Transportation Research Part C 17 (2009) 541–557

Contents lists available at ScienceDirect

Transportation Research Part C

journal homepage: www.elsevier.com/locate/trc

Intelligent freight-transportation systems: Assessment and the contribution of operations research

Teodor Gabriel Crainic [a,*], Michel Gendreau [b], Jean-Yves Potvin [b]

[a] *Département Management et technologie, ESG and Interuniversity Research Centre on Enterprise Networks, Logistics, and Transportation (CIRRELT), Université du Québec à Montréal, C.P. 8888, succ. Centre-ville, Montréal, QC, Canada H3C 3P8*

[b] *Département Informatique et recherche opérationnelle and Interuniversity Research Centre on Enterprise Networks, Logistics, and Transportation (CIRRELT), Université de Montréal, C.P. 8888, succ. Centre-ville, Montréal, QC, Canada H3C 3P8*

ARTICLE INFO

Article history:
Received 2 March 2007
Received in revised form 16 July 2008
Accepted 17 July 2008

Keywords:
Intelligent Transportation Systems
Freight transportation
CVO
AFMS
City logistics
e-Business

ABSTRACT

While it is certainly too early to make a definitive assessment of the effectiveness of *Intelligent Transportation Systems* (ITS), it is not to take stock of what has been achieved and to think about what could be achieved in the near future. In our opinion, ITS developments have been up to now largely hardware-driven and have led to the introduction of many sophisticated technologies in the transportation arena, while the development of the *software component* of ITS, models and decision-support systems in particular, is lagging behind. To reach the full potential of ITS, one must thus address the challenge of making the most *intelligent* usage possible of the hardware that is being deployed and the huge wealth of data it provides. We believe that transportation planning and management disciplines, *operations research* in particular, have a key role to play with respect to this challenge. The paper focuses on Freight ITS: Commercial Vehicle Operations and Advanced Fleet Management Systems, City Logistics, and electronic business. The paper reviews main issues, technological challenges, and achievements, and illustrates how the introduction of better operations research-based decision-support software could very significantly improve the ultimate performance of Freight ITS.

1. Introduction

The term *Intelligent Transportation Systems*, or ITS, is generally used to refer to tomorrow's technology, infrastructure, and services, as well as the planning, operation, and control methods to be used for the transportation of persons and freight. With ITS, however, tomorrow is already here.

The initial driving force for the development of ITS has been the realisation that further infrastructure construction could no longer be the only answer to address the increase in transportation demand and the various problems that it inevitably creates. The obvious answer to the need to significantly increase the capacity of transportation systems was to try to make them more efficient through an integrated use of the latest developments in various areas, infrastructure and vehicle technologies, electronics, telecommunications, computing hardware, positioning systems, as well as advanced data processing and sophisticated planning and operation methods. Over the last 15 years or so, one has thus witnessed tremendous efforts aimed at creating and deploying a new generation of transportation systems that aim to control congestion, increase safety, increase mobility, and enhance the productivity and effectiveness of private and public fleets.

* Corresponding author. Tel.: +1 514 343 7143; fax: +1 514 343 7121.
E-mail addresses: TeodorGabriel.Crainic@CIRRELT.ca (T.G. Crainic), Michel.Gendreau@cirrelt.ca (M. Gendreau), potvin@iro.umontreal.ca (J.-Y. Potvin).

0968-090X/$ - see front matter
doi:10.1016/j.trc.2008.07.002

In the beginning, ITS research, development, and investment focused on urban automobile transportation and a totally public organisational structure and management. It has now evolved to include all types and levels of transportation, persons as well as freight, for which private industries offer a variety of extended, adapted and targeted services. Tremendous challenges and opportunities exist for ITS research, development, and business, particularly so in the area of freight transportation that, until recently, appeared relatively less prominently on the agenda of ITS stakeholders. Indeed, the development of Freight ITS and the evolution of the freight-transportation industry are closely related, particularly relative to the use of information and decision technologies in response to the tremendous shift in commercial and industrial practices of the last decade. This is in stark contrast to most other ITS areas, where the needs of people mobility in congested urban centers constitute the overwhelming driving force.

While it is certainly too early to make a definitive assessment of the effectiveness of ITS, it is not to take stock of what has been achieved and, more importantly, to think about what could be achieved in the near future. In our opinion, ITS developments have been up to now largely hardware-driven, and have led to the introduction of many sophisticated technologies in the transportation arena. We are thus now, among other things, in the position to collect enormous amounts of data about the current state and the operations of transportation systems, and to transmit rapidly these data, in one form or the other, to transportation authorities, carriers, and travellers. Two critical questions remain though: are all of these data transformed into *useful information*? And, is this information *properly exploited*? The correct answer to both of these questions is clearly negative. The reason for this situation is that the development of the *software component* of ITS, models, decision-support systems, and so on, has been dramatically lagging behind that of its hardware component. In many cases, very detailed data are still processed and acted upon by the human operators with very few decision-support tools, if at all. In a sense, we are now faced with a challenge similar to the one that led to the initial development of ITS, that is, to make the best, the most *intelligent* usage possible of all that wonderful hardware that is being deployed. We believe that transportation planning and management disciplines, and in particular *operations research*, have a key role to play with respect to this challenge.

Challenges for the freight-transportation industry result from the major changes affecting supply chains and logistical processes in trade and commerce. The first factor is the strong impetus toward inventory reduction that led to the "Just-in-Time" procurement practices and, more recently, to just-in-time replenishments of goods in the retail industry. The globalization and liberalization of markets and the creation of free trade zones constitute the second major changing factor. The restructuring of manufacturing and distribution channels worldwide has accompanied the globalization of the economy. Production units are re-located, and the components required for the final assembly of complex industrial products are often brought in from many distant locations. Continuously increasing volumes of industrial, commercial, and consumer goods are imported into Europe and North America and transported over long distances from the so-called emerging-economy countries, e.g., China, India, and Brazil. All the while, trans-national centralized warehousing facilities and value-added distribution centers are changing the flow of goods almost everywhere.

The development of Internet-based electronic business is also strongly contributing to the transformation of the freight-transportation industry. The main external factors driving this transformation are the modifications to the logistic chains and practices of major industries and economic sectors, the proliferation of electronic spaces (websites) where shippers and carriers may meet and close deals, and the continuously increasing volume of individual consumer e-commerce activities. These changes have certainly resulted in higher demand for transportation. They have also increased the requirements for freight-transportation services in terms of enhanced customer value: reduce transportation and distribution costs, while responding to the customer needs in terms of delivery time and reliability. Moreover, events such as 9/11, the war on terrorism, and the war on drugs have created potential impediments to the flow of goods due to safety and security threats that can only be mitigated through the use of technology and increased efficiency.

