in particular, the return value, volume and pace of return flows influence whether or not the forward and reverse logistics networks are integrated. Hence, this partially contradicts the initial claim made by Wu and Dunn (1995). Nevertheless, McLeod *et al.* (2008) found that regardless of the reverse logistics strategy adopted in the UK retailer sector, the sophistication of ICT systems can enable UK retailers to increase the efficiency and responsiveness of their reverse logistics network.

2.1 ICT-based transport applications

The term "Information and Communications Technologies (ICT)" is often used in a broad sense to delineate a set of heterogeneous telecommunication and information technologies that allow for electronic communication, data collection and processing in distribution networks (Black and Geenhuizen, 2006; Giannopoulos, 2004). The extant literature offers different taxonomies regarding ICT adoption in practices. For instance Evangelista *et al.* (2010) classified ICT into basic and advanced but did not specify the criteria for such categorisation. Both the works of Marchet *et al.* (2009) and Perego *et al.* (2011) classified transport-related technologies into four main types from a commercial "company" perspective:

(1) transport management applications;

(2) supply chain execution applications;

(3) field force automation applications; and

(4) fleet and freight management applications.

Although offering useful insights, such categories present some overlaps. For instance some supply chain execution applications will have a module designed for transport management, a real-time tracking function in a field force automation application may well be part of a fleet and freight management application.

Giannopoulos (2004) offers a comprehensive overview of various ICT systems used in transport focusing on both passenger and freight transport, but as highlighted by Perego *et al.* (2011), Giannopoulos' work is largely focused on public transport, which suggests a lack of depth for the specific technologies adopted by road freight operators. Helo and Szekely (2005) emphasised the use of Warehouse Management Systems (WMS) and Transport Management Systems (TMS) among other ICT systems, but did not address technology adopted at individual vehicle level. The work of Stefansson and Lumsden (2008), on the other hand, provides a detailed summary of vehicle and infrastructure-related technologies, termed as "smart transportation management systems (STMS)". The proposed STMS is composed of three main themes: smart freight systems (using several technologies such as Radio Frequency Identification (RFID), General Packet Radio Service and web technology) to manage the movement of goods, smart vehicle systems (which includes in-truck goods identification systems and the vehicle system) to extract engine and driver-related information from the engine control unit and digital tachograph, and smart infrastructure (both digital and physical) to enable data communication and interchange. Though these studies have greatly increased our knowledge of ICT applications in transport in general, the literature fails to offer a structured, comprehensive view of ICT applications in road freight transportation. Therefore before we could fully explore the impact of ICT deployments on CO_2 emission reduction, it is sensible to first understand and map out the main ICT applications in road freight management.

Though there are many ways of categorising various ICT applications used by organisations, we contend that a hierarchical approach could offer a clear "helicopter view" and avoid the aforementioned overlapping problem. Through a synthesis of the literature, the ICT-related applications in road freight transport and logistics operations can be categorised in deployment at four levels as shown in Table I. The table also outlines the key applications and systems used for each level. Even though each level will include a number of applications, only the ones related to road freight transport and with a potential impact on CO_2 emissions are included. For instance, RFID technology has been widely researched but due to the fact that the direct impact of such technology on CO_2 emissions has not been sufficiently reported in the literature, it is thus excluded from the table. This research has also excluded infrastructure-related technologies, for example, road pricing systems, congestion charge management systems and traffic information management systems. These services are designed for both passenger and freight transport, not solely for road freight transport, and as such it is difficult to quantify the impact of such technologies on carbon emissions at individual user and company level. Nevertheless, enterprises and supply chain level systems such as enterprise resource planning (ERP), customer relationship management (CRM) and supply chain management (SCM) are included in Table I, because these systems are relatively mature and have been adopted widely in practical settings. Furthermore, the main benefits of these sort of systems are well documented in the literature, as follows:

- ERP systems aid cross-functional transaction automation and synchronisation resulting in compression of delivery speed and reduced order cycle times (Cotteleer and Bendoly, 2006; Yusuf *et al.*, 2004);
- SCM systems provide more sophisticated planning capability leading to cost and cycle time reduction and improvements in productivity and revenue (Shi and Yu, 2013); and

Levels for the use of ICT	Key references	Key applications and systems
Level1 – vehicle and load	Baumgartner *et al.* (2008)	On-vehicle or in-cab ICT systems managing individual vehicles or loads; typical applications include
	Businesslink.org.uk (2005), Stefansson and Lumsden (2008)	Digital tachograph, which works by digitally storing data on the driver and vehicle in its memory, and also on a credit card-sized plastic card known as the "driver smart card". It is an electronic system for recording driving and rest times for drivers and co-drivers of trucks that are driven under EC driver' hours rules
	Baumgartner *et al.* (2008), Zeimpekis and Giaglis (2006)	Telematics, which is made up of three components: an on-board computer, a satellite receiver/GPS, and a communications device. These are normally combined into a single piece of equipment within the vehicle, supported by office-based equipment and software. It is the wireless backbone of vehicle and load management and helps to monitor the movement of vehicles, fuel consumption and communicate with drivers
Level 2 – company	Botta-Genoulaz *et al.* (2005), Gupta and Kohli (2006), Baumgartner *et al.* (2008), Helo and Szekely (2005), Marchet *et al.* (2009)	Enterprise systems deployed to manage specific business processes Best of breed functional systems: a typical application is transportation management system (TMS) which usually offers the following functions Planning and scheduling: daily route and resource planning and strategic what-if scenarios analysis for long term business plan Execution and monitoring: driver communication, real time or retrospective tracking, management reporting and financial settlement
	Gupta and Kohli (2006), Yusuf *et al.* (2004)	Fully integrated systems: a typical application is Enterprise Resource Planning (ERP) system which integrates all of a company's major business processes (from order processing to product distribution) within a single family of software modules
Level 3 – supply chain	Brown *et al.* (2009)	Inter-organisational systems managing mainly the dyadic business activities between two organisations. Typical applications include
	Evangelista *et al.* (2010)	Customer relationship management (CRM) system, allowing business to carry out b2b sales on the web and provides support for marketing and customer service
	Evangelista *et al.* (2010), Buxmann *et al.* (2004)	Supplier relationship management (SRM) or Supply chain management (SCM) system, designed to deal with the procurement of the components a company needs to make a

