

# ICT in multimodal transport and technological trends: Unleashing potential for the future



Irina Harris\*, Yingli Wang<sup>1</sup>, Haiyang Wang

Logistics and Operations Management, Cardiff Business School, Cardiff University, Aberconway Building, Column Drive CF10 3EU, UK

## ARTICLE INFO

### Article history:

Received 24 July 2013

Accepted 3 September 2014

Available online 16 September 2014

### Keywords:

ICT

Multimodal transport

Barriers to ICT adoption

Technological trends

Cloud computing

Internet of Things

## ABSTRACT

The role of information and communication technologies (ICTs) in freight transport as key enabler is well recognised. However the uptake of recent ICT advances for multimodal freight transport provisions in the UK and Europe has been slow. The aim of our paper is to explore the potential reasons for such a slow adoption and assess how recent technological advances such as cloud computing and Internet of Things might have changed the landscape and thus help to overcome these barriers. Via an extensive review of 33 EU framework programme projects, we are able to consolidate and present current major efforts in ICT developments in the freight multimodal transport setting at European level. We further discuss barriers inhibiting quick take-up of ICT applications in multimodal transport. Resolutions were then explored by reviewing four key ICT development trends recently emerging and evaluating their potential impact in reducing such barriers for deployment. Our contribution is two-fold: it advances current knowledge by presenting an up-to-date overview of existing and emerging ICT applications in the field of multimodal transport and barriers to e-enabled multimodal transport. It also captures some of the best practices in industry and aims to provoke a debate among practitioners and academics via the analysis of how innovative use of recent technological developments could potentially lower the barriers to multimodal ICT adoption and lead to a more integrated freight transport network. Therefore it lays the foundation for further research.

© 2014 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/3.0/>).

## 1. Introduction

Growing environmental problems, increasing fuel price and congestion on many road networks require new solutions to freight transport operations. An integrated multimodal transport network is a critical factor for companies to successfully execute their supply chain processes both domestically and internationally. However, the complex nature of multimodal integration, for instance the involvement of a wide variety of operators can limit the growth of multimodality. One of the major constraints is the lack of effective and efficient information connectivity among and between various modes (water, air, road and rail).

Meanwhile, it is well recognised that information and communication technology (ICT) functions like the nerve system of a multimodal transport chain and brings multiple benefits to organisations by providing real-time visibility, efficient data exchange, and better flexibility to react to unexpected changes during shipment (Durr and Giannopoulos, 2003; Coronado et al., 2009; Gunasekaran and Lenny Koh, 2009; Perego et al., 2011; Prajogo

and Olhager, 2012). Recent developments in the field of ICT such as cloud computing, social networking and wireless communication have further revolutionised the ways information is shared and supply chains are structured.

In the UK, the Digital Economy Act was published in April 2010 which outlines the United Kingdom Government's strategic vision for its digital economy. Recognising the transformational impact of digital technologies on aspects of community life, future society, and the economy, the Technology Strategy Board launched, in May 2011, an initiative aimed at accelerating this (Technology Strategy Board, 2011). Subsequently priorities identified include development of new user-centric methodologies, managing big data, visualisation and augmented reality, service-oriented architectures across future networks.

Despite the aforementioned benefits and strong government promotion, the uptake of recent technological advances for multimodal transport provisions in the UK and Europe has been slow

\* Corresponding author. Tel.: +44 29 20874447.

E-mail addresses: [HarrisI1@cardiff.ac.uk](mailto:HarrisI1@cardiff.ac.uk) (I. Harris), [WangY14@cardiff.ac.uk](mailto:WangY14@cardiff.ac.uk) (Y. Wang), [wanghaiyang@live.co.uk](mailto:wanghaiyang@live.co.uk) (H. Wang).

<sup>1</sup> Tel.: +44 29 20875066.

(Huckridge et al., 2010; Perego et al., 2011; Marchet et al., 2012). The aim of this paper is to explore the potential reasons for such a slow adoption and assess how recent technological advances might have changed the landscape and thus help to overcome these barriers. The contribution of this paper therefore is two-fold: it advances current knowledge by presenting an up-to-date overview of existing and emerging ICT applications in the field of multimodal transport and barriers to e-enabled multimodal transport. It also captures some of the best practices in industry and aims to provoke a debate among practitioners and academics via the analysis of how innovative use of recent technological developments could potentially lower the barriers to multimodal ICT adoption and lead to a more integrated multimodal freight transport network, and hence lays the foundation for further research.

Our paper is mainly conceptual but a wide source of secondary data has been utilised in order to improve the validity of our analysis. An overview of the characteristics of multimodal transport is presented in Section 2 followed by a discussion of the research methods deployed in the paper in Section 3. The classification and discussion of recent ICT developments in multimodal transport are presented in Section 4. Section 5 discusses the barriers to ICT adoption in general, as well as for multimodal transport referring to both academic publications and exemplar EU projects. Section 6 tackles how recent technological developments could help reduce those barriers. Four types of merging technological trends are identified and analysed, which represent key trends in ICT developments. As those developments have only emerged recently and are still in their infancy stage, their potential application to the management of multimodal transport has not been fully explored, either in practice or by academics. We articulate our viewpoints under this section in a forward-looking fashion to invite further debate or validation from both practitioners and academia. Section 7 links technological trends to "Big Data" and decision support systems for managing multimodal transport. In Section 8 we subsequently evaluate the impact of technological trends on barriers related to the ICT adoption and finally, Section 9 concludes the paper and provides recommendations for future research.

## 2. Multimodal transport

Multimodal transport refers to the transportation of goods by two or more different modes of transport (such as road, rail, air or inland waterway, and short- or deep-sea shipping) as part of the contract where often a multimodal transport operator (MTO) is responsible for the performance of the entire haulage contract from shipping to destination (UN, 1980). The movement of goods could be within one country or international with additional procedures such as goods clearance at customs. Fig. 1 illustrates the whole international transport process where goods are moved from a country A to final destination in country B and the

involvement of MTO during their journey. Its aim is to transfer goods in a continuous flow through the entire transport chain to make a transportation journey more efficient from a financial, environmental and time perspective (Beresford et al., 2006; Chao, 2011; SteadieSeifi et al., 2014). With the massive growth in containerisation and the great shift in thinking from a conventional unimodal to a system concept multimodal transport approach, multimodal is currently the main method used in the international transportation process as it enables the optimisation and organisation of all transport modes into an integrated continuous system in order to achieve operationally efficient and cost-effective delivery of goods in the supply chain.

Multimodal transport is often used interchangeably with terms such as intermodal, co-modal and synchromodal transport. But there are subtle differences between those terms; multimodal is considered as a type of transportation which uses at least two different modes of transport; intermodal can be seen as a particular type of multimodal transportation that uses the same loading unit (e.g. a TEU container), co-modal adds the efficient use of different modes (resource utilisation) and synchromodal emphasises the real-time aspect of the transport (SteadieSeifi et al., 2014; UN/ECE, 2001). In our paper we use the term multimodal in a broad sense, however other terms are also used occasionally in the context when we refer to specific works in the literature or to highlight the differences discussed above.

A combination of different features of each transport mode could place additional constraints on goods during transportation such as packaging, transportation conditions and storage. On the other hand, multimodal combines the specific advantages of each mode in one voyage, such as the flexibility of road haulage, the relatively large capacity of railways and the lower costs of short/deep-sea transport in the best possible way (Zaheer, 2008). Moreover, in comparison with road transport, which plays a relatively dominant role in the traditional freight transport industry in the UK, several alternative modes of transport, such as rail, inland waterway and short sea shipping, are widely recognised as being less harmful to the environment with regard to CO<sub>2</sub> emissions (Eng-Larsson and Kohn, 2012; Woodburn and Whiteing, 2012). Therefore, due to the advantage of multimodal transport as well as the increasing pressures to act on climate change through the reduction of carbon emissions, government studies have put more emphasis on transport mode shifts and the development of multimodal transport systems. For example, the European Commission proposes several measures aimed at developing a European transport system capable of shifting the balance between modes of transport and encouraging the use of multimodal transport (EC, 2011).

As well as having multiple characteristics of each mode, an added complication is the management of the whole seamless multimodal transportation process which is complex and involves different players such as freight forwarders, third-party logistic service providers, couriers, carriers of different modes of transport,

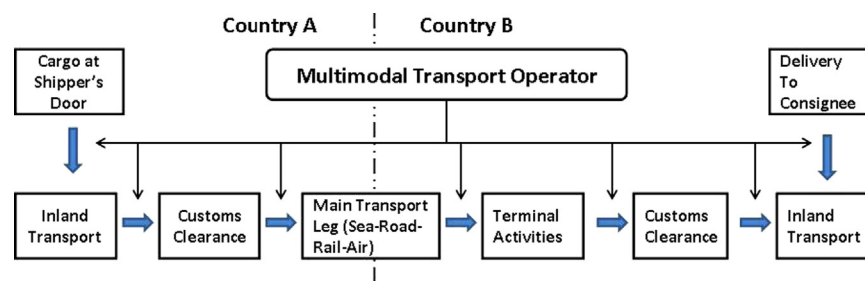


Fig. 1. Goods flow in a typical international multimodal transport chain.  
Source: Chao 2011

MTOs, rail, sea carriers, port and intermodal terminal operators (Marchet et al., 2009). The communication between these parties has to be accurate, timely and efficient to ensure the flawless and visible delivery process which could be challenging due to different technologies being deployed by different companies. The diverse nature of managing the multimodal transport chain is supported by a number of activities where each phase needs to be optimised and possibly integrated with other activities for effective and efficient business operations: transportation order handling (delivery schedule, forecasting); prepare the transportation chain (select and contract actor services); prepare transportation (loading, customs); perform transportation (reports on unloading, loading, damage); monitor transportation (track vehicles and drivers' behaviour); and terminal operations (control loading/unloading, manage stock terminal) (INFOLOG, 1999). The range of activities varies from resource management and port operations to fleet and freight management processes that need to be supported by appropriate ICT solutions.

### 3. Method

Our study is mainly qualitative and explorative in nature utilising a variety of secondary resources. Our research approach is visualised in Fig. 2. While academic literature is consulted intensively to discuss, for instance, multimodal transport and barriers to ICT adoption, we found it offers limited insights regarding existing and emerging ICT developments in the field of multimodal transport. Therefore in our paper, we use major EU framework projects (FP) to showcase recent developments of ICT developments in multimodal transport. Our rationale is that as the landscape of ICT develops and changes very quickly, purely relying on journal publications provide a rather dated and narrow view of the literature. Projects sponsored by EU framework programmes represent the current major efforts to address the need to adopt ICT for multimodal transport at the European level and inform the cutting edge developments in this field, therefore offering us a more comprehensive and accurate picture of the current state of ICT adoption in the provision and management of multimodal transport.

A list of EU projects under the 4th, 5th, 6th and 7th Framework Programme through the European Commission's Community Research and Development Information Service portal (CORDIS, <http://cordis.europa.eu>) and Transport Research and Innovation Portal (TRIP), ([www.transport-research.info](http://www.transport-research.info)) were identified and scrutinised in depth. In total, 33 projects were finally selected for a review of current ICT development initiatives. The selected projects are multimodal (intermodal) with a focus on specific ICT applications to address certain challenges facing multimodal transport. The data were collected via CORDIS and TRIP project archives and the projects' own websites. A repository was established consisting of essential project details such as web addresses, background, aims, work packages and deliverables. Projects were then grouped together based on the nature of the problems they intended to tackle. Such information enables us to be able to establish a fairly comprehensive understanding of past and current technological focuses and the issues they attempted to address.

With regards to the future technological trends that we have identified for an analysis of how those advances impact on barriers to ICT adoption, they have been deducted mainly from our close observation of ICT developments in industries, as academic

literature tends to lag behind those innovations. Authors have been researching in the field of ICT deployment for logistics and transport for the past decade. Innovative practices from IT pioneers and technology service providers such as IBM, Google, SAP, GT Nexus, Descartes, Facebook and Yammer were closely followed and scrutinised. Best practices or early adopting examples emerged from both shippers and carriers and other parties in the multimodal chain were studied. Meanwhile, we also consulted developments from other disciplines such as e-commerce (for example, Rainer and Cegielski, 2011; McAfee, 2011; Laudon and Laudon, 2012; Cegielski et al., 2012). The use for industrial forums such as the Chartered Institute for IT ([www.bcs.org](http://www.bcs.org)), the Chartered Institute of Logistics and Transport ([www.ciltuk.org.uk](http://www.ciltuk.org.uk)), the Automotive Telematics Forum, UK ICT and Transport Knowledge Transfer Networks (<https://connect.innovateuk.org/web/ict-ktm> and <https://connect.innovateuk.org/web/transportktm>) provided us with further insights. The accumulated knowledge has enabled us to cluster our observations into four trends which we believe encapsulate the key developments of ICT in multimodal transport. These four trends were categorised by the nature of the technologies.