Last but not the least, environmental and energy concerns are taking center stage. Indeed, the transportation sector is responsible of a significant amount of greenhouse gas emissions: 13% of all emissions of greenhouse gases and 23% of world CO_2 emissions from fossil fuel combustion (ITF, 2008). The last measure stands at 30% in countries of the Organisation for Economic Co-operation and Development (ITF, 2008) and was 27% in the United States in 2003 (EPA, 2006). It is estimated that the freight transportation contributes roughly a third of the CO_2 emissions of the world transport sector (ITF, 2008). This distribution is uneven, however, being worse in large cities, for example. Thus, a report by the Organisation for Economic Co-operation and Development (OECD, 2003) assigns 43% of sulphur and 61% of particulate matter emissions in London to freight transportation, while for nitrogen oxides emissions, the figures are 28% for London, 50% for Prague, and 77% for Tokyo. These contributions are growing and are expected to continue to grow with the increase in the freight-transportation activity and the corresponding consumption of fossil fuels. The impact on the freight transportation and logistics sector comes both from the initiatives to control, hopefully reduce, emissions and environmental impacts (e.g., vehicle emission legislation and environmental and congestion road pricing) and from the increases in the cost of energy.

These factors have put, and continue to put, tremendous pressure on the freight carriers and the managers of intermodal facilities to reduce and control costs, to plan and operate efficient, timely, and reliable services, and to react rapidly to new customer requests, emerging or shifting business opportunities, and changes in the economic and regulatory environment.

The freight-transportation industry bases a significant part of the answer it offers to these challenges on information and decision technologies: two-way communication, location and tracking devices, electronic data interchange, advanced planning and operation decision-support systems, and so on. Intelligent Transportation Systems integrate and enhance these technologies within the firm, as well as through the linkages and exchanges between the firm and its environment (customers, partners, regulators, etc.). Moreover, the volatility of the stock exchange notwithstanding the trend of e-business development and utilization is clear and strong. This signals to transportation firms, as to other economic agents, that significant opportunities exist in terms of larger and stronger business partnerships, more streamlined, rapid, and demand-responsive decision processes, improved operations and service levels, enhanced customer satisfaction and, ultimately, profitability. To reap the benefits of these opportunities, freight carriers may take advantage of the convergence of ITS and e-business technologies and the possibility of integrated, advanced operations research-based planning and operation decision-support systems.

The purpose of this paper is threefold: (1) to make an assessment of Freight ITS achievements; (2) to illustrate the convergence of Freight ITS and e-business technologies by focusing on electronic auctions; and (3) to show how the introduction of better decision-support software, based on operations research models and methods, could very significantly improve the ultimate performance of these systems.

The paper is organized as follows. We first recall briefly the scope, components, and main enabling technologies of Freight ITS. The next sections are dedicated, respectively, to Commercial Vehicle Operations, Advanced Fleet Management Systems, City Logistics, and a brief exploration of linkages between Freight ITS and e-business. We conclude with a number of perspectives and research and development challenges.

2. Intelligent freight transportation

The core of ITS consists in obtaining, processing, and distributing information for better use of the transportation system, infrastructure and services. It is traditional to examine Freight ITS according to the scope of the systems, classified into two broad classes: *Commercial Vehicle Operations* (*CVO*) for system-wide, regional, national, or continental applications and *Advanced Fleet Management Systems* (*AFMS*) dedicated to the operations of a particular (group of) firm(s). Although different in scope, both categories of systems require a number of enabling technologies, some of which are already firmly established, while others are still emerging. Most of these technologies also enable the e-business activities of the firm.

Prior to examining the components of Freight ITS, it is important to remember that the ITS idea is not a brand new concept emerging suddenly, but rather a logical evolution of transportation management drawing on old and new technologies. What is new about ITS is the vision of a globally integrated framework realising a synergy between previously isolated systems. The rapid and concurrent development of electronic exchanges and partnerships is exacerbating the integration requirements.

Integration for ITS and e-business alike is not a simple task, however, as it must engage with a large array of disparate entities covering three broad areas: technical, political, and geographical. At the technical level, ITS brings together the fields of transportation planning, telecommunications, computing, vehicle and electronics manufacturing, and infrastructure construction. Many stakeholders are involved in the development, deployment, and operation of ITS: government agencies at the national, regional, and municipal levels, highway operators, carriers, equipment manufacturers, system vendors, service operators, etc. They must all collaborate to implement and run a system that is composed of a mixture of public and private assets, means and services. A geographical integration must also be achieved at regional and, in many cases, international levels. An end user, a container carrier for example, would not like to be forced to buy a different set of equipment for each city or country it intends to travel to. Intelligent Transportation systems are all about mobility, they are not meant to infringe on it. The efforts aimed at the development of standards and national architectures attempt to address these issues.

The continuity in the ITS evolution is illustrated by the strong relations between *Electronic Data Interchange* (*EDI*) and freight transportation. One may argue, in fact, that the common ancestor to CVO and AFMS developments is the adoption by the freight-transportation industry of EDI, two-way communication, and vehicle (and cargo) location and tracking technologies (e.g., Allen et al., 1992; Johnson et al., 1992; Crum et al., 1998; Roy et al., 1997; Walton, 1994). This area of development is still going strong.

One can define EDI as the inter-organisation, computer-to-computer exchange of business documentation in a standard, machine processable format (Emmelhainz, 1990). Its popularity has grown rapidly due to customer (shipper or large carrier) requirements as well as to several benefits associated with its use: minimisation of manual data entry, increased transaction speed and accuracy, lower communication costs, and simplification of procedures. Major shippers (e.g., the auto industry), large carriers (e.g., railways) or infrastructure managers (port authorities) have initially promoted the utilisation of EDI in the transportation industry, and they continue to be among the heaviest users of the technology. Smaller carriers followed, motivated mainly by the need to increase customer service and remain competitive. Pre-clearance activities in CVO-equipped corridors or regions and at maritime and land border crossings require the utilisation of EDI for information transmission among shippers, carriers, and officials. EDI supports Advanced Fleet Management Systems not only to enable communications between dispatchers in control centers and vehicle operators in the field, but also to ensure timely and correct data delivery to the planning and monitoring systems of the firm (Golob and Regan, 2000a, 2000b, 2001a, 2001b, 2002a, 2003, 2005). This reinforces the observations that there has to be a critical mass of EDI users in the market before it is financially justifiable (Giannopoulos, 1996; Udo and Pickett, 1994), and that investing in technologies such as EDI may only be profitable when they are fully integrated with other systems within the organisation (Ratliff, 1995).

The continuous improvement and integration of Global Positioning Systems (GPS; Mintsis et al., 2004) and communication technologies resulted in the improvement of their quality (up) and prices (down). This means wider acceptance of these technologies and their utilisation in many modal and intermodal settings. The current focus of Information Technologies development is on wireless communications, the use of Internet, and the integration of the various technologies and data (Hook, 1998; Giannopoulos and McDonald, 1997; see also Giannopoulos, 2004, for a review of information technologies and their integration into ITS from the point of view of the European Community and the series of major projects undertaken in Europe starting in the late 1990s).