(*continued*)

Table I.
A hierarchical categorisation of ICT use in transport and logistics operations

Levels for the use of ICT	Key references	Key applications and systems
		product or service and the movement and distribution of components and finished products throughout the supply chain
Level 4 – network (multiple supply chains)	Auramo *et al.* (2002)	Network systems usually involve multiple participants and communications are simultaneously conducted between two or more companies. Typical applications include
	Davies *et al.* (2007), Wang *et al.* (2009), Wang *et al.* (2011)	Open electronic logistics marketplaces, mainly for sport trading of transport services between shippers and carriers. Such systems can be used for identifying backhaul opportunities Closed electronic logistics marketplaces, for long-term logistics provision and execution. Such systems integrate shippers (consignors), carriers and customers (consignees) and can be used for horizontal transport collaboration between shippers or between carriers

Source: Authors

Table I.

- CRM systems facilitate effective centralised customer-relationship management resulting in more accurate demand forecast and more effective production and distribution scheduling (Hendricks *et al.*, 2007).

2.2 Food and grocery industry in the UK

The food and grocery sector is one of the key industrial sectors in the UK. It is estimated that around 52 per cent expenditure of retailing is spent on groceries (Bourlakis and Weightman, 2004; Institute of Grocery Distribution (IGD), 2012). Retailers play a significant role in exploring innovative ways of managing their supply chains for competitive advantage, for example, the implementation of just-in-time (JIT) practices and the introduction of the Efficient Consumer Responsive (ECR) initiative. Many such initiatives are driven or enabled by developments in ICT. As a result, logistics in British grocery retail is claimed to be among the most efficient in the world (Fernie *et al.*, 2010). The food and grocery industry is one of biggest users of road freight transport in the UK. The past two decades have also witnessed a trend of centralised manufacturing and global sourcing of materials and products for manufacturers and retailers, in order to further reduce cost and improve supply chain efficiency. Although delivering great commercial benefits, the aforementioned initiatives have also posed a number of challenges to logistics provisions, particularly on environmental sustainability as summarised in Table II, and summarised by Green *et al.* (2012) and Abbasi and Nilsson, 2012. Those key trends and challenges in Table II are derived mainly from various online publications by ECR Europe and ECR UK (operated by IGD). Notable publications include ECR's Sustainable Distribution Toolkit (ECR, 2009), Transport technology user guide (IGD, 2009) and IGD's white paper on on-shelf availability (IGD Supply Chain Analysis, 2012). ECR is an international joint trade and industry body for the food and grocery industry through which major retailers and manufacturers as well as other stakeholders such as third party logistics companies actively participate and share best practices.

Table II.
Challenges facing transport in the grocery sector

Key trends over the past two decades in the grocery sector	Challenging facing transport
For manufacturers	
Centralised manufacturing/global sourcing	Lengthier supply chain
Fewer plants	Higher transport costs
Lower production costs	Longer lead times
Lower cost of raw/packing materials	Less flexibilities
	Stiffer inventory requirements
For retailers	
Increasing demand of delivery excellence from retailers	Empty running and low vehicle utilisation
Small and frequent orders	Delivery complexities: diverse unit loads, delivery constraints
Shelf-ready packages	KPIs conflicts between manufactures and retailers
New distribution channels, e.g. convenience delivery	
Customer response	
For both manufacturers and retailers	
Promotions/on-shelf availability	Peaks and troughs of transport demand
Seasonal promotions	Pressures of warehouse and transport planning and operation
Joint promotions	
New product introduction	
On shelf availability (affects both supplier and retailer)	

Source: Authors, based on various online publications from ECR Europe and UK (2012)

For manufacturers, the centralised manufacturing and global sourcing has provided cost advantages on labour and materials, but it has also created a lengthy supply chain. In many cases, sourcing overseas involves multimodal transport provisions which imply a lengthier and more carbon-intensive supply chain, relatively high transport cost and often a lack of flexibilities in responding to demand changes. For retailers, the application of JIT principles has largely reduced the level of stock at distribution centres (DCs) and stores, contributing to a healthier cash flow; nevertheless it also has led to more frequent deliveries to stores with smaller quantities of goods, resulting in lower vehicle utilisation and higher percentage of empty running consequently more CO_2 emissions and increased transport cost (McKinnon *et al.*, 2009). The competition for new distribution channels, for instance online grocery and convenience retailing, also increases delivery complexities (Griffths, 2009). For both retailers and manufacturers, on-shelf availability is critical for sales and customer retention. Seasonal and joint promotions between retailers and manufacturers increase the customers' awareness on certain brands with a potential for increased sales (Ettouzani *et al.*, 2012), and result in demand peaks and troughs for transport (Sanchez-Rodrigues *et al.*, 2010). This in return exerts pressures on warehouse and transport planning and provision.

Given the membership of the major UK food and grocery retailers in the mandatory the Carbon Reduction Committee Energy Efficiency Scheme (a cap and trade scheme, DECC, 2013), retailers from UK's food and grocery sector actively seek innovative ways of using ICT to make their supply chains greener. This motive is further incentivised by the challenges they face as discussed above. It is in this context that we have chosen the food and grocery retail sector as an exemplar of FMCG supply chains for a research study in the use of ICT in reducing CO_2 emissions. The following section provides further details on our research design.

3. Research method

A multiple case study research method was adopted, because it is particularly suitable when we explore the "why", "what" and "how" research questions and examine contemporary events (Voss *et al.*, 2002; Yin, 1994). Since the primary purpose of the research is exploratory in nature, a multiple case study approach was considered appropriate as the research attempted to "provide new conceptual insights by investigating individual cases for an in-depth understanding of the complex external world (Wacker, 1998)". Case study research is primarily used to develop new theories (Barratt *et al.*, 2011), through the use of qualitative methods to collect data to develop testable theories. This inductive, as opposed to deductive, method of reasoning that is prevalent in case study research informs the research questions proposed in case studies. The research questions formulated should be open in nature, avoiding specific directional hypotheses that could impart an overly subjective perspective on the case to the researcher and hence prejudicing the investigation.