### 4. ICT in multimodal transport

Historically, the use of ICT in transport and logistics started in the 1960s. Typical examples are inventory management systems, transport routing, scheduling, also known as Distribution Requirement Planning, and billing systems. These systems are usually function-based and thus are independent of each other. Since the 1970s, Material Requirements Planning (MRP) and Manufacturing Resource Planning (MRP II) emerged in an attempt to integrate materials, labour and financial requirements into the system. This then led to the development of Enterprise Resource Planning (ERP) system in the 1990s. Parallel to the development of such enterprise-wide systems, the development of inter-organisational systems did not flourish until after the Internet being commercialised in 1995. Prior to this, Electronic data interchange (EDI), had been dominating inter-organisational connections since 1960s. Internet-based IOSs have grown significantly since the late 1990s, facilitated by rapid ICT developments. Rather than the costly and complex point-to-point integration of separate systems, Web-based systems are designed for participants to share a single system. Such technological advances accelerated and boosted the development of new e-business models such as electronic marketplace (EM) (Grieger, 2003).

The academic literature provided a rich overview of ICT applications in the road transport industry, which is the most common and relatively effective mode in terms of speed, directness and flexibility compared to other modes (Giannopoulos, 2004; DfT, 2006; Davies et al., 2007; Marchet et al., 2009; Coronado et al., 2009; Perego et al., 2011). The DfT (2006) examines many advanced IT applications used in road transport (such as supply chain planning and management systems, vehicle tracking systems and fuel recording systems) for achieving efficient road freight operations. Moreover, Davies et al. (2007) focuses on the impact of the Internet on freight exchanges and ICT applications on general haulage in the UK which indicates that many smaller haulage operators in the UK remain dependent upon traditional communication and process systems, whilst the larger logistics companies are increasingly developing new ways of working supported by advanced ICT applications.

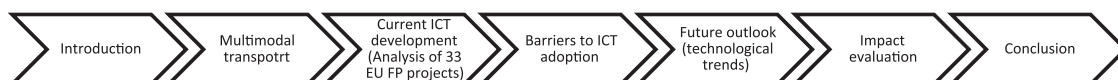


Fig. 2. Research approach.  
Source: authors

As for multimodal transport, [Boschian et al. \(2009\)](#) and [Dotoli et al. \(2010\)](#) indicate that ICT has a huge potential for efficient, effective and reliable real-time management and operations of multimodal freight transport. Most academic publications focus on a particular type of technology or an application in multimodal transport ([Dullaert et al., 2009](#); [Bock, 2010](#); [Coronado et al., 2009](#); [Kengpol et al., 2012](#)). For example, [Dullaert et al. \(2009\)](#) present an intelligent agent-based expert communication platform in order to increase cost efficiency, service and safety for various transport-related actors. [Bock \(2010\)](#) proposes a new real-time-oriented control approach for freight forwarder transportation networks, which integrates multimodal transportation and multiple transshipments, to expand load consolidation, reduce empty vehicle trips, and handle dynamic disturbances. [Coronado et al. \(2009\)](#) examine the feasibility of using vehicular network technology and dedicated short range communication (DSRC) to enhance the visibility and connectivity in the multimodal logistics environment through utilising secure access architecture.

However, few studies have examined the current application of ICT from the viewpoint of multimodal transport as a whole, with the exceptions of [Giannopoulos \(2004\)](#) and [Perego et al. \(2011\)](#). Both papers did not specifically address ICT developments in facilitating multimodal freight transport provisions and execution. Rather than conducting a purely academic literature review of current academic publications which offers rather limited insights, we have adopted a different approach where we have reviewed and scrutinised in depth EU projects (as shown in [Table 1](#)) as we discuss in [Section 3](#). Those diverse ranges of ICT initiatives under EU framework programmes to support multimodal operations could be categorised into the following main types following [TAP \(2000\)](#) classification: freight resource management systems and applications, terminal and port information and communication systems and applications, freight and fleet tracking and management systems and applications and integrated operational/information exchange platform/portal/marketplace. [Table 1](#) presents a summary of selected EU FP projects that focus on the development of ICT solutions within the multimodal setting. In the table we have also included a description of the potential benefits of using these applications where selected projects are discussed in more detail as supporting examples.

*Freight resource management systems and applications* deploy solutions for effective and efficient use of resources supporting an organisation and focus on optimisation and execution of resources supporting infrastructure, equipment and production, financial transactions, human resources, transportation planning optimisation, vehicle routing and scheduling and other. The objective of these applications is to achieve a match between supply (e.g. transport orders) and demand (e.g. transport capacities including vehicles, drivers and related storage areas) at minimum cost with information consolidation at the dispatchers site and the optimal matching of orders to vehicles ([TAP, 2000](#)). For example, the project F-MAN developed a prototype of a telematics system that provides wagon position and status information to allow the fleet manager (rail) to carry out an economic selection of “his” wagons and update that decision if the wagon is delayed ([F-MAN, 2005](#)). The [MarNIS \(2009\)](#) project represents the Maritime Information Management and Maritime Operational Services concepts for port traffic management, maritime operation services and maritime information management.

*Terminal and Port information and communication systems and applications* support intermodal terminal and port operations where transportation movement is temporarily interrupted and freight is changing transportation mode as well as responsibility for certain transshipment times and related costs ([TAP, 2000](#)). Road haulers, railway operators, port authorities, cargo handling companies and customs are among the existing participants of intermodal terminals which could be seaports, river ports, dry ports

and inland container depots. Single window system, often initiated by government bodies, is a popular concept in this regard, which allows traders to submit all import, export, and transit information required by regulatory agencies via a single electronic gateway, instead of submitting and processing the same information many times to different government entities ([Choi, 2011](#)). For example uTradehub in Korea and TradeNet in Singapore represent such initiatives. At individual terminal or port level, FP projects such as the CHINOS (Container handling in intermodal nodes) project ([CHINOS, 2009](#)), address challenges faced by container terminal and transport operators due to security issues and cargo volumes through innovative IT technology such as RFID. The Metrocargo Intermodal Transport ([MIT, 2011](#)) project aims to scale up to a full industrial installation of a fully automated system for the distributed intermodal transport over a territory and for processing full trains in port/dry-port shuttling.

*Freight and Fleet tracking and management systems and applications* aim to reduce uncertainty in every link of the multimodal transport chain and improve operational efficiency between modes of connection. ICT management systems enable the tracking, monitoring and controlling of cargo and vehicles: they are underpinned by the appropriate reporting tools and based on real-time related information through the integration of various technologies such as on-board computers, web-based tools and short-range identification technologies. For example, the focus of the D2D project ([D2D, 2005](#)) is on an integrated and global management system for door-to-door intermodal transport operations through the development of a transport chain management system, a freight transport monitoring system and the application of “smart technologies” to improve the efficiency of multimodal transport operations. The main objective of the M-TRADE project ([M-TRADE, 2007](#)) is an integrated end-to-end system providing services related to tracking and tracing goods, the identification of freight and efficient transshipment at terminals and nodes and monitoring transportation of hazardous and perishable goods. A container door-to-door transport chain is conducted through the use of advanced technology in the SMART-CM project ([SMART-CM, 2011](#)).

*Integrated operational/information exchange Platform/Portal/Marketplace* intend to improve overall performance of multimodal transport to create a seamless and secure information system by interconnecting developments in mobile and wireless communications, tracking and tracing, fleet and freight management and Internet-based technologies. Integrated platforms aim to link all actors together to allow cooperation, collaboration and information sharing from the point of dispatch to the point of arrival. Global Intermodal Freight Transport System (GIFTS) framework aims to improve and integrate existing and emerging intermodal freight transport technologies into one internet platform (the GIFTS Integrated operational Platform – GIP) focusing on small and medium players ([GIFTS, 2004](#)). Applications support activities related to administrative services, freight transport and operational monitoring and control functions and E-Commerce services. Within the KOMODA project, the architecture for a visionary Europe-wide e-Logistics system has been proposed in order to optimise the logistics chain through ICT and co-modality. The e-FREIGHT project aims to achieve optimal and sustainable deployment of European freight transport resources through e-Freight Platform that provides a repository of e-Freight solutions and services and a “run-time” environment to support interaction with solutions ([e-FREIGHT, 2011](#)).

## 5. Barriers related to ICT adoption

The positive role of ICT in improving the overall performance, visibility and communication between multimodal



**Table 1**A review of EU FP projects in ICT developments for multimodal transport (source: authors, based on [TAP \(2000\)](#)).

ICT application	Potential benefits	Exemplar EU FP projects
<b>Freight resource management systems and applications</b>	<ul style="list-style-type: none"> <li>● Improved operational efficiency</li> <li>● Reduced empty runs through better route planning</li> <li>● Improved utilisation of transport infrastructure</li> <li>● Improved customer satisfaction</li> <li>● Reduced overall costs due to vehicle optimisation</li> </ul>	<ol style="list-style-type: none"> <li>1. Intra-company resource management system (COREM, 1996–1998, <a href="#">COREM (1996)</a>)</li> <li>2. Integrated route planning with mobile communication (SURFF, 1996–1998, <a href="#">SURFF (1996)</a>)</li> <li>3. Information exchange and freight resource management in multimodal transport (WELCOM, 1996–1996, <a href="#">WELCOM (1996)</a>)</li> <li>4. Telematics and software system to support expanding national and trans-European traffic planning needs (EUROPE-TRIS, 1996–1999, <a href="#">EUROPE-TRIS (1996)</a>)</li> <li>5. Automatic, optimal and intelligent warehouse- and (un-) loading system for small inland vessels (IWV, 2000–2001, <a href="#">IWV (2000)</a>)</li> <li>6. Telematics system for rail car asset management (F-MAN 2001–2004, <a href="#">F-MAN (2005)</a>)</li> <li>7. Maritime navigation and information services (MarNIS 2004–2008, <a href="#">MarNIS (2009)</a>); port traffic management, maritime operation services and maritime information management</li> </ol>
<b>Terminal &amp; Port information and communication systems and applications</b>	<ul style="list-style-type: none"> <li>● Reduced loading- and unloading time at intermodal terminal due to advanced terminal operation systems</li> <li>● Improved utilisation of intermodal terminal infrastructure</li> <li>● Improved, efficient interfaces between different modes at transshipment points for achieving seamless transfer of cargo</li> <li>● Reduced operation costs</li> <li>● Improved customer service and satisfaction</li> </ul>	<ol style="list-style-type: none"> <li>8. Cargo pre-notification system, Container identification &amp; location system and Ferry reservation system (COREM, 1996–1998, <a href="#">COREM (1996)</a>)</li> <li>9. Automatic Equipment Identification for monitoring load units, vehicle and staff (INTERPORT, 1996–1998, <a href="#">INTERPORT (1996)</a>)</li> <li>10. Logistics Information &amp; Communication System for intermodal cargo terminals (EUROSCOPE, 1996–1998, <a href="#">EUROSCOPE (1996)</a>)</li> <li>11. Information exchange between road freight transport and freight centre operators (SURFF, 1996–1998, <a href="#">SURFF (1996)</a>)</li> <li>12. ICT tools and services for easing the mandatory data supply and data delivery to improve the integration of ports into intermodal transport chains (IP, Intermodal Portal 2000–2001, <a href="#">IP (2000)</a>)</li> <li>13. Container Handling in Intermodal Nodes (CHINOS, 2006–2009, <a href="#">CHINOS (2009)</a>)</li> <li>14. Integrated ICT tools to support logistic and business operations in the port and dry port areas (SAIL, 2010–2014, <a href="#">SAIL (2010)</a>)</li> <li>15. Fully automated system for the distributed intermodal transport over a territory and for processing full trains in port to dry-port (MIT, 2011–2013, <a href="#">MIT (2011)</a>)</li> </ol>
<b>Freight and Fleet tracking and management systems and applications</b>	<ul style="list-style-type: none"> <li>● Enabling operators to monitor and manage the cargo and vehicle, as well as obtain up-to-date information</li> <li>● Improved utilisation of intermodal terminal infrastructure</li> <li>● Improved customer service through better communication and providing sufficient and real-time information regarding cargo and shipment</li> <li>● Improved security and safety procedures</li> <li>● Shorter lead time, resulting in a reduction in inventory</li> </ul>	<ol style="list-style-type: none"> <li>16. Intermodal Fleet and Cargo-Monitoring System (MULTITRACK, 1996–1998, <a href="#">MULTITRACK (1996)</a>)</li> <li>17. Cargo Supervision System (<a href="#">TRACAR, 1996–1998, TRACAR (1996)</a>)</li> <li>18. Tracking and tracing services (ParcelCall, 2000–2001, <a href="#">ParcelCall (2000)</a>)</li> <li>19. Integrated and global management system for door-to-door intermodal transport operations: transport chain monitoring system and freight transport monitoring systems (D2D, 2002–2005, <a href="#">D2D (2005)</a>)</li> <li>20. Integrated end-to-end system: goods tracking &amp; tracing, freight identification, efficient transshipment at terminals and node, monitoring the transport of hazardous and perishable goods (M-TRADE 2005–2006, <a href="#">M-TRADE (2007)</a>)</li> <li>21. Intelligent cargo infrastructure (EURIDICE, 2008–2011, <a href="#">EURIDICE (2008)</a>)</li> <li>22. Intermodal global door-to-door container supply chain visibility (INTEGRITY, 2008–2011, <a href="#">INTEGRITY (2011)</a>)</li> <li>23. Global container chain management (SMART-CM, 2008–2011, <a href="#">SMART-CM (2011)</a>)</li> <li>24. Container security through visibility (CASSANDRA, 2011–2014, <a href="#">CASSANDRA (2011)</a>)</li> </ol>
<b>Integrated operational/ information exchange Platform/Portal/ Marketplace</b>	<ul style="list-style-type: none"> <li>● Electronic one-stop-shop marketplace for all parties along the multimodal chain, enabling them to provide bespoke services and accelerate data and information exchange between the participants</li> <li>● Allow the related authorities (e.g. customs and port authority) to interact with the operators and exchange information and transport-related documentation</li> </ul>	<ol style="list-style-type: none"> <li>25. E-commerce system: booking, scheduling, negotiation, brokerage, payment and invoicing data; connect intermodal users in short-sea shipping (DOLPHINS, 2000–2001, <a href="#">DOLPHINS (2000)</a>)</li> <li>26. Integration of intelligent traffic management systems with the freight transport management systems operation, including intermodal freight transport (THEMIS, 2000–2004, <a href="#">THEMIS (2000)</a>)</li> <li>27. Integrated logistic networks and operational platform with inland navigation (ALSO DANUBE, 2000–2003, <a href="#">ALSO DANUBE (2000)</a>)</li> <li>28. Integrated Operational Platform accessible to the Small and Medium players (GIFTS, 2001–2004, <a href="#">GIFTS (2004)</a>)</li> <li>29. European Intelligent Transport System Framework Architecture (E-FRAME, 2008–2011, <a href="#">E-FRAME (2008)</a>)</li> <li>30. Generic system architecture for intermodal transport bringing together transport management, traffic and infrastructure management and administration (FREIGHTWISE 2006–2010, <a href="#">FREIGHTWISE (2006)</a>)</li> <li>31. Roadmap of an integrated many-to-many e-logistics system in Europe. (KOMODA 2008–2009, <a href="#">KOMODA (2009)</a>)</li> <li>32. e-Freight Framework to facilitate paperless information exchange among all EU freight transport stakeholders (e-FREIGHT 2010–2013, <a href="#">e-FREIGHT(2011)</a>)</li> <li>33. Support new intermodal logistics services: synchronise vehicle movements and logistics operations; adapt to changes through an intelligent cargo concept and develop an open freight management ecosystem (iCargo 2011–2015, <a href="#">iCargo (2011)</a>)</li> </ol>