EDI, GPS, Automatic Identification Systems and similar technologies are also playing a continuously central role in freight terminals with a significant impact on the performance of transportation systems, particularly intermodal transportation, and logistic chains. Progress has been accomplished in introducing automation and advanced information and (some) decision technologies to freight terminals, port container terminals in particular (e.g., Arendt and Speidel, 1999; Bozzo et al., 2001; Dürr and Giannopoulos, 2003; Giannopoulos, 2001; Giannopoulos and Shinakis, 1999; Lee-Partridge et al., 2000). Considerable efforts are still being undertaken, while many innovative projects are proposed around the world. These developments are paralleled by an international effort to agree on standards for EDI exchanges not only for the transportation industry, but also for the whole range of logistics and value ("supply") chain activities.

The procedures related to logistics and intermodal transports are complex and often cumbersome, particularly at the international level. At work are numerous interactions between different parties with different objectives and operation policies. If intermodal transportation and supply chains are to operate efficiently and effectively, the relationships, actions, and terms used by the different participants must be understood by all. Efficiency and accountability require the seamless exchange of accurate, complete, and timely data among stakeholders. This requirement is further heightened by the growing understanding of needs for security of transport information, and for transfer of information related to security against terrorism, illegal immigration, as well as theft and traditional contraband. Several international organizations and committees focus on these issues for various types of transportation-related activities.

It is remarkable that EDI was one of the strongest initial enabling factors of partnerships and alliances between large numbers of carriers and shippers, before "electronic commerce" became a household name. This trend is actually leading to the electronic integration of carriers, operators of intermodal transfer facilities, and shippers with common interests in the movement of certain commodity groups or the utilisation of particular infrastructures (Sunstrum and Howard, 1996; Crainic et al., 2006). Information technologies and appropriate planning and operating management methods and instruments are required to support and enhance such virtual business-to-business communities of interest.

3. Commercial Vehicle Operations (CVO)

The Commercial Vehicle Operations (CVO) area of ITS has been defined as "Advanced systems aimed at simplifying and automating freight and fleet management operations at the institutional level", Commercial Vehicle Information Systems and Networks (CVISN) programs targeting, in particular, safety information exchanges, electronic credentials administration, and roadside electronic screening.

National or regional authorities, in collaboration with carriers and firms that propose the required technologies, usually initiate CVO projects. The goal is to increase the performance of the infrastructure (mostly highways) and customs systems, simplify and automate government control-related freight and fleet management operations, and, thus, enhance the efficiency of commercial vehicle activities through seamless operations based on electronic vehicle and cargo identification, location and tracking, pre-clearance and in-motion verifications. These systems rely heavily on vehicle or cargo positioning systems (GPS or radio frequency networks), bi-directional communications (DSRC, radio, satellite, or wireless phone), and EDI. The importance of CVO applications has been acknowledged quite early on in ITS history, and a significant number of CVO projects have been undertaken or are currently under way.

Initial deployment efforts of CVO technologies have been organised around the so-called "corridors". A corridor is typically organised around a major highway, or a system of highways, that cross several regional or national jurisdictions. The goal is to increase the fluidity of truck traffic and to offer seamless interstate or inter-nation border crossings, while ensuring adequate levels of control and reporting relative to regulations on safety, traffic, customs, and so on. Weight-in-motion scales, overweight detectors, EDI, automatic vehicle (and cargo) identification and classification systems, vision technology (to read license plates), and variable message signs are among the main technologies used. Corridor projects usually involve national and local governments and agencies, private technology providers (who, sometimes, also contribute significantly to the financing of the technology deployment), and, obviously, carriers.

Several corridor projects have been undertaken in the second half of the 1990s (Crainic et al., 2000, 2001). In the United States, these efforts have led to the establishment of two major continental systems, the *North American Preclearance and Safety System* (*NORPASS*) and the *PrePass* Program (Slevin, 1999). In July 2008, NORPASS (WR2) included 11 members and partner states/provinces in the United States and Canada, while the PrePass (WR3) network covered 49 states. In July 2008, some 425,000 trucks were enrolled with PrePass, which represents an almost 100% increase in 4 years. Both systems offer essentially the same services, weight station bypass (weight-in-motion when available) and are based on transponder technology. The technology now offers transponders that may be used with both systems. A carrier using such transponders and aiming to operate within both systems must register with each system separately, however, and pay the appropriate fees. Both systems offer compatibility with other transponder-based systems, e.g., electronic tolls and terminal access.

The *TruckScan system* installed in the state of New South Wales in Australia (Reid and Myers, 1996; WR9) uses visual recognition systems coupled to electronic databases, in-motion screening testing for weight (per axle and overall), length and height, and vehicle guidance signs and tracking systems. This passive system is designed to automate and improve the roadside checking of vehicles. Various in-motion verification, monitoring, and pre-clearance systems are also deployed by Canadian Provinces (Fu et al., 2003).

In Japan, the emphasis is on the real-time collection of truck operational status and its distribution as basic data to operators, in line with the heavy promotion and use of advanced traveler information systems and in-vehicle navigation systems. Efforts are also directed toward the development of integrated and automated terminals, also called "logistic centers", new road management system with dedicated lines for freight vehicles, and an advanced road–vehicle communication and cruise-assist system (MLITT, 2007, 2008).

In the European Community, the European Commission and the member states have embarked on a comprehensive effort of research, development, and deployment of ITS. It is an exemplary effort in its reach and scope, as well as in the framework it established for collaboration and partnership among all the stakeholders – government and public agencies, private firms, consulting bureaux, universities, research centers, and so on. The website of ERTICO (WR4) together with those of its members details the many European projects. Two main directions are defined for Freight ITS in the policy of the European Commission (the White Paper and measures to support freight transport may be found on the site of Directorate General for Energy and Transport, WR5). The first concerns the connection of the countries of Central and East Europe to the rest of the continent. ITS is seen as an essential tool to achieve this objective. The second direction concerns the development of intermodal transportation as the main mechanism to influence the current mode choice that is heavily biased toward trucks and highways. The document argues that the improvement of infrastructures, such as ports, and the enhancement of information and decision systems, will result in some of the cargo currently "on the road" to move to less environmentally invasive means of transportation such as rail and coastal and fluvial navigation.

A major class of CVO projects, particularly widespread in North America, concerns border-crossing operations. This area has acquired a sense of urgency and high priority following the terrorist attacks on the United States and the continuing terrorist threat. Ports have thus become prime targets for ITS and e-business projects with security issues as the driving objective. While the urgency has been primarily felt in the United States (WR1; TRB, 2002), border CVO systems are being developed worldwide. The main goal was and continues to be to clear drivers, vehicles, and cargo in order to speed up the passage of vehicles (trucks, containers, railcars) carrying manufactured and agricultural goods through the border inspection facilities, within the parameters set by the border control requirements in terms of security, immigration, illicit cargo, agricultural controls, etc.