A common criticism associated with case study research is the potential lack of objectivity, as the researchers may lose their independence through heavy involvement with the case. To improve the validity of case studies, Checkland and Holwell (1998) suggest a particular framework of ideas should be developed in advance as a guide for research so that "the process is recoverable by anyone interested in subjecting the research to critical scrutiny". Incorporating this suggestion in our research, we have developed a research protocol (enclosed as an Appendix) to ensure that data required was collected in a systematic, rather than ad hoc manner. The protocol developed structured the interviews with participants, and informed the observational process. As the protocol is in itself a framework for the conducting of research, as opposed to a specific interview proforma, the interviews that formed part of the case studies were semi-structured in nature, with the protocol updated and modified within its remit based on emerging data and observations of the company's operations. While system demonstration, interview and site observations provide researchers direct essential interactions with the case companies, the use of archival information obtained from case companies provides useful complementary information and positions our study in a meaningful context. Typical information obtained includes annual reports, corporate distribution strategies, network structures, freight flows (products, volume, routes), costs of delivery and ICT-related project documents.

The use of multiple data collection techniques, i.e. interviews, system demonstrations, site observation and the use of archival documents, were deployed in order to triangulate the research findings (Barratt *et al.*, 2011) and reduce the negative effect of lack of objectivity. This triangulation provides greater reliability of data (as interview data can be verified by other source, for example) and stronger substantiation of constructs. The use of multiple researchers in this study also aids in the triangulation of the data and leads to a better ability to handle the richness of the contextual data (Barratt *et al.*, 2011; Eisenhardt 1989).

Three leading retailers in the UK's grocery sector were chosen as appropriate cases for study, that represent over 60 per cent of the market share in the UK. Table III summarises their backgrounds and indicates the scale of their businesses.

With Retailer A, the case study involved one of the researchers working closely with to the company for three months, and helping to set up a new depot-to-store

Table III.
A summary of case examples' background

Retailer	Market position	No. of depots (UK)	No. of store (UK)	No. of stock keep unit (SKU)	Size of fleet	Annual mileage travelled (km)	CO_2 reduction target
A	A leading grocery retailer in the UK and one of top five retailers across the world with 440,000 staff serving 30 million customers weekly	29	1,800	76,000	2,000+	659 million	Zero-carbon business by 2050
B	A UK leading grocery retailer and one of the top three retailers in the UK with 150,000 staff serving 21 million customers a week	32	934	70,000	1,400+	156 million	Reduce CO_2 emissions per square metre by 25 per cent by 2012, against a 2005/2006 baseline
C	A multinational retailer and is also one of the top five retailers across the world with over 170,000 staff	28	400	119,000	1,000+	142 million	10 per cent reduction in carbon footprint by 2015 using 2005 emission as baseline

Source: All data based on the year of 2010

distribution channel. This offered the opportunity to collect data required for this particular research. The same research protocol was also used for studying Retailers B and C, which allowed the cases to be compared with one another in a cross-case analysis that forms part of the data analysis in this work. For case B, again one of the researchers worked closely with the company for three months, conducting an in-depth case study. The same amount of data were acquired through the use of the same techniques. Table IV summarises the details of our data collection methods.

In the case of Retailer C, one of the researchers worked with the company over a two-month period on an assessment of their current ICT systems efficacy and flexibility. Secondary data were used based on the information available from the company's own web site, promotional case studies made available online by ICT service providers and the web sites of the IGD (UK) and the ECR Europe as well as trade and academic articles. The information collected via the aforementioned channel proved to be sufficient to fulfil the needs of this research both as a validation of the case study findings of cases A and B and as a means of establishing the manner of usage of ICT in the organisation as very similar to cases A and B. Archival sources are acknowledged as a valid data source for case studies (Barratt *et al.*, 2011). This was further validated through three onsite systems demonstrations, two naturalistic observations of the operations of DCs and three interviews with key national-level managers of logistics operations. Although the method of data collection varied from cases A/B to C, there is still the ability to conduct cross-case analysis between the three cases as the systems used in all three cases were shown to be closely aligned and the same protocols were followed.

Case company	No. of site observations	No. of employees involved	No. of ICT system demonstrations	Archive data
Retailer A	Four depots and ten stores observations, focusing on the physical delivery processes and ICT systems in place	In total 12 interviews with a number of people, including depot manager, transport manager, transport scheduler, store manager, stock controller and IT managers for store replenishment system and vehicle management system	In total four, including transport scheduling system, vehicle tracking system, store replenishment system and warehouse management system	Plan vs actual delivery-related data, store performance data
Retailer B	Three depots and three stores observations focusing on the physical delivery processes and ICT systems in place	In total ten interviews with head of transport, ICT transport manager, transport planning manager and planners, depot transport manager as well ICT facilitators implementing integrated transport management system	In total, three, including transport scheduling system, vehicle tracking system, store replenishment system	Plan vs actual delivery-related data and store performance data
Retailer C	One depot observation, one head office visit and three meetings with specifications team and ICT provider	Three interviews with fleet manager, ICT manager, inbound logistics manager, and meetings with software account manager, three regional fleet managers, three drivers, operations manager	In total four, including transport management system, pre-delivery check system, vehicle tracking system and transport scheduling system	Plan vs actual delivery-related data and off-route mileage data