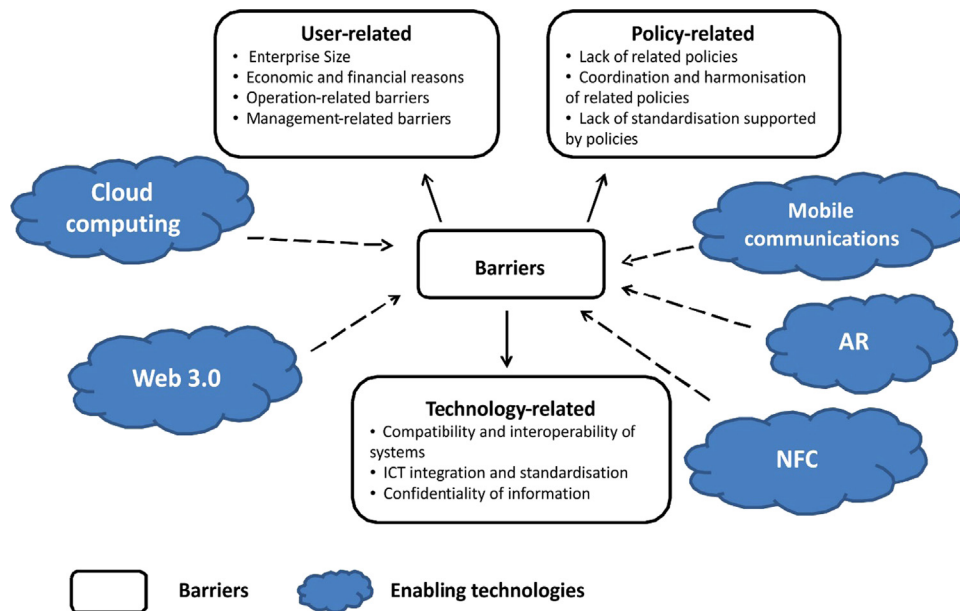


Fig. 3. Barriers to ICT adoption in multimodal transport (based on KOMODA 2009).

transport operators has been recognised by many stakeholders, but there also exist many barriers to the adoption of ICT which vary from mode to mode (Coronado et al., 2009) and company to company, especially between small and large enterprises (Pokharel, 2005). Based on the literature review, we identified several factors inhibiting ICT adoption according to their area of impact which can be classified into three categories following KOMODA (2009): user-related, technology-related, and policy-related barriers (Fig. 3). This section will examine in-depth the barriers and associated factors to ICT adoption with the focus on its impact on multimodal transport. It should be noted that the users here are transport-related organisations involved in multimodal operations, authorities and companies who employ ICT applications in their daily operation and management.

### 5.1. Barriers to ICT implementation

The *user-related* barriers include economic, operational, managerial barriers and relate to the company's environment. Traditionally, the size of the company plays a crucial role in the level of ICT implementation where small and medium size enterprises (SME) are more likely to have constraints on financial, human resources and ICT expertise leading to a greater probability of not being able to "afford" appropriate solutions compared to larger enterprises (Kuan et al., 2001; Stefansson, 2002; Harindranath et al., 2008). This could lead to a loss of confidence and reduce the overall use of ICT applications in their daily operations and management (Pokharel, 2005). There are several examples in the literature illustrating a higher level of ICT implementation in the larger companies compared to small enterprises that mainly depend on traditional communication and processing systems (Davies et al., 2007; Pokharel, 2005). It is also been noted that ICT management in SME often depends on short-term, informal and ad hoc practices (Rantapuska and Ihanainen, 2008) where large companies have capabilities to develop bespoke applications or platforms for their business needs.

The economic and financial factors are another constraint, including large investment requirements, the implementation costs, managing and maintenance costs, as well as the unfavourable financial conditions of relevant companies (Evangelista and Sweeney, 2006; Hollenstein, 2004; Zeimpekis et al., 2006;

KOMODA, 2009). Evangelista and Sweeney (2006) examined 153 firms from the Italian transport and logistics industry where high investment costs and high running costs rank as the top two factors inhibiting ICT adoption. These barriers are more obvious in the SMEs, especially for those with a relatively low turnover and inadequate resources.

Operation-related barriers are discussed by several researchers (Pokharel, 2005; Hollenstein, 2004; Zeimpekis et al., 2006) and include human capital issues such as difficulty in employing qualified personnel, lack of ICT specialists, and personnel skill shortage to operate new applications, as well as insufficient ICT-oriented training and educational activities. In particular, due to the scarcity of high skilled workers and specialists and the limited career advancement prospects (Kuan et al., 2001), the small transport-related companies may suffer disproportionately from these types of barriers. Moreover, in some companies, especially traditional firms, personnel reluctance to change or to learn new technology are also identified as a barrier (Huckridge et al., 2010; Perego et al., 2011).

Management capability has a large impact on how companies perceive the adoption of ICT. For example, the uncertainty of commercial success with regard to ICT applications, including a lack of knowledge on payback times and unclear returns on investment, seems to act as an obstacle hindering organisations from investing and implementing ICT applications in multimodal transport (Evangelista and Sweeney, 2006; KOMODA, 2009). In addition, unfamiliarity with the commercially available ICT applications and difficulty in quantifying the potential benefits of ICT (Pokharel, 2005), as well as deficient strategic orientation of ICT management (Hollenstein, 2004) could lead to the inadequate adoption or inappropriate use of ICT applications in daily operations and management. Therefore it may not be utilised efficiently and effectively to facilitate the whole multimodal transport process.

The *technology-related* barriers relate to the technological constraints that prevent operators making full utilisation of ICT applications, including the issues such as interoperability of systems, ICT integration, standardisation, security and data protection (DISCWISE, 2012). Due to the unique characteristics of multimodal transport involving different modes of transport and various related actors into one coherent transport system, the

technology-related barriers mainly stem from the series of difficulties arising from the need for interaction among various related actors, as well as the differences in the way each actor operates (PROMIT, 2009).

There are different levels of ICT penetration in every mode of transport or among different stakeholders along the multimodal transport chain (PROMIT, 2009; KOMODA, 2009). Moreover, each of the operators may have different separate ICT applications provided by various technology service providers (e.g. IBM and ORACLE), focusing on particular individual needs. According to the PROMIT (2009), low compatibility may exist between these ICT applications thus serving as a key barrier to the interconnectivity between different applications and integration with future applications. Issues of this nature will negatively affect the cooperation and collaboration of all actors in the multimodal transport process.

The issue related to a lack of homogenous ICT standards has an impact on the development of systems for the entire multimodal transport chain and for unimodal operations (Evangelista and Sweeney, 2006; PROMIT, 2009; KOMODA, 2009). The challenges are extended from the integration of all related modes of transport into a single application without standardisation (KOMODA, 2009); integrating ICT applications with legacy systems (GIFTS, 2004; Hollenstein, 2004; Pokharel, 2005; Zeimpekis et al., 2006; Perego et al., 2011); and the cost of installing and integrating new technology (Jakobs et al., 2001; Pokharel, 2005). The interconnectivity of applications used by different actors in multimodal transport is of vital importance for reliable and efficient cargo movement (PROMIT, 2009). Therefore integrating customer and partner applications is also considered as a significant barrier to ICT adoption (Piplani et al., 2004; Pokharel, 2005).

Other barriers include the influence of other actors in multimodal transport, long implementation for ICT projects and lack of data transmission interoperability. The presumed length of time required for full implementation of ICT and rapid obsolescence of technology are also identified in some research within the freight transport industry as barriers to ICT implementation (Piplani et al., 2004; Pokharel, 2005; Perego et al., 2011). According to PROMIT (2009), the lack of data transmission interoperability is mainly caused by the unwillingness of stakeholders to cooperate with each other. For instance, the reluctance of sharing related information with their counterparts hinders some haulage operators from participating in the open Electronic Logistics Marketplaces (ELMs). In addition, the lack of trust in online transactions and consideration for the security and liability issues regarding the information to be exchanged may be regarded as an obstacle to the adoption of Internet-based applications.

The *policy-related* barriers relate to the coordination and harmonisation of different policy levels which could prove to be an effective enabler for facilitating some new technologies or methods implemented through specific regulation. Tsamboulas et al. (2007) assessed the potential effects of related policies on intermodal transport from the European perspective, and indicate that policies should be designed to improve productivity and efficiency of intermodal transport through technological and organisational enhancement. Due to the nature of multimodal transport that mainly deals with international freight transport, it is likely that each country will have their own policies which could have an impact on ICT adoption. KOMODA (2009) and INTEGRITY (2011) pose different barriers with aspects related to policy including different legal requirements and customs regulations in different countries; various regulations for every transport mode; different safety and security standards or regulations between transport modes as well as countries; different legal frameworks according to cargo category; different administrative procedures and standards between countries; and insufficient harmonisation of national and European policies between

transport modes. Furthermore, standardised interfaces and open communications mechanisms for the adoption of ICT in multimodal transport also require promotion and support from related policies both on a national and EU level (PROMIT, 2009). As a result, there is an urgent need to coordinate and harmonise these fragmented and isolated policies which impact negatively on ICT implementation in different countries in order to ensure efficient and reliable transnational freight transport operations. Although several action plans and policy packages relating to ICT and intermodal transport issues have been published by the European Commission (EC, 2011), there is still a lack of coordination and synergy between stakeholders and related member states (KOMODA, 2009).