The current state of the world affairs and the US response has elevated these issues at a level of urgency and complexity never felt before. The creation in the United States, in Canada, and elsewhere of new government structures dedicated to security issues including customs and border control illustrates this urgency.

Several security policies significantly increase delays at ports and border crossings and thus influence the efficiency of commerce and supply chains. Among others, the US Customs Container Security Initiative (WR6) requires the inspection and pre-clearance of containers *before* they leave the port of origin or the last major transhipment port. The US Customs and Border Protection agency also requires advanced transmission of cargo information for shipments destined for the United States. Systems are being deployed to mitigate the associated significantly longer delays. For instance, US, Canadian, and Mexican customs commercial programs are being aligned (the *Free and Secure Trade*, *FAST*, program) to support moving preapproved goods quickly across borders. The program is based on registering and pre-approving import/export firms (shippers), carriers, and drivers.

For ports and border ITS/CVO, as for most other ITS areas, the development of the "intelligence" part must accompany that of the hardware and the availability of information. Very few efforts have been undertaken in this area, however. The determination of the optimal number of containers to be inspected to satisfy the security requirements and to limit the delays in ports is an example of such a topic (Lee et al., 2008; Lewis et al., 2002, 2003). Many challenges and opportunities are also offered by the intense automation of container terminals in ports (Crainic and Kim, 2007).

4. Advanced Fleet Management Systems (AFMS)

This type of Freight ITS applications corresponds to "Advanced systems aimed at simplifying and automating freight and fleet management operations at the carrier or business-to-business level", or AFMS for short.

Once the fleet is equipped and linked to the dispatchers' computers and company's data processing and storage infrastructure, a huge quantity of data becomes available for immediate decisions, as well as for background analysis and planning activities. Advanced Fleet Planning and Operation Systems aim to process this information and to integrate it to the current transportation plan to achieve a more timely operation, efficient allocation and utilization of the fleet, and satisfaction of customer requests. Differently put, similarly to other ITS areas, there is the need to infuse these systems with intelligence. This need is more and more widely acknowledged, and it is directly reflected in the national ITS architecture proposals.

Developments, challenges, and opportunities occur at the level of a carrier or of groups of carriers, shippers, and agencies joined through business-to-business networks in both urban centers and over large areas. A number of applications already exist. Some are implemented. Most still appear as proposals and prototypes out of research centers and laboratories. More may still be accomplished, however. In the following, we attempt to single out a number of important probable and feasible developments that will use the ITS infrastructure and architecture to do more and perform better.

Operations research offers the methodology to represent problems and to identify solution strategies through various optimization and simulation techniques. Such approaches have demonstrated their central role in designing efficient and powerful decision-support systems for the planning and operations of transportation systems, and are uniquely positioned to assist the transformation of the huge quantity of data provided by ITS into timely and meaningful information for intelligent decisions and operations. Operations research principles, models, and methods are increasingly found at the core of Advanced Fleet Management Systems. Bodin et al. (2003), Crainic (2003), Crainic and Kim (2007), Crainic and Laporte (1997), Powell (2003), Powell and Topaloglu (2003, 2005), Powell et al. (1995, 2007), Christiansen et al. (2007), Toth and Vigo (2002), etc. present general survey of operations research methodologies for freight-transportation planning and operations. Séguin et al. (1997) present a general framework for operations research methodologies in real-time decision-making.

Most current developments and a significant part of contemplated future applications address operational issues, load matching and resource allocation, dispatching, and routing, in particular. The principal goal of these systems is to offer the possibility to control and coordinate operations in *real-time*.

Indeed, in a typical large or medium-sized city, many private firms and public organizations operate fleets of vehicles of different types to cater to various needs of the population: emergency vehicles (fire trucks, ambulances, etc.), police cars, commercial delivery vehicles, taxis, courier fleets, etc. Some of these fleets have to perform tasks that may be known well in advance or that are sometimes repetitive (e.g., vehicles making regular deliveries to food and retail stores). Many of them, however, operate essentially in a demand-responsive mode: the demands for services are not known beforehand and the fleet has to be deployed and managed (re-routed) in real-time to handle them as effectively as possible. The same description applies to ‘‘local” pick up and delivery operations performed within a relatively short time period (e.g., a day) in the surrounding area of major intermodal terminals such as ports and major rail yards (Barnhart and Kim, 1995).

Carriers that ensure interurban, long-haul transportation services also evolve in highly dynamic environments and face similar challenges. Full-load motor-carriers and container transportation companies offer typical examples of such requirements. On the one hand, most demands for empty vehicles arrive dynamically, are very difficult to forecast accurately, and require instantaneous decisions (the customer is on the phone or Internet line) regarding the most appropriate combination of vehicle, tractor, crew, etc., to service the demand. On the other hand, a decision has to be made concerning the next assignment of a vehicle as soon as it has completed its current task and is empty. Each such ‘‘local” decision has a non-negligible impact on the future deployment of the fleet and thus on the long-term efficiency and profitability of operations. The complexity of the impact evaluation is further complicated by the length of the planning horizon, significantly longer in interurban operations than for urban transportation.

The deployment of ITS technologies, in particular accurate positioning devices and in-vehicle computing and communication equipments, opens up the possibility of enhanced customer service and increased productivity by re-routing vehicles in real-time to serve new requests. The information is there. One only needs the appropriate methodology to transform these data into accurate and timely decisions. It is thus normal that a significant line of research addresses the issues of real-time dispatching, routing, and re-routing of vehicles in response to changes in demand (Ichoua et al., 2007), travel time (Fleischmann et al., 2004; Potvin et al., 2006; Topaloglu, 2006) or other conditions of travel. This information can be conveyed via Advanced Traveller Information Systems, as well as wireless or on-board communication devices.

Traditionally, the organisations facing real-time demands have relied on human dispatchers to manage their fleets. As with any other system relying heavily on human intervention, the performance of these fleets was strongly dependent upon the quality and the experience of their dispatchers. Among other factors, cognitive limitations make it extremely difficult for human dispatchers to effectively monitor and control fleets made up of a large number of vehicles, a situation frequently encountered in many applications. From a modelling standpoint, fleet management problems correspond to combinatorial optimisation problems (e.g., vehicle routing, covering, or design problems) that are notoriously difficult to solve, even in a static context. This, coupled with real-time requirements, explains to a large extent the reliance up to now on human dispatchers. Fortunately, recent developments in the area of algorithms, in particular the emergence of powerful meta-heuristics, and advances in computing technology, in particular distributed and parallel computing, now make it possible to contemplate tackling in real-time large combinatorial problems in a reasonably effective way. In fact, currently, the main obstacle in most AFMS applications is the need to handle dynamic (stochastic) data.