Source: Authors

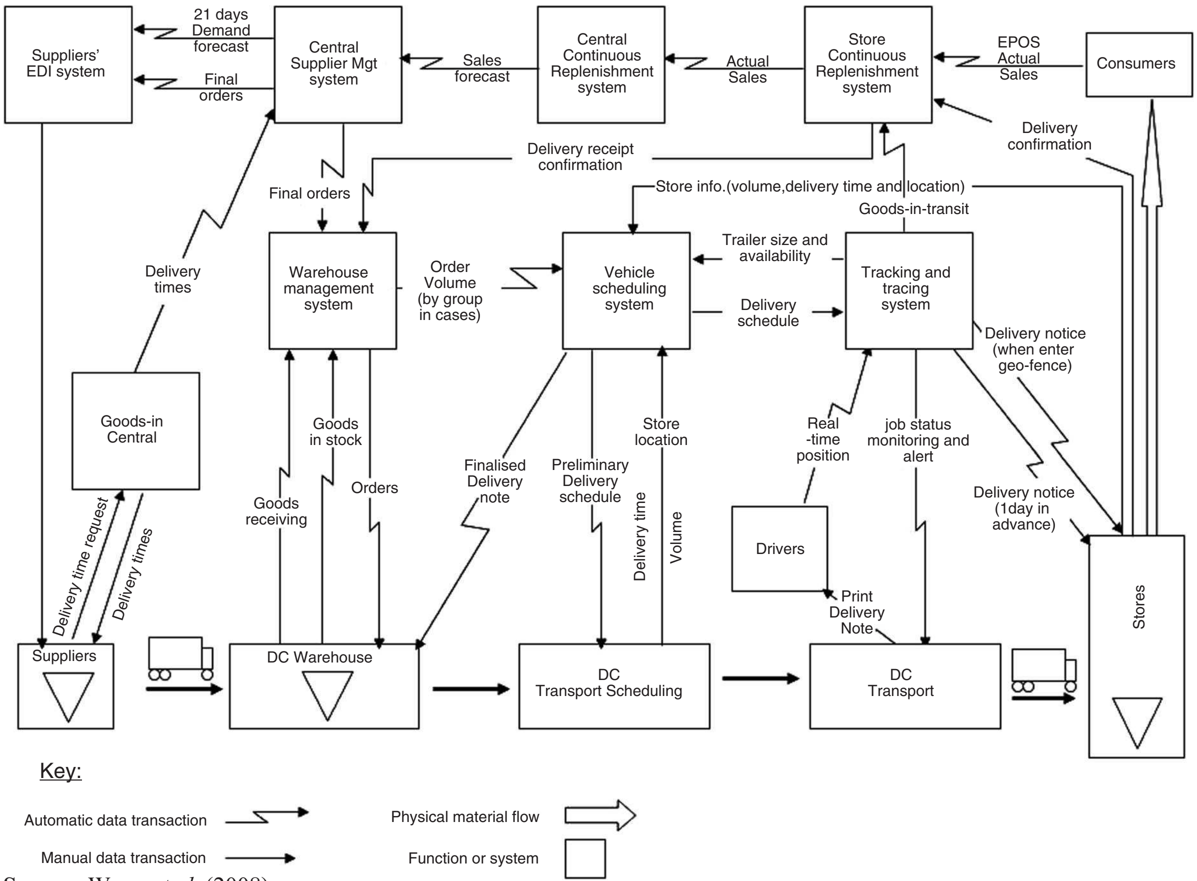
Table IV. A summary of data collection methods

It is important to evaluate the quality of the research in terms of its validity and reliability, as recommended by Yin (2009). The three types of validity proposed by Yin (2009), construct, internal and external, have been addressed in the research. A collection of evidence was collected in the case studies and all the data sources were appropriately triangulated. The themes developed from the literature review were used in the data analysis to cross-compare the findings from the case studies. Evidences from the data collection undertaken in a heterogeneous sample of case study companies were triangulated with findings from the literature review. Furthermore, in order to ensure reliability in the data collection process, a protocol was developed to undertake the research based on the themes found in the literature review.

4. Analysis of the case studies

4.1 Retailer A's ICT deployments

Figure 1 shows an overview of the information flows within the company and between the company and its suppliers. The whole replenishment process begins with a "pull" signal generated the EPOS sale which then triggers the update of store and central



Source: Wang *et al*. (2008)

Figure 1.
A process map of information flows of Retailer A's distribution operation

replenishment system. Rolling forecasts are generated and fed into the supplier forecasting system which consequently generates firm orders which are passed on to suppliers via EDI links. In the meantime, orders are also sent to the DC's WMS automatically, and they are also downloaded into the vehicle-scheduling system. The transport scheduler prepares a daily schedule accordingly. This is then passed to both warehouse and transport managers for loading and delivery management, as well as to the stores. Once the vehicles were loaded, a vehicle tracking and tracing system monitored their progress. When vehicles were close to the delivery point, the tracking system automatically alerted the store that arrival was imminent. This helped stores to prepare for the receipt of goods. Deliveries were confirmed automatically by the store replenishment system after the truck's departure. If stock was damaged or the incorrect quantity delivered, a manual correction may be conducted by the store manager.

Levels 1 and 2 technologies (at vehicle and company levels). The use of the digital tachograph is found to have limited impacts on carbon emission reduction, while the telematics technology, in contrast, has seen direct positive link to CO_2 emission reduction. Vehicle telematics is the main application for managing individual vehicles and aiding the real-time tracking of goods. It offers an internet-based service for vehicle management, analysing driver performance against a range of criteria and highlights areas in which improvements can be made. These include revving, harsh braking, idling, speeding and "green band" driving. A six month trial with a specific commercial telematics application using 25 tractors reveals a reduction of fuel consumption of 7.2 per cent in 2009 and Retailer A has started the rolling out of this commercial package throughout the whole distribution network. A reduction in fuel consumption will result in a direct reduction of carbon emissions. Given the scale of the business (with over 2,000 trucks), the impact on environment sustainability is substantial. This is mainly achieved through the change of drivers' behaviour.

The use of a vehicle routing and scheduling system also helps in reducing CO_2 emissions. It is claimed that the overall mileage savings equate to over 150,000 miles saved each week, which when expressed in terms of CO_2 equates to around ten thousands of tonnes saved each year. The system offers advanced modelling techniques by reviewing the allocation of stores to depots, balancing warehouse capacities and daily throughput limits and optimising the detailed transport schedules. A result of improved store allocation, increased backhauling and improved fleet utilisation has led to a positive impact on the environment.