## 6. Technological trends

The current application of ICT in multimodal transport and in freight transport in general is largely supported by and dependent on a number of enabling technologies. Some of these technological drivers such as transport management system (TMS) could be considered as mature and well established in the commercial environment, while others are still emerging or in their infancy. The majority of such technologies in the freight sector were developed in the 1990s and early 2000s (Perego et al., 2011), and form the core of current ICT applications used in the field of transport (ENABLE, 2010a).

More recently, the rapid development of web technologies has also triggered the emergence of a new concept called “cloud computing (Weber, 2010)”. Under cloud computing, ICT systems can be hosted by a third party and user companies just “plug in and play”. Offering greater flexibility, cloud computing also enables not only large companies but also small and medium sized companies to use the system. Parallel to this is the ever increasing use of wireless communication technologies (such as smart mobile phones, QR code, RFID and telematics tracking). As computing power is increasing exponentially and smart devices are getting smaller, more affordable and capable, this will allow people, as well as devices, to be connected anywhere at any time. Such ubiquitous connectivity and network services enable real time and extended visibility across supply chains which is critical for dealing with rising uncertainty and complexity in a multimodal environment.

Meanwhile, the rise of social media networking enabled by recent advances in web technologies has revolutionised the way we communicate. Switching from dyadic one-to-one communication to simultaneous one-to-many communication changes the way supply chains are structured and information is shared, and thus has significant implications for transport provision and execution. Advances in interface technologies have fostered a breed of new applications. For instance, hands-free operation and voice control has gained popularity recently in the logistics industry. Emerging concepts such as augmented reality is still in its infancy but has been piloted for use in some industries such as retailing and construction.

Although widely considered as the next-generation technical advances in practice (Dubey and Wagle, 2007; Lynch, 2005; O'Sullivan 2007; Viswanathan et al., 2007), our understanding of these new business models and concepts from an academic perspective is very limited. We shall therefore endeavour to bring our understanding of recent ICT advances up-to-date and explore the potential impact of these emerging technologies on reducing multimodal transport barriers to ICT adoption as discussed in Section 5 and illustrated in Fig. 3. By doing so, we hope to provoke debate or further exploration by practitioners and academia of these emerging technological developments.

### 6.1. Cloud computing

The need to invest in IT infrastructures and purchasing expensive hardware and software solutions could be prohibitive to the of efficient business practices. *Cloud computing* is a service provided by IT experts that acts as an alternative to the ongoing high-cost of investment into IT resources and management which minimises technology- and in particular user-related barriers. Tapping into already existing data centres, processing applications and specific on-demand solutions (software as infrastructure, software as a platform and software as a service) will integrate the latest network and database technologies to provide information services to make them flexible and accessible. The companies using cloud computing will only need to pay for specific computing resources on an as-needed basis, accessing them on-demand via a web-based interface using smart phones, computers and other devices. *Software as a service (SaaS)* is becoming a popular way of accessing specific software on-demand through an Internet browser via a fixed or per usage subscription fee (O'Sullivan, 2007).

By using technology in the cloud as a service, organisations are freed from the burden of managing the complexities of ICT applications and are able to focus on their core business strategies. This is of strategic importance to small and medium enterprises which otherwise cannot afford or do not have in-house capability and expertise to deploy sufficient ICT solutions to support business needs. On the other hand, the users of on-demand services should also be aware of the security implications before using these facilities where cost gains could be offset by potential risks. For example, IAS (2013) developed a suite of on demand integrated transportation management applications based on best practice which could be implemented to allow their customers to gain immediate benefits from connecting to intermodal partners. The system utilises a number of industry standards and integrates with a number of commercial and bespoke software packages.

A typical example using cloud computing in a multimodal transport environment is a *cloud-based* Electronic Logistics Marketplace. ELMs are web-based ICT systems that link shippers, carriers and customers together for spot trading of transport services (known as open ELM) or for information sharing and long term collaboration (known as closed ELM) (Wang et al., 2007). The traditional method of communication between shippers and carriers, and between shippers (consignors) and their customers (consignees) are dyadic in nature and fragmented. For example, if the customer wants to track down a particular consignment, they would have to contact the shipper, who would then contact the relevant carrier to get an update. If a freight forwarder is involved, the process would be even more complicated. The lack of visibility and delays in communication often lead to a fire-fighting approach when something goes wrong.

Fig. 4 demonstrates how a closed ELM can be used to manage the order-fulfilment process and speed up communications across the whole supply chain. The process starts with the customer generating a purchasing order in the ELM and the order is automatically transferred to the shipper. Following this, transport planning and execution takes place between the shipper and carrier. During the goods-in-transit period, the system gives a constant update on the status of this consignment (for instance via real time tracking using GPS) to all parties involved. A closed ELM could be either hosted in house or by a third party technology service provider based on cloud computing. The latter is often referred to as a *cloud-based* ELM. One of the major advantages of using a *cloud-based* ELM is that it provides centralised management of all the data relating to a particular consignment. Therefore, any change can be simultaneously communicated to all the different parties involved. This increased visibility enables companies to be in more control of the supply chain and be proactive

in responding to exceptional events. The system can also facilitate financial settlements and performance reviews such as total delivery cost and on-time delivery. By changing the structure of communications between shippers, carriers, an ELM integrates various modes of transport into an inter-connected streamlined supply chain and brings multiple benefits including cost reduction and customer service improvement (Wang et al., 2007).

### 6.2. Wireless/mobile communication technologies and Internet of Things

To allow operators to track individual assets/containers within multimodal freight operations and to access further information on cargo, such as the temperature and humidity for frozen or liquid goods or a vehicle's mechanical condition, radio-frequency identification (RFID) tags with embedded microchips, are used (Wang and Potter 2007; ENABLE, 2010a; 2010b; Ferrer et al., 2010). Yuan and Huang (2008) discuss a new integrated solution that integrates passive RFID and GPS container tracking of long distance cargo to enhance supply chain visibility and security. Recent emergence of *near field communication (NFC)*, which is based on RFID technology, is perceived to be the next step in the way companies operate. NFC enables quick and easy wireless data transfer within close proximity using smart phone technology and already includes applications for making payments using mobile phones.

Jones (2011) argues that RFID does not stand out against other legacy systems used by companies thereby leading to its limited use in the auto-id market. Furthermore, Jones states that RFID technology is extensively used for identification and security in the Business to Business (B2B) market whereas NFC has a wide range of applications for Business to Consumers (B2C). The potential for development of further applications using NFC technology in a supply chain and/or for multimodal transport are vast. The need to purchase or develop specialist handheld devices which could hinder integration and the creation of a seamless flow of goods could be replaced by developing smart mobile applications using an NFC framework and everyday cheaper mobile devices. For example, the driver arriving at the terminal could scan his mobile phone using an installed application to notify the operator of their arrival and then receive instant feedback on the mobile device as to where to unload the goods. If the mobile device is GPS-enabled it could automatically inform the driver of their next task. The application could extend to faster customs clearance, tracking goods at any point in time, and instructions for dealing with hazardous goods. A range of barriers to ICT adoption could be lifted by the technology including but not limited to the size of the company, integration visibility issues, and financial constraints.

Container tracking is another area of Internet of Things application. Container tracking usually relies on RFID tags which are attached to the containers, boxes and pallets included in the shipment and then read at a number of points along the way. The limitation of using RFID only for container tracking is that data can only be captured where appropriate infrastructures such as RFID readers are in place. Recently a new breed of container tracking devices has been developed. They feature several sensors that can operate simultaneously, and offer a range of tracking, security and monitoring functionality (Smith and Hale, 2010). These devices are equipped with onboard photoelectric sensors to monitor changes in the light level within a container (indicating that a container has been opened or breached), accelerometers that detect impact and GPS modules for location tracking. They are also able to access GSM networks and SMS channels to send text or email alerts when waypoints are reached or anomalies occur, i. e. a container can be tracked in real time in any part of the world.



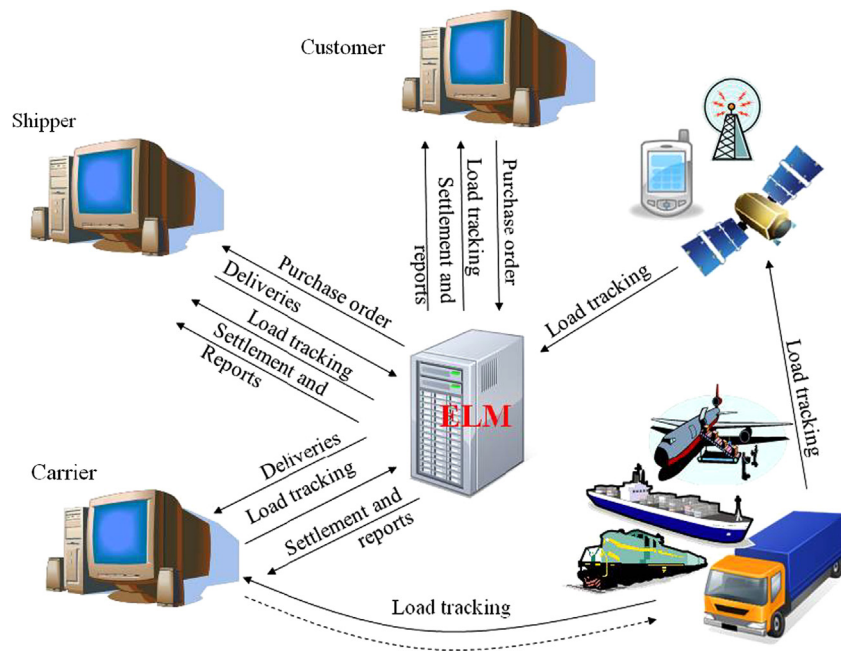


Fig. 4. An overview of a closed ELM operational model.

Source: Wang et al. 2010

All the sensor data is available to shippers, consignees, third party logistics providers and/or customs as well as terminal and port authorities, via proprietary web and mobile interfaces. A typical example is the container tracking system developed by Maersk and IBM (Maersk, 2005; BDP1, 2005) known as tamper-resistant embedded controllers, or Trecs, for large shipping containers. The Trecs are supported by back-end software and a wireless network, and a sensor system gives shippers a remote view of the state of their cargo in transit. The data can be sent via antennas on a container roof over short-range wireless networks such as Zigbee or Bluetooth, and over longer-range mobile and satellite networks. Such systems give multimodal transport users the opportunity to manage their supply chain more easily and to make changes in advance of cargo arriving at its destination.

### 6.3. Web3.0 and social networking

The evolvement of the Web has opened up even more opportunities for supply chain management to take advantage of the information available to them. Web 3.0 takes it to the a higher level and companies need to be prepared to analyse information on the trends and preferences of their customers quickly and efficiently. Web 3.0 provides the infrastructural framework supported by a new wave of languages such as SPARQL, SWRL, RDF to allow intelligent, contextual decisions of the semantic Web with the Internet of Things to connect different devices to create an informative stream of data (BOOZ and CO, 2011). In relation to its application to multimodal transport, through a contextual search Web 3.0 capabilities could be applied to enable the identification and optimisation of the distribution flow of unladen trucks or cargo ships in a particular location.

The development of social networks should accelerate the development of the business network sector because of the nature of this communication which matches people with similar requirements and ideas to each other in a type of "hauler/user dating". This idea is sharply opposed to that of an auction where the highest or lowest bidder wins. With social networking, the truck, cargo ships or train best suited to the delivery requirements is recruited without compromising on cost

With social network sites such as Facebook and Twitter bringing revolutionary changes in the way individuals communicate, the same technological platform could be used in the transport and logistics environment to facilitate instant communications between various stakeholders. For example, a private social network for business called Yammer has recently gained momentum. Companies such as Tesco, Vodacom, LG Electronics have started to use it for intro-organisation communication. "Regular users at LG estimate Yammer saves them approximately three hours per week by getting quicker answers, developing solutions faster, and more effectively connecting with colleagues. (Laurence Smith, VP of Global Learning & Development at LG Electronics)". For business organisations, social media has helped them to be more effective and innovative in existing tasks such as project management, and staff communication. For instance, Tesco staff use Yammer to share best practices, often by posting photos and management teams use it operationally for sharing messages and asking for feedback (Tesco Annual Report 2012).

In a multimodal transport chain, it has been a challenging task to obtain an instant update of the status for a particular consignment, due to the fact that multiple players (consignors, consignees, freight forwarders, carriers) are involved in the physical execution of the consignment. Using a private social network to create a community where instant updates and sharing of information between various parties across geographies could largely reduce the time and cost of point-to-point communication. This online community portal concept could equally be applied to the context of ports or railway terminals, which often involves complex activities of receiving and dispatching vessels and freight trains as well as container yard management.