Interestingly enough, it seems that in some applications simple schemes can be devised to address this issue. The simplest that one can come up with is certainly to base current decisions on the current information. Actual experiments with this scheme in the context of courier applications showed that it could be surprisingly effective (Gendreau et al., 1999, 2006). In most cases, however, such a myopic strategy cannot account for the future consequences of current decisions and policies that try to anticipate future events generally dominate it (Bent and Van Hentenryck, 2004; Branke et al., 2005; Ichoua et al., 2006; Mitrović-Minić et al., 2004; Mitrović-Minić and Laporte, 2004; Powell, 1988; Powell et al., 2000; Spivey and Powell, 2004; Yang et al., 1999, 2004).

The class of dynamic vehicle routing formulations offers a methodological framework to many real-time routing problems encountered in the Freight ITS domain. As already mentioned, these are difficult problems to solve (Powell et al., 1995). Yet, meta-heuristics, and particularly tabu search (Glover and Laguna, 1997), have demonstrated their ability to address adequately these challenges (Gendreau and Potvin, 1998; Gendreau et al., 2002). Most applications address local-area problems, which are the cases where the geographical region is limited and vehicles (and drivers) return at their home bases at the end of the day. Distribution (pick up and delivery) problems in urban zones belong to this large class of applications, which includes the local operations of interurban Less-Than-Truckload (LTL) motor carriers. It is also in this context that most of the studies aimed at real-time dispatching and routing of vehicles have been undertaken. Gendreau et al. (1996, 1999, 2006) proposed adaptive-memory tabu search procedures and parallel implementations that ensure an efficient optimisation of the routes. Experiments performed using discrete-event simulators showed the superiority of sophisticated optimisation approaches to handle real-time demands as compared to simpler, classical heuristics (Gendreau et al., 1999).

Dynamic traffic simulation offers an alternate approach. Simulation certainly offers the tools to explore and validate operating strategies and appears as part of the core methodology for predicting travel times for Advanced Traffic Management and Traveller Information systems (ATMS). Its precise role in actual real-time dispatching and routing of vehicles has yet to be assessed, however. The challenges here are very similar to those of the ATMS area. The initial exploration of the subject by Taniguchi et al. (1999) is an encouragement to further pursue research in this direction.

Very few efforts have been dedicated to real-time re-routing of vehicles to satisfy new demands over larger geographical regions and longer periods. Reagan et al. (1995, 1996a,b) explored various local rules for the dynamic assignment of loads under real-time information. Simulation experiments tend to indicate that these rules perform relatively well in a stochastic environment (Reagan et al., 1998). Additional comparisons to a rolling-horizon, dynamic assignment formulation offer interesting results (Yang et al., 1999, 2004). However, not all strategies are efficient and the information context may influence the impact of stochastic assignment rules. Clearly, more research is required in this area.

The studies mentioned in the preceding paragraph address issues that belong to the large class of dynamic fleet management problems (Crainic, 2003; Crainic and Laporte, 1997; Powell et al., 1995, 2007; Zeimpekis et al., 2007). Here, limited resources are dynamically allocated to requests and tasks: empty vehicles, trailers and rail cars are allocated to the appropriate terminals, motive power tractors and locomotives to services, crews to movements or services, customer loads to driver–truck combinations, empty containers from depots to customers and returning containers from customers to depots, and so on. Dynamic and stochastic network formulations have been, and continue to be, extensively studied for these problems (e.g., Godfrey and Powell, 2002a,b). This has resulted in important modelling and algorithmic results, a number of which have been transferred to industry (e.g., Armacost et al., 2004; Attanasio et al., 2007; Powell et al., 1992, 2002). Moreover, recent methodological advances allow to simultaneously manage in real-time, when required, several resources (Powell, 2003; Powell et al., 2002, 2007; Powell and Topaloglu, 2005; Spivey and Powell, 2004). This is an extremely rich field for research, development, and application, and it naturally dovetails the Freight ITS and E-logistics areas.

A critical issue in real-time settings is that of response time. In situations such as emergency vehicle management, or when a customer is waiting for a decision, there is no time to compute an "optimal" response when a call is received. This does not preclude, however, the use of deliberate decision-making to optimise the response: one simply has to find ways of anticipating future events in an effective fashion. Thus, for example, one may combine data processing and forecasting methods, optimisation-simulation models, and decision heuristics into comprehensive decision-support systems. The optimisation-simulation models continuously generate and evaluate future conditions and deployment scenarios, while rapid, simpler heuristics respond in real-time to customer requests or changing conditions (congestion, accidents, and so on). Note, however, that this may result in significant computational requirements, since one has to prepare for many potential outcomes. Parallel computing may help address this issue as well as provide more robust solutions (Gendreau et al., 2001; Crainic, 2008).

While custom-service transportation firms, such as truckload motor carriers, would appear as prime beneficiaries of ITS, consolidation-type carriers, e.g., railroads, LTL motor carriers, and intermodal and express courier firms, may also attain substantial gains by using advanced information and decision technologies. Of course, the local pick up and delivery operations of these firms are similar to those described earlier on and would enjoy the same benefits. Similarly, the control in real-time of vehicles during their long-haul journeys (trucks speeding on highways or the pacing of trains) may be significantly improved by the use of ITS technologies.

A very promising research and development avenue consists in a better integration of the information obtained in real-time and the planning and dispatching tools and systems available to consolidation-type carriers. We have already mentioned the possibility to re-route a vehicle already dispatched to serve a new customer or to avoid a congested area (due to an incident, for example). The timely availability of accurate data may enhance the planning of other important activities such as driver and vehicle assignment and empty vehicle management. The connection of port, customs, and carrier intelligent information and decision systems could enable the scheduling and smooth operation of advanced transportation systems, such as the rail intermodal services operating according to strict schedules and recently introduced full-asset-utilization policies (Bektaş and Crainic, 2008; Crainic et al., 2006).

Another area of potential benefits for consolidation carriers resides in a more efficient scheduling of terminal operations and resources. Thus, for example, a terminal working schedule that smoothes out the workload and reduces overtime and terminal congestion could be produced through an analysis of dispatch decisions at the various terminals in the network, combined with real-time data on the location and load of the vehicles and the results of the optimisation-based scenario analysis described above. Similarly, data that are more accurate are available for adjusting the maintenance planning process to real-time events during actual operations. Not many studies have been dedicated to these promising areas yet.