In addition to the use of the aforementioned systems which directly manage the distribution operation, the company has also deployed a software package to measure, report and analyse carbon emissions across its operations worldwide. This application, according to the company, has enabled the on-going accurate and auditable measurement of its carbon emissions.

Levels 3 and 4 technologies (at supply chain and network levels). At level 3, Retailer A has established an electronic exchange with its suppliers for the sharing of supply chain information and the development of collaborative supplier relationships, providing its suppliers with EPoS data, in-store and warehouse availability levels and service-level performance information. The system is hosted by a third party company.

Currently, deliveries from suppliers to the retailer's depots are mainly managed by individual suppliers. In some instances, the retailer will collect products from its suppliers instead, a practice known as Factory Gate Pricing (FGP). For instance the FGP with a major food supplier has resulted in an estimated annual saving of over

6,835 miles. The supplier system is not designed to facilitate the identification of synergies between Retailer A and its supplier. Therefore FGP is scheduled manually.

Retailer A also utilises rail freight transport for several long-haul routes but the role of technology in aiding the current process is very limited. The company has tried to share the use of rail services with other companies when the company itself is unable to provide the critical mass for a rail delivery, but so far with limited progress. ICT systems like web-based electronic logistics marketplaces (ELMs) may play a role in facilitating this collaboration by analysing the potential synergies but this has yet to be explored.

At level 4, no strategic information systems or managerial attempts have been deployed to aid the exploration of horizontal collaborative transport opportunities, such as joint deliveries between suppliers or between retailers.

4.2 Retailer B's ICT deployments

As confirmed by the systems development manager in Retailer B, the process map of information (as shown in Figure 1) is largely the same. The only difference is that Retailer B's tracking system does not feed goods-in-transit information into the store continuous replenishment system.

Levels 1 and 2 technologies (at vehicle and company levels). Findings from Retailer B on digital tachograph concur with Retailer A. In terms of vehicle scheduling and tracking, Retailer B uses exactly the same commercial packages as Retailer A. The difference is that Retailer B has fully integrated its transport scheduling system with a vehicle-tracking system which previously operated individually. Such integration has enabled the business to plan a multishifted schedule that can be re-optimised during execution. For instance, if drivers are predicted to return early or late, the system automatically reallocates loads to others. "Previously, this relied on the transport clerk's best guess (a quote from the transport manager)." As a result of an 18-month trial at four depots between 2008 and 2009, the business has achieved 12 per cent reduction on empty running (equivalent of 2,000 fewer empty vehicle journeys per week). This is primarily due to more planned backhaul, salvage and asset collections. CO_2 reduction across those four depots resultant from fuel savings is around 1.4 million kilograms.

An additional finding from Retailer B is that the business also deploys a yard management system monitoring the movement of trailers. Those trailers are tracking independently, mainly for security and planning purposes. As there are usually very limited movements with trailers within the yard, such system is seen to exert limited influence on CO_2 reduction.

Levels 3 and 4 technologies (at supply chain and network levels). At level 3, Retailer B has established several B2B systems, as opposed to one single system in the case of Retailer A, as a toolkit with its suppliers. A product performance system allows suppliers to examine EPoS data and manage promotional events. A supplier portal enables suppliers to view procure-to-pay information such as invoice received, payments sent and order history. An e-sourcing system is also in place for suppliers to negotiate the cost of products and services. To complement this, a data entry and self-billing system provides the visibility of data – from agreements through to volume movements and creation of all necessary financial transactions for hauliers and suppliers.

The company is also exploring the use rail services with other companies when it is unable to gain the critical mass from long-haul deliveries particularly those originated in European locations such as Italy and Greece. Similar to Retailer A, there has been limited progress. Naturally there has been no established IT system in supporting the provision of switching from road to rail.

As with Retailer A, current deliveries from suppliers to the retailer's DCs are mainly managed by individual suppliers. Through FGP, the company also use empty trucks to collect goods from suppliers on their way back from store deliveries. The number of these collections has reached over 140,000 per year. FGP was found contributing to the majority of CO_2 emission savings at level 3. At level 4, no strategic information systems or management initiatives have been deployed to explore the synergies between suppliers, consequently no carbon savings identified.

4.3 Retailer C's ICT deployments

Compared to Retailers A and B, Retailer C had reservations in participating in the carbon disclosure project organised by the IGD. However, since 2005, a more proactive approach has been adopted resulting in a number of transport CO_2 reduction initiatives taking place.

Levels 1 and 2 technologies (at vehicle and company levels). Under this category, the technologies (telematics, vehicle routing and scheduling and real-time tracking) deployed by Retailer C are largely the same as with Retailers A and B, so are the information flows. Recently, Retailer C has moved away from individual planning for each DC and has created several planning regions across the UK that provides a clear differentiation between regional planning. Through this change, Retailer C has managed to maximise geographical resources and local execution for compliance to plan and accountability for store service. This business change has resulted in on-time delivery improvements to the stores, optimisation of driver and vehicle resources and greater route compliance, which is also reducing mileage, road freight transport costs and emissions, as confirmed by Retailer C's national transport manager.

Through the improved utilisation of its 1,000 plus fleet of tractor unit and 1,600 trailer units after a move to regional, as opposed to individual depot planning, an estimated saving of 5-10 per cent on fleet cost has been achieved. Additionally, the efficiencies gained by routing improvement also reduce fuel usage and vehicle-related emissions which have made a positive contribution to the achievement of 40 per cent fleet-related emissions by the end of 2009. A systems demonstration indicated that retailer C uses a co-piloting software system that is optimised for heavy goods vehicles. The optimised routing has been deployed with the express aim of reducing costs of off-route driving, which are estimated to be 25 per cent of the total transport costs of the business per annum. Retailer C has also introduced an automated pre-delivery safety checking system utilising a mobile data terminal, with the effect of reducing engine idle running time before leaving DCs.