### 6.4. Advances in interface technologies

The latest development of augmented reality (AR) technology, where interactions with the real world environment are augmented by virtual images, graphics or other data could seen as another step in enhancing management of resources within the port or warehouse settings. For example, in the retail sector, Tesco has begun trials of augmented technology, where web cameras and

mobile devices are used to view life-size projections of products before buying them (Whiteaker, 2011). In the warehouse operations setting, KiSoft is an example of a picking system using AR technology which displays the information regarding location (optimising navigation) through a head mounted display (KNAPP, 2013). The advantages of the system include visual, error-free picking instructions with fully automated tracking of goods and serial numbers, adaptable to every warehouse without any structural changes.

Recently, Google announced the development of Google smart glasses, a voice controlled device/computer combined with augmented reality (Newman, 2012). The device will be equipped with GPS and motion sensors and interacts with the Internet using a natural language (Bilton, 2012). The built-in camera on the glasses streams images to Google computers and augmented reality information is displayed to the person wearing the glasses for a specific query. Some examples could include real time delivery maps displayed for a logistics provider; picking up goods en-route to support backhaul processes as relevant information will be displayed in real time; and its location-aware functionality could allow the delivery vehicle to check in easily and navigate around a port terminal.

Further applications of AR technology will connect the virtual world with reality to assist in more efficient decision making and minimising operations-related barriers. AR also has a potential application in rail freight operations by operators for assets and infrastructure management. GIS mapping coupled with building information modelling (*digital representation of physical and functional characteristics of a facility*) data and asset data help to create a “virtual” railway and offer rail operators as well as freight users the real time visibility of train movements.

## 7. “Big Data” and decision support systems for managing multimodal transport

While the aforementioned technological developments have brought increasing volume and detail of information captured by organisations, what matters more is how we can harness and capture the value from those large data sets (so called “Big Data”). The future of decision support systems (DSS) for managing multimodal transport lays in the real-time, dynamic and integrated nature of decision making with enhanced capabilities through the developments of technological trends discussed. Sophisticated analytics can substantially improve decision-making.

Major efforts in the existing literature have been focusing on areas such as terminal planning, vehicle scheduling, loading, route optimisation and network design. For instance, Caris et al. (2008) provide an overview of planning decisions and solution techniques in intermodal freight transport according to the level of the decision and their review includes integrated applications and decision support systems. Macharis et al. (2011) propose a decision support framework to analyse policies supporting the intermodal transport industry and applied to the location analysis of intermodal terminals. The framework has three models (NODUS, LAMBIT and SIMBA) that support the evaluation of different decisions for the optimal location of the new terminal, market area and potential of the new terminal and finally, it evaluates the impact on the waterways network performance. Kengpol et al. (2012) present a decision support system for the selection of multimodal transportation routing for logistics service providers and SMEs. The system is capable of optimising multimodal routing within the Greater Mekong sub-region countries through the integration of the Analytic Hierarchy Process and Zero-One Goal Programming.

Trends related to cloud computing, the Internet of Things together with business analytics will allow further enhancement of DSS capabilities and improve users’ accessibility to relevant features. In Table 1, we have presented our findings related to EU framework programme projects, such as e-Freight and iCargo, which already integrate “intelligence” and dynamic capabilities. Some research presents DSS for a static environment (Macharis et al., 2011; Kengpol et al., 2012) whereas a few recent academic papers incorporate a dynamic nature and in some cases business intelligence as part of their contribution. For example, Bock (2010) proposes a dynamic model, with a real-time-oriented control approach to allow the expansion of load consolidation, the reduction of empty vehicle trips, and handling of dynamic disturbances for freight forwarder transportation networks. The model integrates multimodal transport chains and multiple transshipments. Boschian et al. (2011) present a metamodeling framework for an integrated system (IS) to manage Intermodal Transportation Networks (ITN) at the tactical (offline mode) and operational levels (real time). There are two core modules in the system: an ITN reference model (knowledge base) and a simulation module that predicts the system’s behaviour and enables the IS to tune the proposed management strategies and choices. Dotoli et al. (2013) present a DSS for co-modal transportation for multiple route planning in real time with the consideration of conflicting multiple criteria (such as cost, time or gas emissions) that is based on the distributed multi-agent framework. The genetic algorithm is used to obtain user-vehicle-route combinations according to the users’ preferences. In addition, the system suggests solutions when the transportation is not available due to external factors such as strikes.

Leveraging and capturing the value derived by DSSs from deep and up-to-real-time information will offer competitiveness to multimodal players and most likely impact on their business bottom line. For instance, increased visibility would lead to organisations being more proactive if things go wrong. Consignees would be notified and alternative options could be developed to cope with uncertainties and disruptions. Real time positional tracking data using telematics would provide insights as to truck drivers’ behaviour and route optimisation. Automation in transactions would reduce the need for paper work and result in lead time reduction.

The challenge, however, lies in how to quickly analyse increasing volume of data (often loosely structured). Big data usually refers to very large data sets in the petabyte and exabyte range, i.e. billions to trillions of information from different resources. Traditional DSSs would often not be capable of managing and analysing those nontraditional data. One of the resolutions industries are taking up is to use Hadoop, an open source software framework for working with various big data sets. It breaks a big data set into smaller clusters, processing them distributedly, and then combines the results into a smaller data set that is easier to analyse (further information can be obtained via <http://www-01.ibm.com/software/data/infosphere/hadoop/>).

## 8. Impact evaluation

In this section, we attempt to evaluate current efforts poised at ICT deployment in multimodal transport based on the 33 EU projects discussed in Section 4 and predict the future impact of the four technological trends on the barriers related to ICT adoption for multimodal transport operations.

Note that it is not within the immediate remit of this paper to substantiate the impact of those technological trends on the performance of a multimodal chain, which will require a more rigorous approach rather than the proposed simple weighting

system. Ideally, for instance, a longitudinal case study should be conducted in order to examine in depth the impact of a specific technological adoption at organisational or supply chain level. This will enable us to quantify improvements (or otherwise) on a number of Key Performance Indicators (such as cost, lead time, adherence to schedule and quality) as well as other appealing aspects such as flexibility and agility.

However, given the fact that those technologies are still at their infancy stage and yet to see a wide industrial take-up in the transport industry, many organisations have not yet begun their deployment, thus far, which means it is too embryonic to allow the measurement of its impact. Our intention is to highlight which technological trend is more likely to have the most effect on the aforementioned three types of barriers, and therefore serve as a starting point for further studies. Our evaluation is thus rather predictive than confirmative, and is based on exemplar practices discussed in Section 6 as well as a wide consultation of literature.

Table 2 (part a) presents the results we interpreted by analysing what technologies are currently being deployed in Europe and their likely impact on ICT adoption barriers. It uses data presented in Appendix A. Binary encoding is applied if a particular project uses that technology. It is important to point out that the time span of all projects is between 1996 and 2015. As can be seen from the table, only two EU projects explore the use of cloud computing where three projects deploy Web 3.0 and social network. For example, iCargo (iCargo, 2011) deploys the latest ICT innovation where cloud computing, semantic web and the Internet of Things are used to support the Intelligent Cargo concept for sustainable global logistics operations where goods are self-context and location aware and connected to a range of services. Wireless/Mobile technologies and the Internet of Things are used by 23 projects due their recent rapid developments and the level of maturity of the technologies. Other projects tend to focus on traditional technological applications or address a specific issue such as security or data standardisation.

Table 2 (part b) also shows the relevance and the level of impact each individual trend is likely to have on multimodal transport provisions in the future. A weighting approach has been proposed in order to allow comparisons. The associated weighting is assigned according to the critical analysis in Section 6. The relative weightings for each trend are depicted in Table 2 and vary from a strong to weak impact of technological advances on barriers for ICT.

Visualising the two tables in a radar chart produces interesting results as seen in Fig. 5. In Fig. 5(a), we can see that current efforts are largely skewed towards the use of wireless and mobile communications. This is largely because those both positional and item tracking technologies have seen an increased adoption lately in the transport and logistics sectors. Therefore, we argue that the current impact of this trend on technology-related barriers is strong at present. But it does not imply that this technology has reached its full potential and will have no further influence on the barrier to ICT adoption.

In Fig. 5(a), the radar graph does not have axes related to the interface technologies because there is no evidence from the projects that, for example, augmented reality is used within the multimodal environment; however, there are examples in other disciplines as discussed in the paper. Policy-related issues have been considered by some projects as policy implications but not necessarily through the technology application as discussed in our paper. User-related barriers in the current review of projects are linked to capabilities of cloud computing at present, where it provides an infrastructure for affordable communication and collaboration across different players in multimodal transportation.

Our future outlook, as depicted in Fig. 5(b), will be different from the current state. We argue that the development of all four

**Table 2**

Current IT deployment for multimodal transport and future impact of technological trends.

Source: authors

Enabling ICTs Barriers	Cloud computing	Web3.0 and Social networking	Wireless/Mobile communication technologies and Internet of Things	Advances in interface technologies
<b>(a) Current efforts in IT deployment</b>				
User-related barriers	○	○	○○	n/a
Technology related barriers	○	○	○○○	n/a
Policy related barriers	○	n/a	○	n/a
<b>(b) Impact of technological trends on barriers to ICT adoption</b>				
User-related barriers	○○○	○○○	○○○	○○○
Technology related barriers	○○○	○○	○○○	○○
Policy related barriers	○○	○	○○	○

Key: ○○○=Strong impact, ○○=Medium impact, ○=Weak impact.  
n/a Denotes the technology is not deployed currently.

technological trends will have a positive impact on lowering barriers to ICT adoption but its extent will depend on the stage of technology development, and the ability of users to take advantage of technological trends. Our detailed justifications of our predictions are as follows.

Cloud computing will have a strong influence on user-related and technology-related barriers. Affordable ICT solutions, such as SaaS and apps for mobile devices, will be used to support a number of business processes related to resource and freight management and communication. This will have a significant impact on the various players, in particular SMEs of the multimodal supply chain, where cost is one of the main barriers to adopting the technology. There has been a slow uptake of cloud by large organisations due to uncertainty related to the cost, where putting the entire data centre of a large enterprise in the cloud needs initial investment that could increase costs and over time “the economics of running and building technology infrastructure will favour the cloud over on-premises computing” McAfee (2011). On the other hand, the economy of scale of purchasing large amounts of hardware and related components by service providers will reduce the prices in the cloud that they offer to their customers and allow those prices to reduce further over time, where at present there is no intensive competition.

As discussed earlier, SMEs have different challenges, such as tapping in into the software and hardware side of the cloud concept where their data requirements are not as large as for big companies, therefore they will not need initial heavy investments into IT infrastructures. This will increase their likelihood of adopting the cloud concept and having a bigger impact on barriers to ICT adoption if software developers will address a gap in the software applications related to multimodal operations. Indeed, the largest and most identifiable economic benefit of cloud computing is the direct cost savings. It is achieved via lower upfront IT costs, providing users with a low barrier to entry because cloud computing follows a utility-based pricing model in which service costs are based on consumption. A recent study by KPMG (2012) indicates that direct cost savings on IT related



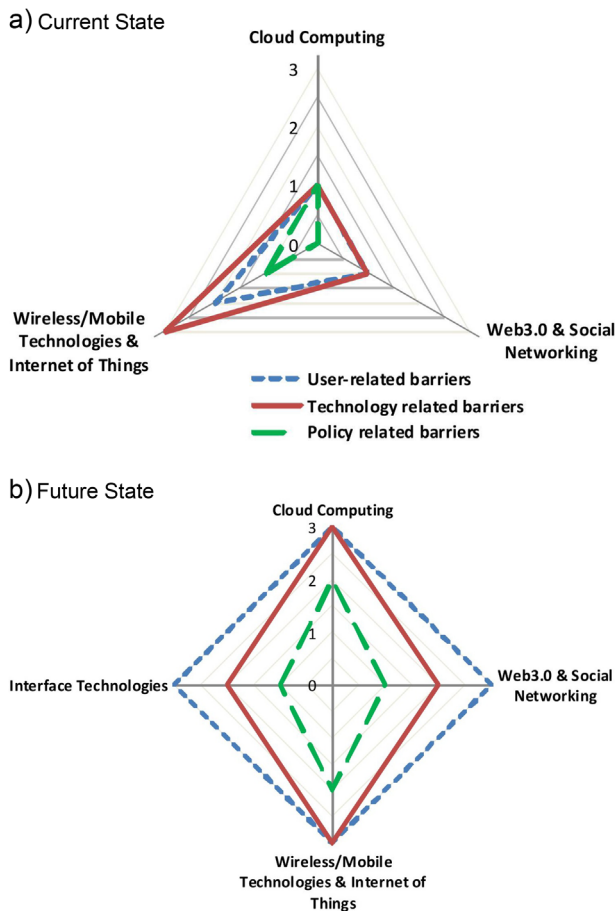


Fig. 5. Overall impact of technological trends on lowering barriers.

expenditure occur between 25 and 50 per cent, while the work of Etro (2009) finds that the productivity improvement of an average employee is by an average of 2.1 per cent.