A more challenging area concerns the interactions between the planning of operations, the availability of real-time data, and the actual implementation of transportation plans in an ITS environment. A number of methodologies and decision-support systems to assist the planning and operations of freight carriers and terminal facilities exist (e.g., the surveys by Crainic

(2003), Crainic and Kim (2007), Günther and Kim (2005) and Steenken et al. (2004)). Most are based on static formulations using the carrier's historic data and forecasts. The advent of ITS location and communication technologies offers the possibility to dramatically enhance the quantity and quality of the data available for the forecast and planning processes. This should translate into better plans and operations that are more profitable.

Parallel and distributed computing is an enabling factor for ITS in general and CVO-AFMS in particular. Its challenges are of two different but complementary natures. On the one hand, parallel computing offers the possibility to design data analysis and decision-support system architectures to answer efficiently complex requests in real or quasi-real time. Thus, processors may be dedicated to the various tasks of receiving, validating, and formatting data, analysing and aggregating it, forecasting, background simulation-optimisation, real-time selection of the appropriate strategy, etc. On the other hand, parallel computing also offers a challenging perspective with potentially great rewards: to solve realistically formulated and dimensioned problem instances within reasonable times. Each class of problems and algorithms presents its own challenges. It appears clearly, however, that research efforts have to be dedicated both to the decomposition and distribution of tasks corresponding to one particular problem instance and algorithm, and to the development of co-operating search mechanisms that bring to bear on any given problem instance the combined power of several exact methods and meta-heuristics.

5. City Logistics

The transportation of goods constitutes an extremely important activity within urban areas. For people, it directly ensures adequate supplies to stores and places of work and leisure, as well as delivery of goods at home. For firms established within the city limits, it forms a vital link with suppliers and customers. There are few activities going on in a city that do not require at least some commodities being moved. Moreover, the urban freight-transportation industry is a major source of employment. Yet, freight transportation is also a disturbing activity in urban centres. Vehicles carrying freight move on the same streets and arteries as the private and public vehicles transporting people. These vehicles make a significant contribution to congestion and environmental nuisances, such as emissions and noise, that impact adversely the quality of life in urban centres (OECD, 2003; Patier, 2002; Figliozzi, 2007). Freight traffic also contributes to the belief that "cities are not safe," which pushes numerous citizens to move out of the city limits. Moreover, the problem is not going to go away any time soon. In fact, the already significant volume of freight vehicles moving within the city limits is growing, and is expected to continue growing at a fast rate. Other than the reasons discussed in Section 1, a major contributing factor to this phenomenon is the worldwide urbanization trend, which is emptying the countryside and small towns and is making large cities even larger. Within the countries members of the OECD, the urban population represented 50% of the total in 1950, 77% in 2000, and should reach the 85% mark by 2020 (OECD, 2003). It is estimated that in 2007, for the first time in recorded history, the worldwide urban population became larger than the rural population.

New organizational models for the management of freight movements within the city are proposed to address these issues. The fundamental idea of *City Logistics* is to stop considering each shipment, company, and vehicle in isolation, but rather as components of an integrated logistics system to be optimized. Coordination and consolidation are at the basis of this idea: Coordination of shippers and carriers and consolidation of shipments of different shippers, carriers, and customers within the same energy-efficient and environmentally-friendly vehicles. City Logistics aims to optimize this system, and ITS is acknowledged as a fundamental component and enabling factor (Taniguchi et al., 2001). The goals are to reduce congestion and increase mobility; reduce emissions, pollution, and noise; contribute to reach the Kyoto agreement targets; improve the life conditions of the city inhabitants; avoid penalizing the city centre activities such as not to "empty" it.

City Logistics challenges the city authorities, businesses, carriers, and citizens in their relation to freight transportation and requires public–private understanding, collaboration, and innovative partnerships. City Logistics also challenges operations research to develop the appropriate design, evaluation, planning, and operation models, methods, and decision-support systems. Contributions answering this challenge are still in limited number, however.

Historically, one finds a brief period of intense activity at the beginning of the 1970s dedicated to urban freight-transportation issues. This period yielded traffic regulation to avoid the presence of heavy vehicles in cities to limit the impact of freight transport on automobile movements. Very little activity took place from 1975 to the end of the 1980s. The increased traffic-related problems and the associated public pressure have revived the interest from 1990 on, and have resulted in significant research activities, prototypes, and deployments, some of which continue to operate. The initial developments took place mainly in the countries of the European Union and Japan. Several business models and policies were proposed and tested, but ITS and operations research-based decision technologies were very little used, if at all. More details of these early contributions may be found in van Duin (1997), Kohler (1997, 2001), Ruske (1994), Taniguchi et al. (2000, 2001), and Thompson and Taniguchi (2001). The situation started to change with the new millennium. More countries and cities around the globe are contemplating or introducing City Logistics policies and systems (but still quite limited in North America), and the role of ITS and operations research is increasingly acknowledged. More detailed information may be found in, e.g., Benjelloun and Crainic (2008), Benjelloun et al. (2008), Dablanc (2007), Russo and Comi (2004), Taniguchi et al. (2001), Thompson and Taniguchi (2001), WR6, WR7, and WR8.

The concept of *City Distribution Center* (CDC) is instrumental in most City Logistics proposals and developments. A CDC is a facility where shipments are consolidated prior to distribution. It is noteworthy that the concept of CDC as physical facility is close to those of intermodal *logistic platforms* and *freight villages* that receive large trucks and smaller vehicles dedicated to local distribution, and offer storage, sorting, and consolidation (de-consolidation) facilities, as well as a number of related services such as accounting, legal counsel and brokerage. They may be stand-alone facilities situated close to the access or ring highways, or they may be part of air, rail or navigation terminals. City distribution centers may then be viewed as intermodal platforms with enhanced functionality to ensure coordinated and efficient freight movements within the urban zone, and constitute an important step toward a better City Logistics organization.

Most City Logistics projects address single-tier CDC-based systems, i.e., systems where delivery circuits are performed directly from a single CDC. Such approaches have not been successful for large cities, however, in particular in the large city-center areas one aims to control and display high levels of population density as well as commercial, administrative, and cultural activities (Dablanc, 2007). Another characteristic of large cities which plays against single-tier systems, is the rather lengthy distances vehicles must travel from the CDC on the outskirts of the city until the city center where the delivery tour begins, and the fact that vehicles with dimensions appropriate for such distances often do not have access to the city-center street network. Multi-tier systems have been proposed for such cities, e.g., a three-tier (road–tram–road) system for Amsterdam (http://www.citycargo.nl/) and two-tier systems for Rome (Crainic et al., 2004, 2007; Gragnani et al., 2004).