Levels 3 and 4 technologies (at supply chain and network levels). Like Retailer A, Retailer C established an electronic exchange platform with its suppliers, though leveraging its parent company's infrastructure rather than building a dedicated system for the UK's operation. In addition to the normal functionalities offered by Retailer A's supplier platform, the company has taken initiative in using this system to identify potential backhaul opportunities within the company's own distribution network and promote joint deliveries between its suppliers. Based on the data gained from the system, backhauls and fronthauls are scheduled to reduce miles driven. Backhauls are based on the information of the fill rate of vehicles running between RDC and stores, and the information about shipment of purchasing goods from supplier in the same or adjacent route(s). Fronthauls are created for different suppliers of Retailer C which ship goods to the same destination to share loads. This demonstrates good carbon-saving practice at level 4.

5. Discussion – answer to *RQ1*

All three cases have well-established corporate social responsibility frameworks which set clear carbon emission reduction targets, though these targets vary between organisations. The analysis of the three case examples has reveals that there are striking similarities between retailers in terms of using ICT to manage their distribution, and to aid carbon emission reduction. Table V summarises the commonalities and differences between three case retailers. It also highlights the new applications (in italic) which were not identified in our literature review (in Table I) but are now used in practice. These are: digital pre-delivery check system, carbon auditing system and

Levels for the use of ICT	Key applications and systems	Retailer A	Retailer B	Retailer C	Impact on CO_2 reduction
Level 1 vehicle and load	Digital tachograph	✓	✓	✓	Limited impact
	Digital pre-delivery check system	X	X	✓	Limited impact
	Telematics	✓	✓	✓	Direct impact via the change of driving behaviour and route optimisation
Level 2 company	Best of breed transport management system Planning and scheduling Execution and real time tracking	✓	X	✓	Direct impact via improved store allocation, increased backhauling, fleet utilisation and routine improvement
	Fully integrated transport system	X	✓	X	
	Carbon auditing system	✓	X	X	No direct impact but useful for self-monitoring and reporting
	Yard management system	X	✓	✓	No direct impact
	Regional planning	X	X	✓	Increased opportunities for joint deliveries and backhauling, using centralised planning
Level 3 supply chain	CRM system	✓	✓	✓	Limited impact
	SRM or SCM system	✓	✓	✓	Direct impact through factory gate pricing
Level 4 network (multiple supply chains)	Open ELM	X	X	X	n/a, however, literature suggests a positive impact
	Closed ELM	X	X	✓	Direct impact if appropriate functionality in place enabling supplier joint deliveries

Source: Authors

Table V. The summary of case findings regional planning. While the first two systems are found of limited impact on CO_2 emission reduction, Table V can be read in conjunction with Figure 1, as Table V concretises some of the ICT applications that are common between cases in the context of their use within the internal distribution operations of the retailers. For example, the tracking and tracing systems detailed in Figure 1 correspond to the digital tachometers and telematics systems at level 1 in Table V, which are responsible for cost savings and CO_2 emissions reductions through the coding of driver behaviour (and potential for modification and training). The TMS identified at level 2 in Table V are contextualised as vehicle scheduling systems in Figure 1, and these are responsible for route optimisation and delivery optimisation which are again important in the reduction of costs on transport, and in turn CO_2 emission reductions through reduced mileage travelled and reduced idling times. It is important to note is that these systems are embedded within a wider ICT infrastructure that operates across the organisation with regards to optimisation of logistics, and that their effectiveness is to some extent contingent upon the effective supply of data from other areas of the business, and as such the effect of ICT on CO_2 emissions reduction is necessarily dependent upon the key systems identified in Table V, but that these alone are not sufficient for optimised emission reduction as the linked systems must provide accurate data for the economic and environmental savings to be realised through these applications.

Overall it is felt that the use of ICT for environmental benefit still needs development, with most of the current initiatives focusing on levels 1 and 2 technologies, namely within the boundary of the individual retailer. In particular, there has been a focus on in-cab technologies using telematics to reduce fuel consumption, improving the individual driver's driving behaviour and achieving preventative maintenance. Evidence has shown that there are substantial economic and environmental benefits if companies utilise effective ICT applications at those levels, and the three cases in this research all utilise these applications effectively to reduce costs and therefore emissions. The use of a carbon footprint measuring system has shown some benefits but it seems that it is only an affordable solution at present to larger retailers. Whether carbon footprint measuring systems can be adopted by SMEs is not well understood yet. Lack of IT expertise as well as limited financial resources are often the primary factors inhibiting the take-up of more advanced IT systems (Evangelista and Sweeney 2006; Shiels *et al.*, 2003).

This research has found that in the UK grocery sector, inter-organisational systems at levels 3 and 4 are mainly deployed to manage the strategic and operational activities, usually without a deliberate consideration of environmental impact. However, Retailer C's approach has proved that with an appropriate system in place, intra- and inter-organisational collaborative opportunities on transport provision can be more easily identified. The use of ICT at level 4 by Case C indicates that there is a potential affordance for further economic and environmental savings through the use of ICT beyond applications at level of the individual retailer. This kind of application usage requires a measure of flexibility with suppliers as cross-platform (or novel platform) data sharing and integration is required for effective network collaboration at level 4. As this is the level of usage where least attention has been paid to the potential cost and environmental savings through the use of ICT in the cases studies, it is intuitive to suggest that one of our major contributions of this work is the identification of ICT at a network level as a potential area of further development for the realisation of economic and environmental benefits using ICT in the logistics operations of grocery retailers in the UK.

Traditional systems will have significant complexities in accommodating inter- and intra-organisational communications at a network level, as data is currently disparate in source and format and integration would require the transformation of formats or the implementation of new systems. If done manually, such integration would become even more difficult if not impossible, and would negate many of the economic benefits around time saving and efficiency that the deployment of ICT applications realises. Although the electronic supplier exchange platform identified in case C does not facilitate the close monitoring of the execution of a specific consignment, it does help to reveal the potential collaborative opportunities at the planning stage, therefore bringing benefits not only to the retailer itself but also to participating suppliers at the network level, and realising efficiencies in costs through reduced mileage, which in turn realises environmental benefits through the reduction of CO_2 emissions.