Another benefit of cloud computing is its simplicity to manage and administer IT solutions deployed, because companies could rely more on the service provider instead of an internal IT department (Aymerich et al., 2008; Buyya et al., 2009; Armbrust et al., 2010; McAfee, 2011; Cegielski et al., 2012). Cloud computing also provides elastic scalability (i.e. the ability to add and remove computing capacity on demand) which is a significant advantage for businesses with high level of uncertainty. This enables flexible partnership configuration and collaboration. For instance, an MTO could, based on the needs of a particular consignment, build up specific information linkages with the various parties involved. Once that consignment is completed, the MTO can quickly switch off some linkages which will be no longer needed in the future without much sacrifice on sunk costs.

Technology-related issues related to compatibility will be addressed by the providers of “on-demand” solutions through the implementation of a number of ICT standards which enable enhanced interconnectivity between applications. This should allow a user to connect seamlessly to support their legacy application and “other” systems for efficient cargo movement. Application deployment is greatly accelerated because cloud computing can provide self-service access to a shared pool of computing resources where the software and hardware components are standard, re-useable and shared. However, one major concern companies hold about cloud is security and reliability. The responsibility for the reliability and security of cloud infrastructure lies mainly with the technology service providers (TSPs) where

those issues are still under scrutiny and are increasingly being addressed through appropriate infrastructure and continuous monitoring (McAfee, 2011; Cegielski et al., 2012).

Policy-related barriers may be moderately affected by cloud computing due to the international nature of multimodal transport and the various policies deployed in different countries participating in the movement of freight. However, the enhanced streamlined systems which cloud computing enables might promote the harmonisation of relevant international freight transport procedures and laws in different countries. Indeed, the concept of a “single window system” has seen an increasing adoption by countries such as Singapore (TradeNet) and South Korea (uTradehub), in aid of cross border customs cargo clearance processes between traders and governments (UNESCAP, 2010). In addition, ethical issues related to data privacy, accuracy, property and accessibility in the cloud that covers a number of participating countries that have different regulations in relation to handling the data will have to be addressed by TSPs to ensure that all legal requirements are met by all parties.

Web 3.0 and social networking with advances in interface technologies could have the strongest impact on user-related barriers due to the “human” element of the software trend. E-enabled communities promoting the use of applications and providing a platform for effective communication where a contextual search is at the essence of gathering knowledge will lead to further confidence in the use and development of ICT applications. As to the impact of such technological deployments on technology-related barriers, there could be a mixed (both positive and negative) effect. On one hand, compatibility and interoperability issues can be addressed via the increasing use of open-source software packages. On the other hand, integrating social media/networking sites as well as interface technologies such as augmented reality into business operations poses potential data security, confidentiality and ethical challenges. Therefore, we judge an overall moderate effect on technology related barriers. Regarding the impact on policy related barriers, we are yet to see any strategic actions or initiatives in a multimodal transport environment taking into consideration such technologies, and therefore a weak impact is predicted here.

Wireless/mobile communication technologies and the Internet of Things could have a strong impact on user-related and technology-related barriers. The “digital divide will cease to exist” by 2016 according to IBM (2011), where 80% of the global population will have mobile devices which eliminates accessibility issues. As the “digital divide” will no longer be a barrier to accessing information through the Internet due to the development of mobile communications and the wide availability and affordability of the devices, the development of supporting applications to provide timely information for decision makers without having the need for specific technological expertise will be accelerated. The Internet of Things, designed for the intelligent use of resources, will transform a physical world into an information system world where sensors are linked together and connected over the Internet (BOOZ and CO, 2011). Issues related to bandwidth bottleneck and compatibility will need to be addressed due to a number of standards for sending information currently still in place. Looking into the future, Chui et al. (2010) noted that networking technologies and supporting standards will evolve to allow free data flow among sensors, machines and computers where software will aggregate and analyse huge volumes of data in real time. The Internet of Things, as discussed in Section 6.2, has received considerable attention from government bodies, in recognising its potential impact on the future economy and society in general and on transport specifically. Yet in the context of multimodal transport, we are yet to see any specific initiatives led by policy makers. Therefore we observe a moderate impact.



The *user-related* and *technology-related* barriers will be lowered due to advances in the Internet of Things and in wireless/mobile networking technology and there are some examples which can already be seen in road transport operations where an increasing level of competition has pushed road carriers to adopt real time position tracking. Such technological deployment requires significant investment on telematics equipment to support the Internet of Things, of which the unit price could vary from a few hundred to thousands of pounds. In addition to this, there are the running costs of data transactions, administration and maintenance. UK cloud based tracking services developed by technology service providers can be seen as an effective solution to address the problem where TSPs lease telematics equipment to haulage companies and offer web-based applications, with the cost per unit vehicle being around £20 or above (Data acquired from [www.roadtech.co.uk](http://www.roadtech.co.uk)). Some providers allow their users to cancel their service subscriptions at any time.

With regard to the impact of big data and the rapid development of decision-support systems discussed in Section 7, it will improve further decision-makers' capabilities. The analysis of "Big Data" together with local intelligence through the use of DSS is changing business operations now, making businesses much closer to their customers and suppliers with benefits that improve the bottom line of their business, leading to cost reduction, lead times and improving service levels. Through services offered by the technology providers on the cloud-based platforms, multimodal transport users would be able to use the capabilities offered by DSS without heavy investments in technologies and those systems will aid to lowering user and technology related barriers. Examples already exist where real time tracking data is used to analyse drivers' behaviours (such as harsh breaking, or incorrect routes) and their relationship to fuel consumption. Appropriate training could be developed to target those drivers who need improvement (Wang and Potter, 2007).

## 9. Conclusion and recommendations for future research

In this paper via an extensive review of 33 EU framework programme projects, we are able to consolidate and present current major efforts in ICT developments in the freight multimodal transport setting at a European level. We further discuss barriers inhibiting the quick take-up of ICT applications in multimodal transport. Resolutions were then explored by reviewing four key ICT development trends recently emerging and evaluating their potential impact on reducing such barriers for deployment.

An important contribution of the paper to the literature is that to the best of the authors' knowledge, this is the first study that links multimodal operations, barriers to technology adoption and technological trends. Compared to previously published work, our paper presents the following contributions: (1) we offer valuable insights to academia as there has been a lack of a comprehensive and up-to-date overview of ICT developments in freight multimodal transport; (2) our analysis of the four key emerging ICT trends and their impact on reducing barriers is forward-thinking and allows other academic researchers to scrutinise or build on the research findings and explore further this important, yet underdeveloped subject hence laying the foundation for future research. Much academic research in the field focuses on the past, rather than being future oriented and tends to emphasise the testing of already established theories and ideas; and (3) our research is also beneficial to practitioners as it advances and updates our knowledge towards the use of ICT in the freight multimodal transport field as well as providing guidance and inspiration for the management and use of existing and emerging information technologies. We also believe that our approach in examining EU projects to

capture the current ICT deployment efforts in the field of multimodal transport is unique, as many studies in the literature tend to focus solely on a specific technology solution e.g. RFID hence do not provide us with a "helicopter" view across countries.

Our research is not without limitations. Data collected in this study are mainly secondary therefore future research should apply a number of methodologies, such as case studies, surveys, simulations or mathematical models to further investigate ICT developments and deployments in multimodal practice in terms of motives, barriers, costs and benefits. For instance, academics such as Cegielski et al. (2012) have started to employ interviews to collect primary data in order to investigate further the applications of cloud computing. Indeed, collecting primary data is a major piece of research on its own to investigate the impact of recent ICT developments in reducing barriers for deployment. Our rating scale about the impact of certain ICT developments in reducing barriers for deployment is rather simplistic due to the early developments of technological trends that we discuss in our paper. Nevertheless, this analysis is valid where we match current and predicted features of technological trends to barriers to ICT adoption through published articles on ICT developments and exemplar practices in the field.

For future research, a more rigorous approach should be explored where existing IS theories, such as the diffusion of innovation (Rogers, 1995), the organisational processing theory (Galbraith, 1974), the Technology Acceptance Model (TAM) and the extended TAM (Davis, 1989), technology–organisation–environment (TOE) framework (Tornatzky and Fleischer, 1990) could be deployed to analyse the relationship between barriers/drivers and the adoption of technological trends within a multimodal setting, linking the theory on the barriers to innovation. In addition, the development of new IS theories could further contribute to future research.

There is also a need to examine the influence of technology service providers of multimodal solutions on the adoption of ICT applications in the transport and logistics industries, as they may play a strategic role in promoting wider ICT adoption in multimodal transport communities (Pokharel, 2005; Marchet et al., 2009; Perego et al., 2011). An analysis of the security and ethical risks related to these technologies, for example cloud computing, is also extremely important and interesting.

Further research needs to be undertaken to analyse the impact of different policies on positive ICT adoption by using and developing appropriate methodologies. For example, Tsamboulas et al. (2007) proposes a methodology with the capacity to assess the impact of specific policies on the development of intermodal transport on a European scale. Pokharel (2005) also highlights the need to investigate the impact of policy on motivation and barriers to ICT adoption from a logistics perspective. According to KOMODA (2009) and PROMIT (2009), the use of ICT applications in multimodal transport is in dire need of a standardisation that is supported by specific government policy, as well as the coordination and harmonisation of related policies in different countries.

## Acknowledgement

This research was supported by The Engineering and Physical Sciences Research Council (EPSRC/UK) under its first grant scheme, grant number EP/J009210/1.

## Appendix A

See Table A

**Table A**  
EU Projects and Technological Trends.

Project number	Technological trends EU project	Cloud computing	Web3.0 & social network	Wireless/mobile technologies & Internet of Things	Interface technologies
1	COREM	0	0	0	0
2	SURFF	0	0	1	0
3	WELCOM	0	0	0	0
4	EUROPE-TRIS	0	0	0	0
5	IWV	0	0	0	0
6	F-MAN	0	0	1	0
7	MarNIS	0	0	1	0
8	COREM	0	0	0	0
9	INTERPORT	0	0	1	0
10	EUROSCOPE	0	0	1	0
11	SURFF	0	0	1	0
12	IP	0	0	1	0
13	CHINOS	0	0	1	0
14	SAIL	0	0	0	0
15	MIT	0	0	1	0
16	MULTITRACK	0	0	1	0
17	TRACAR	0	0	1	0
18	ParcelCall	0	0	1	0
19	D2D	0	0	1	0
20	M-TRADE	0	0	1	0
21	EURIDICE	0	1	1	0
22	INTEGRITY	0	0	1	0
23	SMART-CM	0	0	1	0
24	CASSANDRA	0	0	1	0
25	DOLPHINS	0	0	0	0
26	THEMIS	0	0	1	0
27	ALSO DANUBE	0	0	1	0
28	GIFTS	0	0	1	0
29	E-FRAME	0	0	0	0
30	FREIGHTWISE	0	0	0	0
31	KOMODA	0	0	0	0
32	e-FREIGHT	1	1	1	0
33	iCargo	1	1	1	0
Total		2	3	23	0

0=technology not in use, 1=technology in use.