Multi-tier systems build on and expand the CDC idea, as illustrated by the two-tier City Logistics concept of Crainic et al. (2004, 2007) (Gragnani et al. (2004) present a simpler proposal). CDCs form the first level of the system and are located on the outskirts of the urban zone. The second tier of the system is constituted of satellite platforms, *satellites* for short, where the freight coming from the CDCs and, eventually, other external points may be transferred to and consolidated into vehicles adapted for utilization in dense city zones. In the more advanced systems, satellites do not perform any vehicle-waiting or warehousing activities, vehicle synchronization and transdock transhipment being the operational model. Existing facilities, e.g., underground parking lots or municipal bus garages, could thus be used for satellite activities. Two types of vehicles are involved in a two-tier City Logistics system, and both are supposed to be environmentally friendly. *Urban-trucks* move freight to satellites, possibly by using routes specially selected to facilitate access to satellites and reduce the impact on traffic and on the environment. They may visit more than one satellite during a trip. Their routes and departures have to be optimized and coordinated with satellite and city-freighter access and availability. *City-freighters* are vehicles of relatively small capacity that can travel along any street in the city to perform the required distribution activities. The objective is to have urban-trucks and city-freighters on the city streets and at satellites on a "need-to-be-there" basis, while providing timely delivery of loads to customers and economically through environmentally efficient operations.

Similarly to any complex system, City Logistics transportation systems require planning at the strategic, tactic, and operational levels (Benjelloun and Crainic, 2008). The strategic level is concerned with the design of the system and the evaluation of City Logistics proposals and systems. The latter activity refers to the study of the probable behaviour and performance of proposed or deployed systems, and the planning of their evolution, under a broad range of scenarios, both as stand-alone systems and in relation to the general transportation system of the city and the larger region that encompasses it. While very few formal models have been proposed specifically for City Logistics (Taniguchi and van der Heijden, 2000; Taniguchi et al., 2001; Taniguchi and Thompson, 2002), these issues are generally part of transportation-system planning methodologies, which are well known, particularly for passenger transportation within urban zones, but also for passenger and freight regional/national planning (e.g., Cascetta, 2001; Crainic and Florian, 2008; Florian, 2008). The main components of such methodologies are: *Supply modeling* to represent the transportation infrastructure and services with their operation characteristics and economic, service, and performance measures and criteria; *Demand modeling* to capture the product definition, identify producers, shippers, and intermediaries, represent production, consumption, and point-to-point distribution volumes, and determine the *mode choice* for particular products or origin–destination markets; *Assignment* of multicommodity flows (from the demand model) to the multimode network (the supply representation). This procedure simulates the behaviour of the transportation system and its output forms the basis for the strategic analyses and planning activities.

A few models have been proposed for evaluating the freight movement demand within urban areas (see Gentile and Vigo, 2007, for a recent review). Most are descriptive models based on economic principles and extensive surveys in large cities (e.g., Patier, 2002; Ambrosini and Routhier, 2004; Friedrich et al., 2003; Boerkamps and van Binsbergen, 1999). A gravity-based methodology is presented in Gentile and Vigo (2007). The models integrate elements representing the city topology, traffic regulation, and some representation of the logistics chains and vehicle tours used to move products within major product classes. Significant work is still required in this area, however, to integrate City Logistics considerations to demand modelling.

The supply and assignment aspects are even less developed. The former requires decisions on the number, location, and characteristics of facilities, CDC, satellites, etc. The models should also select the City Logistics network, e.g., the access corridors and the street networks open to each vehicle type and the determination of the vehicle fleets composition and size. We are aware of only two contributions, Taniguchi et al. (1999) and Crainic et al. (2004), targeting these important and challenging issues.

The assignment step requires simulating the behaviour of the system under various scenarios relative to the system organization and the social, economic, and regulatory environment. Dynamic traffic simulation, where passenger and other freight vehicles may be considered as well, appears as the methodology of choice for such evaluations. City Logistics simulators require methods to represent how vehicles and flows would circulate through the city, and how the proposed infrastructures services would be used under the conditions of a given scenario. These are the same tactical and, eventually, dynamic routing models and methods that are also required to plan and control operations for an actual system. We are aware of only one contribution, where a traffic micro-simulator is coupled to a City Logistics dynamic routing model (Barceló et al., 2007). This methodology has been used to evaluate City Logistics projects for small European cities, but appears difficult to scale for larger urban areas. Mezo-traffic simulators coupled to tactical planning models offer more promising perspectives for larger urban zones, but no such contribution has been made yet.

City Logistics systems rely on consolidation. Tactical planning for consolidation-based transportation systems aims to build a plan to provide for efficient operations and resource utilization, while satisfying the demand for transportation within the quality criteria (e.g., delivery time) publicized or agreed upon with the respective customers (see, e.g., the surveys of Crainic (2000) and Crainic and Kim (2007)). The same issues must be addressed in a City Logistics context, but for a shorter planning horizon due to the day-to-day demand variability. Tactical planning models for City Logistics concern the departure times, routes, and loads of vehicles, the routing of demand and, when appropriate, the utilization of the satellites and the distribution of work among those. Tactical planning models assist the deployment of resources and the planning of operations and guide the real-time operations of the system. They are also important components of models and procedures to evaluate City Logistics systems, from initial proposals to deployment scenarios and operation policies. According to the best knowledge of the authors, Crainic et al. (2007) are the only contributors targeting these issues.

On the operational side, issues related to the work schedules of vehicles, drivers, and terminal personnel must be addressed, as well as the control and dynamic adjustment of vehicle and terminal operations within an ITS environment. We are not aware of any specific contribution to the first topic, and only a few papers deal with the second, focusing generally on the operations of a single fleet within a limited part of the city (Taniguchi et al., 2001; Thompson, 2004). Again, much work is required before City Logistics enjoys the same level of methodological richness as the other, more traditional, transportation systems.

6. CVO/AFMS and e-business

While there have been ups and downs in its development, e-business is now a central element of everyday life. From the standpoint of transportation firms, as for other economic agents, this means that significant opportunities exist in terms of larger and stronger business partnerships, more streamlined, rapid, and demand-responsive decision processes, improved operations and service levels, enhanced customer satisfaction and, ultimately, profitability. To reap the benefits of these opportunities, transportation carriers may take advantage of the convergence between ITS and e-business technologies.

The definition and development of Intelligent Transportation Systems concepts and technologies started well before the business community realized the potential of Internet-based operations, and electronic commerce started to penetrate the business-to-consumer and business-to-business exchange world. The two application domains share several characteristics and enabling technologies, including information and decision technologies, two-way communications, electronic data interchange, computing and data handling technologies, advanced planning and operation decision-support systems (Crainic and Gendreau, 2003).

These links appear even more clearly when one observes that the vast majority of business transactions are part of logistics activities. *E-logistics* aims to perform the traditional logistics goals (plan, manage, and control the efficient movement of goods, information, and money) within the "new" environment of partner integration and seamless electronic exchanges (Crainic and Speranza, 2008). The technologies required to manage the fleets and interact with external partners are similar to those encountered in Freight ITS.