6. Future opportunities – answer to *RQ2*

Given that the identification of a lack of ICT provision and usage at level 4 (network) in the food and grocery sector, it is practical to explore what options may be available to implement ICT-based solutions at that level: either within the scope of ICT applications already deployed within the major UK grocery retailers and identified through the case studies, or already in use in the retail or other relevant sectors. Though the food and grocery sector have been actively exploring ways for transport-related CO_2 reduction, the empty running at national level remains largely unchanged at around 19 per cent, according to a series of benchmark studies sponsored by DfT (UK) since 1998 (McKinnon, 2007b). This has urged both practitioners and academics to think beyond the boundary of one company's own distribution work. We envisage that exploring synergies between supply chain partners could lead to further reductions on CO_2 emissions, through the following collaborative initiatives as shown in Figure 2.

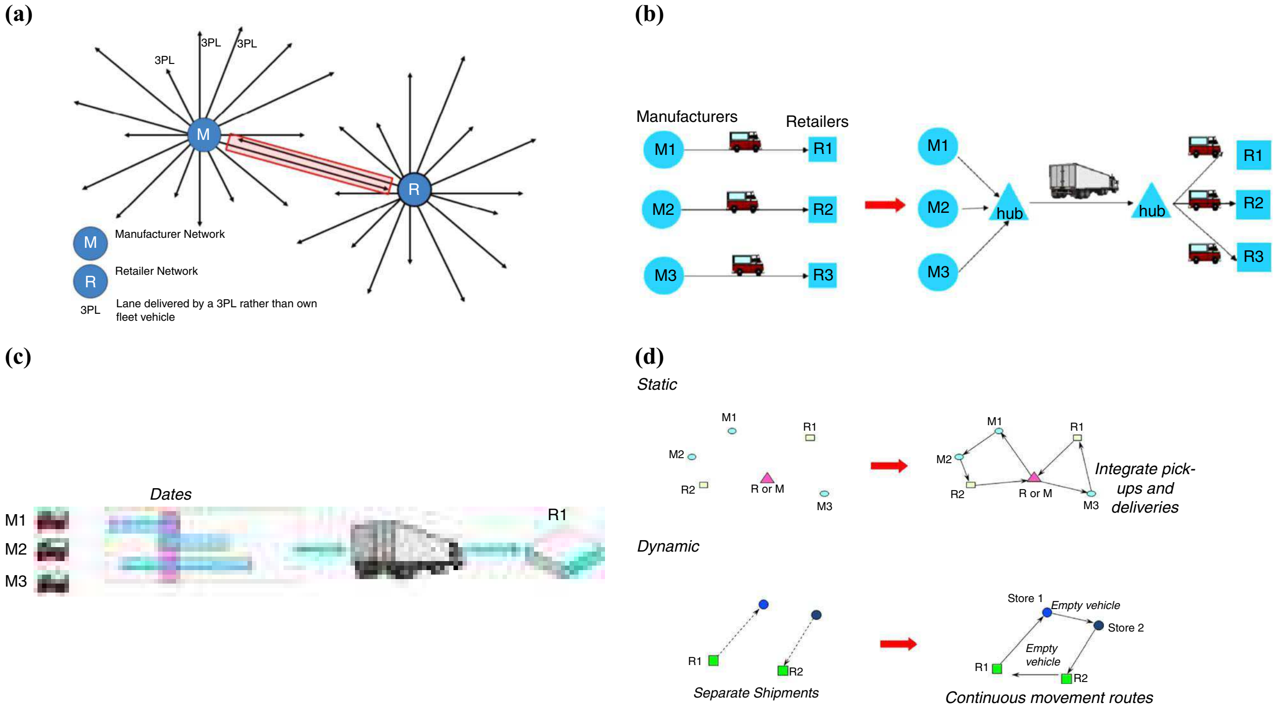
6.1 Backhaul opportunities

Backhaul could occur between manufacturers or between manufactures and retailers. Most manufacturers and retailers have established their distribution networks where delivery volume and routes are relatively stable. It is the lack of visibility of freight flows outside one's own network which makes the identification of synergies between companies a challenging task. An open ELM or freight exchange such as teleroute.com (one of the earliest online freight exchanges in Europe) will be sufficient to support this type of collaborative arrangement. While the use of such a freight exchange is popular within 3PLs, the shippers are less enthusiastic even though they may not have a large in-house fleet. This might be largely due to the spot-trading nature inherited in those IT platforms with high level of uncertainty. A potential solution for mitigating this problem would be for a third party agency or a 4PL company to facilitate and execute the initiative.

6.2 Fronthaul opportunities (i.e. joint deliveries)

This could be provisioned between manufacturers, or between retailers. Though such practices are still relatively rare in the UK's grocery sector, there is an increasing awareness about the potential economic and environmental benefits generated. For instance, the collaborative arrangement between Nestlé and United Biscuits has saved one million km of road usage over a period of four years and recently has received positive media exposure (Logistics Focus, 2011).

Between manufacturers, joint deliveries are feasible if either the following conditions can be established:



Notes: (a) Backhauling; (b) joint deliveries – spatial pooling; (c) joint deliveries – temporal pooling; (d) integrated pickup and deliveries
Source: The authors

Figure 2.
Collaborate transport illustrative diagrams

- Spatial pooling: is viable when a few manufactures locate in a cluster and close to each other and serve the same customer(s) or different customers. A joint deliver offers a collective volume for a fuller truck load.
- Temporal pooling: is viable when a few manufacturers all deliver to the same customer and have an overlapping time window.

The same principle can be applied to joint deliveries between retailers, in particular when deliveries of small consignments are made to stores under significant demands in the delivery process such as congestion charges, restricted loading/unloading areas and rigid delivery windows.

With regards to ICT requirements, synergies between two or more companies can be identified and planned using simple worksheets. When it comes to large volumes and a variety of routes, manual planning will become increasingly difficult if not impossible and often schedules produced are not optimised. A transport planning system with "what-if" scenarios analysis functionality will serve as a good decision support tool for companies to identify synergies and potential opportunities for collaboration. Ideally, such a system should be able to integrate with geographic information systems so that transport flows can be visualised on a base map.