## References

- ALSO DANUBE, 2000. Advanced Logistic Solutions for Danube Waterway. Available at: [http://www.transport-research.info/web/projects/project\\_details.cfm?id=4868](http://www.transport-research.info/web/projects/project_details.cfm?id=4868) (accessed January 2012).
- Aymerich, F.M., Fenu, G., Surcis, S., 2008. An approach to a cloud computing network. In: Proceedings of the First International Conference on the Applications of Digital Information and Web Technologies, Ostrava, Czech Republic, pp. 113–118.
- Armbrust, M., Fox, A., Griffith, R., Joseph, A.D., Datz, R., Konwinski, A., Lee, G., Patterson, D., Rabkin, A., Stoica, I., Zaharia, M., 2010. A view of cloud computing. *Commun. ACM* 53 (4), 50–58.
- Beresford, A.K., Qu, W., Pettit, S.J., 2006. Multimodal transport efficiency: milk products from New Zealand to China. In: Proceedings of International Conference on Logistics and Supply Chain Management. Hong Kong.
- Buyya, R., Yeo, C.S., Venugopal, S., Broberg, J., Brandic, I., 2009. Cloud computing and emerging IT platforms: vision, hype, and reality for delivering computing as the 5th utility. *Future Gener. Comput. Syst.* 25 (6), 599–616.
- BDP1, 2005. Box Tracking: Big Blue and Blue Ships IBM and Maersk Team Up Available at: <http://www.conconnect.com/Workingpapers/digitalshipibm.PDF> (accessed 24.03.12).
- Bilton, N., 2012. Behind the Google Goggles, Virtual Reality. *The New York Times*. Available at: [http://www.nytimes.com/2012/02/23/technology/google-glasses-will-be-powered-by-android.html?\\_r=4&](http://www.nytimes.com/2012/02/23/technology/google-glasses-will-be-powered-by-android.html?_r=4&) (accessed 17.04.13).
- Bock, F., 2010. Real-time control of freight forwarder transportation networks by integrating multimodal transport chains. *Eur. J. Oper. Res.* 200 (3), 733–746.
- BOOZ&CO, 2011. Designing the Transcendent Web. The Power of Web 3.0. Available at: <http://www.booz.com/media/uploads/BoozCo-Designing-Transcendent-Web-3.0.pdf> (accessed 23.07.11).
- Boschian, V., Fanti, M., Iacobellis, G., Ukovich, W., 2009. Using information and communication technologies in intermodal freight transportation: a case study. In: Proceedings of the 2009 IEEE International Conference on Systems, Man, and Cybernetics, USA.
- Boschian, V., Dotoli, M., Fanti, M.P., Iacobellis, G., Ukovich, W., 2011. A metamodeling approach to the management of intermodal transportation networks. *IEEE Trans. Autom. Sci. Eng.* 8 (3), 457–469.
- Caris, A., Macharis, C., Janssens, G.K., 2008. Planning problems in intermodal freight transport: accomplishments and prospects. *Transp. Plan. Technol.* 31 (3), 277–302.
- CASSANDRA, 2011. Common assessment and analysis of risk in global supply chains. Available at: <http://www.cassandra-project.eu> (accessed January 2012).
- Cegielski, C.G., Jones-Farmer, L.A., Wu, Y., Hazen, B.Y., 2012. Adoption of cloud computing technologies in supply chains: an organizational information processing theory approach. *Int. J. Logist. Manag.* 23 (2), 184–211.
- Chao, P., 2011. The Impact of Multimodal Transport Service Value and Relationship on Business Performance – Thai Shippers' Perspective, Unpublished (Ph.D. thesis). Cardiff Business School, Cardiff University.
- Choi, J.Y., 2011. A Survey of Single Window Implementation, World Customs Organization Research paper No. 17, Available at: [http://www.wcoomd.org/en/topics/research/activities-and-programmes/~/\\_media/2DF5A36D3ECA46CCB7B17BDF77ACC021.ashx](http://www.wcoomd.org/en/topics/research/activities-and-programmes/~/_media/2DF5A36D3ECA46CCB7B17BDF77ACC021.ashx) (accessed 12.06.13).
- CHINOS, 2009. Deliverable D0.4 Final report. European Commission.
- Coronado, A.E., Lalwani, C.S., Coronado, E.S., Coronado, C.E., 2009. Facilitating multimodal logistics and enabling information systems connectivity through wireless vehicular networks. *Int. J. Prod. Econ.* 122 (1), 229–240.
- COREM, 1996. Cooperative Resource Management for the transport of load units. Available at: [http://cordis.europa.eu/telematics/tap\\_transport/research/projects/corem.html](http://cordis.europa.eu/telematics/tap_transport/research/projects/corem.html) (accessed January 2012).
- Chui, M., Löffler, M., and Roberts R., 2010. The internet of things, McKinsey Quarterly. Available at: [http://www.mckinsey.com/insights/high\\_tech\\_telecoms\\_internet/the\\_internet\\_of\\_things](http://www.mckinsey.com/insights/high_tech_telecoms_internet/the_internet_of_things) (accessed November 2013).
- Davis, F.D., 1989. Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Q.* 13 (3), 319–340.
- Davies, I., Mason, R., Lalwani, C., 2007. Assessing the impact of ICT on UK general haulage companies. *Int. J. Prod. Econ.* 106 (1), 12–27.
- DISCWISE, 2012. Discwise Guide to e-Business: Connecting SMEs to the digital transport and logistics value chain. Available at: [http://www.discwise.eu/media/3671/discwise\\_guide\\_busines\\_part\\_final.pdf](http://www.discwise.eu/media/3671/discwise_guide_busines_part_final.pdf) (accessed 20.01.13).
- DFT, 2006. Freight Best Practice Guide: Information Technology for Efficient Road Freight Operations. Available at: <http://www.freightbestpractice.org.uk/information-technology-guide-for-efficient-road-freight-operations> (accessed 23.07.11).
- DOLPHINS, 2000. Digital On-Line Pilot Project to Help Intermodal Networking & Short-Sea-Shipping. Available at: [http://cordis.europa.eu/projects/rcn/54102\\_en.html](http://cordis.europa.eu/projects/rcn/54102_en.html) (accessed January 2012).
- Dotoli, M., Fanti, M., Mangini, A., Stecco, G., Ukovich, W., 2010. The impact of ICT on intermodal transportation systems: a modelling approach by Petri nets. *Control Eng. Pract.* 18 (8), 893–903.
- Dotoli, M., Hammadi, S., Jeribi, K., Russo C., Zgaya, H., 2013. A multi-agent decision support system for optimization of co-modal transportation route planning services. In: Proceedings of the 52nd IEEE CDC (Conference on Decision and Control). Florence, Italy, 10–13 December, 2013.
- Dubey, A., Wagle, D., 2007. Delivering software as a service. Web exclusive, The McKinsey Quarterly.
- Dullaert, W., Neutens, T., Vanden Bergh, G., Vermeulen, T., Vernimmen, B., Witlox, F., 2009. MamMoeT: an intelligent agent-based communication support platform for multimodal transport. *Expert Syst. Appl.* 36 (7), 10280–10287.
- Durr, E., Giannopoulos, G., 2003. SITS: a system for uniform intermodal freight transport information exchange. *Int. J. Transp. Manag.* 1, 175–186.
- D2D, 2005. D2D: Demonstration of an integrated management and communication system for door-to-door intermodal freight transport operations. Final Technical Report. Available at: [http://www.transport-research.info/Upload/Docu/200607/20060727\\_143636\\_83260\\_D2D\\_Final\\_Report.pdf](http://www.transport-research.info/Upload/Docu/200607/20060727_143636_83260_D2D_Final_Report.pdf) (accessed 02.09.12).
- EC, 2011. European Commission. Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system. Available at: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0144:FIN:EN:PDF> (accessed 25.07.11).
- E-FRAME, 2008. Extend Framework architecture for cooperative systems. Available at: [http://www.transport-research.info/web/projects/project\\_details.cfm?id=44407](http://www.transport-research.info/web/projects/project_details.cfm?id=44407) (accessed January 2012).
- e-FREIGHT, 2011. e-Freight: European e-Freight capabilities for Co-modal transport. Available at: <http://www.efreightproject.eu> (Accessed: 01.03.13).
- ENABLE, 2010a. ENABLE: Stimulate Sustainable Freight Transport Systems with Latin American countries. Deliverable D2.1: Best Practices handbook. European Commission. Available at: <http://www.enable-project.net/Outcomes/tabid/59/language/en-US/Default.aspx> (accessed 26.07.11).
- ENABLE, 2010b. ENABLE: Stimulate Sustainable Freight Transport Systems with Latin American countries. Deliverable D2.2: Freight Transport Innovations List. European Commission. Available at: <http://www.enable-project.net/Outcomes/tabid/59/language/en-US/Default.aspx> (accessed 26.07.11).
- Eng-Larsson, F., Kohn, C., 2012. Modal shift for greener logistics – the shipper's perspective. *Int. J. Phys. Distrib. Logist. Manag.* 42 (1), 36–59.
- Etro, F., 2009. The economic impact of cloud creation on business creation, employment and output in Europe – an application of the Endogenous Market Structure Approach to a GPT innovation. Available at: <http://www.econ.kuleuven.be/rebel/jaargangen/2001-2010/2009/2009-2/RBE%202009-2%20-%>