6.3 Integrated multiple-leg pick-ups and deliveries

This type of collaborative arrangement is probably the most complex, as multiple drops and pick-ups are integrated into one completed journey. In the case of dynamic routing, companies not only have to find compatible routes, they also need to exchange huge amounts of data at sufficient speed, i.e. synchronise delivery information in real time, in order to be able to "re-spin" transport plans in response to real-world events. This requires the transport scheduling system to be fully integrated with the execution and tracking system:

- Static routing: routes with potential for a round trip between various sites are identified in advance and once determined; routes are fixed for a relatively longer term.
- Dynamic routing: continuous routing based on real-time dynamic transport demands. This usually requires a very sophisticated scheduling technique and a high level of visibility between companies.

Technically a collaborative web-based system such as ELM, recently investigated by Wang *et al.* (2011) as an enabler of collaboration in logistics and freight transport, is able to facilitate all four approaches if sufficient data is provided and shared amongst participating companies. The data could include; for instance, the locations of production and distribution, fleet size and vehicle types (own and 3PL), where loads are moving from and to (volumes, frequency and temperature streams), lanes returning empty and any special considerations or constraints.

Although the aforementioned initiatives are technically achievable, the challenges lie in the relational and process configurations between companies. According to our interview with one of Retailer B's senior transport managers, the company has attempted to set up joint primary deliveries with another retailer via a logistics service provider in a specific geographic area, but failed because the retailer pulled out due to the fear of losing competitive advantage over its direct competitor, Retailer B. Our interviews with managers from both Retailers A and C have also suggested a number of barriers for transport collaboration, including the fear of sharing commercial sensitive information, the asymmetry of costs and benefits allocation, the compatibility of equipment and a lack of common performance measures to monitor the whole process. This concurs with the findings from the literature regarding barriers for collaboration, such as the works of Barratt (2004), Cruijssen *et al.* (2007), McKinnon (2007b), Wallenburg and Raue (2011) and Wang *et al.* (2011). Our research confirms that without the proper alignment of process, technology and collaborative arrangements, it is unlikely that the network opportunities will be fully exploited and materialised.

7. Concluding remarks

While sustainability issues have received increasing attention recently, the role of ICT in freight transport for CO_2 emissions reduction has not been investigated in depth and its impact is largely unknown. Through an in-depth intervention and analysis of three leading retailers in the UK's grocery sector, valuable insights have been obtained in understanding the current status of ICT deployments in aiding CO_2 emission reduction.

We found that the use of ICT solutions in road freight transport have a direct positive impact on CO_2 emissions reduction. The main academic value of this paper is that a framework has been developed and tested to benchmark ICT advancements and the links to CO_2 reduction of these advancements. Serving as a key enabler, ICT contributes to improved energy efficiency at vehicle and fleet level, better routing and scheduling at company level and collaborative transport arrangements at supply chain and network level. These ICT systems in practice are predominantly telematics systems, TMS and supplier management systems. Retailers tend to concentrate on company-specific initiatives rather than collaborating with each other. Opportunities to further reduce CO_2 emissions are perceived to be lying beyond the retailers' own distribution network and because of this such opportunities have not been fully explored. This is largely because retailers are reluctant to share information and risk losing their perceived unique competitive advantages. The complexities of technology, processes and collaborative provisions also pose challenges for companies to explore and capitalise on the synergies their respective distribution networks could share.

From a research perspective, our study confirms the findings from a recent literature research by Wiese *et al.* (2012) that environmental sustainability has received more attention in retail management practice compared to research applications. Therefore our research is both important and timely as it advances academic understanding about the role of ICT in CO_2 emissions reductions and thus lays a foundation for further investigating this important yet under-explored subject. It also contributes to the literature by developing a structured framework (i.e. the four-level categorisation) for researchers to benchmark individual business practices at sector level. The framework may also be used to evaluate advances in ICT and link these improvements to CO_2 reductions in other sectors.

For practitioners, our work can be used to as a useful guide for businesses on how to leverage the existing and emerging information technologies for environmental and economic benefits. The study can also help the policy-making process, by providing an assessment of popular available ICT systems to resolve some challenges facing sustainable mobility from a road freight perspective.

Even though the three case retailers count for over 60 per cent of grocery retailing market in the UK, other smaller retailers may deploy significantly different ICT applications to enable CO_2 reduction within their freight transport networks. Therefore, it is pertinent to investigate other retailers as well as manufacturers to further validate the proposed framework. Future research should also extend to examine practices in other FMCG sectors such as textiles, and lower pace sectors such as automotive and furniture. Given the different nature of those supply chains, different ICT initiatives may have been adopted or the take-up of same technologies could be at different maturity levels. A large-scale survey could be undertaken in order to quantitatively evaluate ICT deployments for environmental sustainability, again either within the same sector or across sectors. Furthermore, future research to identify the main barriers which can hinder the implementation those collaborative transport options is pertinent. Following this, further analytical modelling techniques could be applied to investigate potential costs and benefits if certain collaborative initiatives are to be deployed. There is also the opportunity to use the framework in the context of assessing ICT responses to the legal determinants to reduce CO_2 as identified by Hitchcock (2012). Finally, another important development would be to investigate how recent advances in ICT could enable CO_2 reductions in a multimodal freight transport environment.

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Appendix. Research protocol

(1) Case company background and corporate social responsibility.

(2) Opportunities and challenges facing the business in terms of economic and environmental sustainability:

- current issues faced by management team for carbon reduction;
- potential opportunities to address such issues; and
- overall strategy to reduce carbon emission.

(3) Overview of both primary and secondary distribution processes.

(4) Current ICT deployments:

- intra-organisational systems such as TMSs and WMS; and
- inter-organisation systems and level of integration with business partners.

(5) How has the business leveraged recent developments in ICT to reduce carbon footprint?

(6) What are the costs and benefits as well as motivations and barriers when it comes to DEPLOY a particular ICT system for CO_2 reduction?

(7) Future outlook, short (one to two years) and medium term (two to five years) plans on ICT developments (note that we do not ask for long-term plans on ICT as technologies evolve very fast and it is hardly possible to predict what will be available in the long term).

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