- 20The%20Economic%20Impact%20of%20Cloud%20Computing.pdf) (accessed 04.01.14).
- EURIDICE, 2008. European Inter-disciplinary Research on Intelligent Cargo for Efficient, Safe and Environment-friendly Logistics. Available at: <http://www.euridice-project.eu> (accessed January 2012).
- EUROPE-TRIS, 1996. West-East Logistics Corridor for Multimodal transport. Available at: [http://cordis.europa.eu/teleomatics/tap\\_transport/research/projects/eur-ope-tris.html](http://cordis.europa.eu/teleomatics/tap_transport/research/projects/eur-ope-tris.html) (accessed January 2012).
- EUROSCOPE, 1996. Efficient Urban Transport Operation Services Co-Operation of Port Cities in Europe. Available at: [http://cordis.europa.eu/projects/rcn/32154\\_en.html](http://cordis.europa.eu/projects/rcn/32154_en.html) (accessed January 2012).
- Evangelista, P., Sweeney, E., 2006. Technology usage in the supply chain: the case of small 3PLs. *Int. J. Logist. Manag.* 17 (1), 55–74.
- Ferrer, G., Dew, N., Apte, U., 2010. When is RFID right for your service? *Int. J. Prod. Econ.* 124 (2), 414–425.
- F-MAN, 2005. F-MAN: Rail Car Asset Management. Deliverable D16: Final report. Available at: [http://www.transport-research.info/Upload/Documents/200604/20060411\\_172123\\_25402\\_F-MAN%20Final%20Report.pdf](http://www.transport-research.info/Upload/Documents/200604/20060411_172123_25402_F-MAN%20Final%20Report.pdf) (accessed 15.01.13).
- FREIGHTWISE, 2006. Management Framework for Intelligent Intermodal Transport. Available at: <http://freightwise.tec-hh.net> (Accessed: January 2012).
- Galbraith, J.R., 1974. Organization design: an information processing view. *Interfaces* 4 (3), 28–36.
- Giannopoulos, G.A., 2004. The application of information and communication technologies in transport. *Eur. J. Oper. Res.* 152 (2), 302–320.
- GIFTS, 2004. GIFTS: Global Intermodal Freight Transport System. Deliverable D03. User needs identification and analysis. Available at: [http://gifts.newapplication.it/gifts/project\\_deliverables/public/GIFTS-REP-D03-1\\_0.zip](http://gifts.newapplication.it/gifts/project_deliverables/public/GIFTS-REP-D03-1_0.zip) (accessed 21.08.11).
- Grieger, M., 2003. Electronic marketplaces: a literature review and a call for supply chain management research. *Eur. J. Oper. Res.* 144 (2), 280–294.
- Gunasekaran, A., Lenny Koh, S.C., 2009. Interlocking of information systems for international supply and demand chains management. *Int. J. Prod. Econ.* 122 (1), 127–132.
- Harindranath, G., Dyerson, R., Barnes, D., 2008. ICT in small firms: factors affecting the adoption and use of ICT in Southeast England SMEs. In: *Proceedings of the 2008 European Conference on Information Systems (ECIS)*, Galway, Ireland, ECIS.
- Hollenstein, H., 2004. Determinants of the adoption of information and communication technologies (ICT): an empirical analysis based on firm-level data for the Swiss business sector. *Struct. Change Econ. Dyn.* 15 (3), 315–342.
- Huckridge, J., Bigot, S., Naim, M., 2010. ICT in multimodal transport operations: a framework for future research. In: *Proceedings of 17th International Annual EuroMA Conference*, Portugal.
- IAS, 2013. IAS International Asset systems. Available at: <http://www.interasset.com/data-sheets.php> (accessed 30.06.13).
- IBM, 2011. IBM Reveals Five Innovations That Will Change Our Lives within Five Years. Available at: <http://www-03.ibm.com/press/uk/en/pressrelease/36356.wss> (accessed 05.01.12).
- iCargo, 2011. Intelligent Cargo in Efficient and Sustainable Global Logistics Operations. Available at: <http://i-cargo.eu> (accessed 02.02.14).
- INFOLOG, 1999. INFOLOG: Intermodal Information Link for Improved Logistics. Public summary report. Available at: [ftp://ftp.cordis.europa.eu/pub/transport/docs/summaries/waterborne\\_infolog\\_report.pdf](ftp://ftp.cordis.europa.eu/pub/transport/docs/summaries/waterborne_infolog_report.pdf) (accessed 07.08.11).
- INTEGRITY, 2011. INTEGRITY: Intermodal global door-to-door container supply chain visibility: FP7 project. Deliverable D0.3. Final report. Available at: <http://www.integrity-supplychain.eu> (accessed 20.01.12).
- INTERPORT, 1996. Intermodal Information Link for Improved Logistics. Available at: [http://www.transport-research.info/web/projects/project\\_details.cfm?id=420](http://www.transport-research.info/web/projects/project_details.cfm?id=420) (accessed January 2012).
- IP, 2000. Intermodal Portal. Available at: [http://www.transport-research.info/web/projects/project\\_details.cfm?id=7039](http://www.transport-research.info/web/projects/project_details.cfm?id=7039) (accessed January 2012).
- IWW, 2000. Development of an automatic and intelligent warehouse- and (un-) loading system for pallet freight for small inland waterway vessels. Available at: [http://cordis.europa.eu/projects/rcn/57271\\_en.html](http://cordis.europa.eu/projects/rcn/57271_en.html) (accessed January 2012).
- Jakobs, K., Pils, C., Wallbaum, M., 2001. Using the internet in transport logistics – the example of a track and trace system. *Lect. Notes Comput. Sci.* 2093, 194–203.
- Jones, N., 2011. Near Field Communications (NFC) – The Next Step After RFID. Available at: <http://www.globallogisticsmedia.com/articles/view/near-field-communications-nfc-the-next-step-after-rfid> (accessed 31.01.11).
- Kengpol, A., Meethom, W., Tuominen, M., 2012. The development of a decision support system in multimodal transportation routing within Greater Mekong sub-region countries. *Int. J. Prod. Econ.* 140 (2), 691–701.
- KNAPP, 2013. KiSoft Vision: Augmented reality. Available at: <http://www.knapp.com/glossary?id=35> (accessed 15.03.13).
- KOMODA, 2009. KOMODA: Co-modality – Towards Optimised Integrated Chains in Freight Transport Logistics Deliverable D3.2: Action Plan. European Commission within the Seventh Framework Programme (2007–2013).
- KPMG, 2012. Modelling the Economic Impact of Cloud Computing. Available at: <https://www.kpmg.com/AU/en/IssuesAndInsights/ArticlesPublications/Documents/modelling-economic-impact-cloud-computing.pdf> (accessed 01.02.14).
- Kuan, K.K.Y., Chau, P.Y.K., 2001. A perception-based model for EDI adoption in small businesses using a technology-organization-environment framework. *Inform. Manag.* 38, 507–521.
- Laudon, K., Laudon, J., 2012. *Management information Systems: Managing the Digital Firm*, 12th edition. Pearson p. 630.
- Lynch, K., 2005. Next-generation logistics network. *Asctet* 7, 176–179.
- Macharis, C., Caris, A., Jourquin, B., Pekin, E., 2011. A decision support framework for intermodal transport policy. *Eur. Transp. Res. Rev.* 3 (4), 167–178.
- Marchet, G., Perego, A., Perotti, S., 2009. An exploratory study of ICT adoption in the Italian freight transportation industry. *Int. J. Phys. Distrib. Logist. Manag.* 39 (9), 785–812.
- Marchet, G., Perotti, S., Mangiaracina, R., 2012. Modelling the impacts of ICT adoption for inter-modal transportation. *Int. J. Phys. Distrib. Logist. Manag.* 42 (2), 110–127.
- Maersk, IBM, 2005. Maersk and IBM Develops Container Tracking System. *Computer Weekly*. Available at: <http://www.computerweekly.com/news/2240075241/IBM-and-Maersk-develop-container-tracking-system> (accessed 24.08.11).
- MarNIS, 2009. Maritime Navigation and Information Services. Available at: [http://www.transport-research.info/web/projects/project\\_details.cfm?id=11127](http://www.transport-research.info/web/projects/project_details.cfm?id=11127) (accessed 15.01.13).
- MIT, 2011. MIT – Metrocargo Intermodal Transport. Available at: <http://www.mitproject.eu/> (accessed 15.01.13).
- McAfee, A., 2011. What every CEO needs to know about the cloud. *Harvard Bus. Rev.* (November), 124–132.
- M-TRADE, 2007. M-TRADE. Available at: [http://www.newapplication.it/mtrade/mtrade\\_home.html](http://www.newapplication.it/mtrade/mtrade_home.html) (accessed 15.01.13).
- MULTITRACK, 1996. Tracking, Tracing and Monitoring of Goods in an Inter-modal and Open Environment. Available at: [http://cordis.europa.eu/teleomatics/tap\\_transport/research/projects/multitrack.html](http://cordis.europa.eu/teleomatics/tap_transport/research/projects/multitrack.html) (accessed January 2012).
- Newman, J., 2012. Google 'Project Glass' Replaces the Smartphone With Glasses. *PC Magazine*. Available at: <http://www.pcmag.com/article2/0,2817,2402613,00.asp> (accessed 17.04.13).
- O'Sullivan, D., 2007. Software as a service: developments in supply chain IT. *Logist. Transp. Focus* 9 (3), 30–33.
- ParcelCall, 2000. An Open Architecture for Intelligent Tracing Solutions in Transport and Logistics. Available at: [http://www.transport-research.info/web/projects/project\\_details.cfm?id=15342](http://www.transport-research.info/web/projects/project_details.cfm?id=15342) (accessed January 2012).
- Perego, A., Perotti, S., Mangiaracina, R., 2011. ICT for logistics and freight transportation: a literature review and research agenda. *Int. J. Phys. Distrib. Logist. Manag.* 41 (5), 457–483.
- Piplani, R., Pokhare, S., Tan, A., 2004. Perspectives on the use of information technology at third party logistics service providers in Singapore. *Asia Pacific J. Mark. Logist.* 16 (1), 27–41.
- Pokhare, S., 2005. Perception on information and communication technology: perspective in logistics. *J. Enterp. Inform. Manag.* 18 (2), 136–149.
- Rogers, E.M., 1995. *Diffusion of Innovations*, 3rd ed. The Free Press, New York.
- Prajogo, D., Olhager, J., 2012. Supply chain integration and performance: the effects of long-term relationships, information technology and sharing, and logistics integration. *Int. J. Prod. Econ.* 135 (1), 514–522.
- PROMIT, 2009. D 3.1-3.3 Best Practice Year 1, 2 and 3. Available at: [http://www.promit-project.net/UploadedFiles/Deliverables/PROMIT\\_BPH3\\_April09\\_cp\\_MSR.pdf](http://www.promit-project.net/UploadedFiles/Deliverables/PROMIT_BPH3_April09_cp_MSR.pdf) (accessed 17.08.11).
- Rantapaska, T., Ihanainen, O., 2008. Knowledge use in ICT investment decision making of SMEs. *J. Enterp. Inform. Manag.* 21 (6), 585–596.
- Rainer, R.K., Cegielski, C.G., 2011. *Introduction to information systems: enabling and transforming business*, International Student Version, 3rd edition. John Wiley & Sons p. 539.
- SAIL, 2010. ICT System addressed to integrated logistic management and decision support for intermodal port and dry port facilities. Available at: <http://www.teorema.net/it/UM/ReD/HarborLogistics/SAIL.aspx> (accessed January 2013).
- SMART-CM, 2011. SMART-CM: Smart Container Chain Management. Available at: [http://www.transport-research.info/web/projects/project\\_details.cfm?id=37567](http://www.transport-research.info/web/projects/project_details.cfm?id=37567) (accessed 10.01.13).
- Smith, G., Hale, J., 2010. Shipping Containers and the Future Internet of Things. Available at: <http://www.currentintelligence.net/columns/2010/9/2/shipping-containers-and-the-future-internet-of-things.html> (accessed 04.02.13).
- Stefansson, G., 2002. Business-to-business data sharing: a source for integration of supply chains. *Int. J. Prod. Econ.* 75 (1–2), 135–146.
- SteadieSeifi, M., Dellaert, N., Nuijten, W., Van Woensel, T., Raoufi, R., 2014. Multimodal freight transportation planning: a literature review. *Eur. J. Oper. Res.* 233 (1), 1–15.
- SURFF, 1996. Sustainable Urban and Regional Freight Flows. Available at: [http://cordis.europa.eu/teleomatics/tap\\_transport/research/projects/surff.html](http://cordis.europa.eu/teleomatics/tap_transport/research/projects/surff.html) (accessed January 2012).
- TAP, 2000. TAP (Telematics Applications Programme): Freight Intermodal: Final area report. 4th Framework Programme for RDT&D. Available at: [ftp://ftp.cordis.europa.eu/pub/teleomatics/docs/tap\\_transport/freight\\_report.pdf](ftp://ftp.cordis.europa.eu/pub/teleomatics/docs/tap_transport/freight_report.pdf) (accessed 28.08.11).
- Technology Strategy Board, 2011. Technology Strategy Board to invest £5 m into the Internet of Things. Available at: <http://webarchive.nationalarchives.gov.uk/20130221185318/www.innovateuk.org/content/news/technology-strategy-board-to-invest-5m-into-the-in-ashx> (accessed 20.07.12).
- THEMIS, 2000. Thematic Network in the Optimal Management of Intermodal Transportation Services. Available at: [http://www.transport-research.info/web/projects/project\\_details.cfm?id=4498](http://www.transport-research.info/web/projects/project_details.cfm?id=4498) (accessed January 2012).
- Tornatzky, L.G., Fleischer, M., 1990. *The Processes of Technological Innovation*. Lexington Books, Lexington, Massachusetts.
- TRACAR, 1996. Traffic & Cargo Supervision System. Available at: [http://cordis.europa.eu/teleomatics/tap\\_transport/research/projects/tracar.html](http://cordis.europa.eu/teleomatics/tap_transport/research/projects/tracar.html) (accessed January 2012).



- Tsamboulas, D., Vrenken, H., Lekka, A., M., 2007. Assessment of a transport policy potential for intermodal mode shift on a European scale. *Transp. Res. Part A: Policy Pract.* 41 (8), 715–733.
- UN, 1980. United Nations. Convention on International Multimodal Transport of Goods.
- UN/ECE, 2001. United Nations. Terminology on Combined Goods. New York and Geneva.
- UNESCAP, 2010. Towards single window trading environment: Case of Korea's National Paperless Trade Platform – uTradehub, and Case of case of Singapore's TradeNet. Available at: [www.unescap.org/unnext/pub/brief2.pdf](http://www.unescap.org/unnext/pub/brief2.pdf) and [www.unescap.org/unnext/pub/brief3.pdf](http://www.unescap.org/unnext/pub/brief3.pdf) (accessed 01.03.12).
- Viswanathan, N., Sadlovska, V., Enslow, B., 2007. B2B Collaboration: How On-demand Platforms Accelerate Value and Impact. TCO, Aberdeen Group.
- Wang, Y., Potter, A., 2007. The application of real time tracking technologies in freight transport. In: Proceedings of Third International IEEE Conference on Signal-image Technologies and Internet-based Systems, Shanghai.
- Wang, Y., Potter, A., Naim, M.M., 2007. Electronic marketplaces for tailored logistics. *Ind. Manag. Data Syst.* 107 (8), 1170–1187.
- Wang, Y., Naim, M., Potter, A., 2010. Electronic Logistics Marketplaces. In: Lee, I. (Ed.), *Encyclopedia of E-Business Development and Management in the Global Economy*. Information Science Publishing, ISBN: 978-1615206117, pp. 218–226.
- WELCOM, 1996. West-East Logistics Corridor for Multimodal transport. Available at: [http://cordis.europa.eu/telematics/tap\\_transport/research/projects/welcom.html](http://cordis.europa.eu/telematics/tap_transport/research/projects/welcom.html) (accessed January 2012).
- Weber, T., 2010. Cloud computing for business goes mainstream. Available at: <http://www.bbc.co.uk/news/10097450> (accessed 28.07.11).
- Whiteaker, J., 2011. Tesco to Trial Augmented Reality In-Store. Available at: <http://www.retailgazette.co.uk/articles/44432-tesco-to-trial-augmented-reality-instore> (accessed 10.01.12).
- Woodburn, A., Whiteing, A., 2012. Transferring freight to “greener” transport modes, in McKinnon. In: Browne, A., Whitening, M., A. (Eds.), *Green Logistics: Improving the Environmental Sustainability of Logistics*, (Eds.) Kogan Page, pp. 129–143.
- Yuan, Z., Huang, D., 2008. A novel RFID-based shipping containers location and identification solution in multimodal transport. In: Proceedings of the IEEE CCECE/CCGEI, Niagara Falls, Canada.
- Zaheer, R., 2008. Multimodal transport and logistics: best practices, achieving greater efficiency and challenges. In: Proceedings of the 1st Arab Logistics & Multimodal Transport Conference. Amman, Jordan.
- Zeimpekis, V., Giaglis, G.M., 2006. Urban dynamic real-time distribution services – insights from SMEs. *J. Enterp. Inform. Manag.* 19 (4), 367–388.