An interesting development that may directly and significantly affect the operations and performances of freight carriers and their customers is the emergence of Internet-based community of interests and electronic auction mechanisms. The virtual market places that implement freight exchanges offer carriers the perspective of an easier access to loads and smoother operations. This is certainly true for full-load carriers, but it also presents significant opportunities for consolidation-type companies, LTL motor carriers in particular. The loads that could be obtained by accessing these markets would reduce the need to move empty vehicles to balance the operations. Such markets complement the more traditional auctions of distribution routes of major industrial or retail firms (Ledyard et al., 2002).

A number of such markets have started to appear. The market mechanisms do not appear very sophisticated, however. Significant development is required in this area, particularly concerning the possibility to bid on *bundles* of loads simultaneously. This need stems from the fact that the value of a load to a carrier will very often depend on whether one or several other loads may be secured for the same vehicle to ensure that it is moving loaded most of the time (Chang et al., 2002a; Figliozzi et al., 2002, 2003). Markets where items need to be negotiated in bundles already exist in various settings, such as the allocation of airport take-off and landing time slots (Rassenti et al., 1982), of wireless communications spectrum licenses (McMillan, 1994), of distribution routes (Caplice and Sheffi, 2003; Elmaghraby and Keskinocak, 2004; Ledyard et al., 2002; Sheffi, 2004), and in supply chain formation and coordination (Walsh et al., 2000). All these cases have one thing in common: they all trade items of a different nature that are interrelated from the perspective of the participants: the value of one item to a participant depends on whether the participant managed to obtain (or sell) a number of *other* items, whether these items are *complementary* (the value to the participant of the full set of desired items is greater than the sum of the values of individual items) or *substitutable* (the value to the participant of the full set of desired items is smaller than the sum of the values of individual items). Loads or containers that can be delivered sequentially by the same vehicle are complementary, while loads that are available at about the same time, between the same pair of cities, are substitutable.

Auctions in which participants are allowed to bid directly on attractive bundles are called *combinatorial auctions*. Being able to bid on bundles clearly mitigates the *exposure problem*, which arises when one gains too few or too many of the items desired, since it gives the participants the option to bid their precise valuations for any collection of items they desire. On the other hand, combinatorial auctions require more complex operations research mechanisms to determine load allocations and the corresponding prices (Abrache et al., 2004, 2007; de Vries and Vohra, 2003; Park and Rothkopf, 2005; Rothkopf et al., 1988; Rothkopf and Park, 2001; Figliozzi et al., 2005). Significant research is currently dedicated to combinatorial auction mechanism design issues, as well as to the associated operations research and combinatorial optimization methodologies. These efforts have already resulted in the successful utilization of combinatorial auctions in many applications.

Participants to combinatorial auctions also face serious challenges. Yet, not much research has been dedicated to these issues up to now. The first and foremost challenge faced by the participants in electronic auctions is clearly to identify which items are of interest to them and acceptable price ranges for these items. This is obviously further compounded in the case of combinatorial auctions by the need to build attractive bundles and to price them (Figliozzi et al., 2006; Kuo and Miller-Hooks, 2008; Kwon et al., 2005; Song and Regan, 2004, 2005; Lee et al., 2007; Ma, 2008). A very promising research direction is offered by the development of the so-called *advisors* based on enhanced Advanced Fleet Management Systems to assist carriers when participating to auctions. These advisors may be defined as specialized decision-support software specifically designed to support the participants in the complicated negotiation processes involved in the most sophisticated electronic markets, such as simultaneous auctions for several goods, sequences of sequential auctions or combinatorial auctions. Advisors may have several functions, according to the degree of sophistication of the firm in relation to Internet and the cyberspace: identify promising market places and loads, assess the competition, build and price bids, determine a bidding strategy, conduct the negotiation, close the deal, etc. For most of these functions, the associated models and methods are encapsulated into software agents that help automate the negotiation process. In the following, we focus on one of the critical and most difficult functions: the construction and pricing of bids. Furthermore, we restrict our discussion to freight exchanges, which offer the greatest challenges to participants.

The problem appears simple to state. A number of loads are available on one or several markets. Each load has a number of characteristics, including: time of appearance and duration on the market, time window for pick up and delivery, technical requirements (e.g., refrigerated vehicles), service quality requirements, etc, as well as a maximum price the shipper is ready to pay (this information may be explicitly displayed or not). The carrier has one or several vehicles that could be used to serve one or more of these loads. Each vehicle is (or will be) available at a certain moment and location, and is requested to be at a given location at some specified time (for a confirmed order, maintenance, crew change or rest period, etc.). The carrier aims to determine sets of loads, one for each vehicle, eventually, that would maximize its profit. The difficulty comes from several sources, in particular, how to estimate the possible revenue for any given load and how to determine the best set of loads to maximize overall profit.

Revenue estimation for specific loads is difficult because when a carrier starts bidding on a load, it may have no idea of the price at which it will finally be adjudicated. This would be of rather little importance if the carrier were interested only in this load, since in that case, all it would need to do is to bid on the load as long as it is profitable. In reality, the carrier is also faced with several other loads, complimentary or substitutable, and needs to derive an estimate of the going price of each load *before it is auctioned*. Analysis of bidding strategies and knowledge of other carriers' behaviour in similar past auctions can be extremely useful in that context (An et al., 2004, 2005; Chang et al., 2002b; Ergun et al., 2007; Figliozzi et al., 2002, 2003, 2004; Garrido, 2007). It is also important to note that the advisor component that is responsible for addressing these questions is truly unique and has little to do with the operations management software that may be used by a carrier for its fleet.

The choice of the best bundles of loads in a given setting brings us back to traditional carrier interrogations: what are the attractive loads? Which one to assign to a given vehicle? How much to charge the shipper? This realization clearly highlights the fact that advisors or advisor components handling these functions should be extensions of software for fleet management. We distinguish between two broad classes of advisors: *independent advisors*, in which the evaluation–selection function is performed independently from the planning process of the carrier, and *tightly coupled advisors*, in which this function is integrated into the planning process. The main reason for introducing this distinction stems from the desired *modus operandi* of a specific carrier: the firm may not find desirable, or even feasible, to operate its planning process too close to external networks, such as freight exchanges (this would also be the case if one were to use an advisor for finding full loads for fleet repositioning in an LTL context). In such a case, one would like to first extract from the planning software various cost, time and location information regarding the vehicles to feed to the advisor that would then act in an autonomous fashion. Finding good bundles of loads for the vehicles can then be formulated as a network flow optimization problem. In tightly coupled advisors, the information from the freight exchanges is treated similarly to that from other sources (e.g., calls from shippers asking for quotes) and the loads that are auctioned on these exchanges need to be integrated (*mutatis mutandis*) in the planning software. In state-of-the-art fleet management software, this leads to versions of the dynamic, stochastic network simulation/optimization models that have been proposed in the recent years.

A critical issue with advisors is the need to develop proper contingency plans in case one ends up losing on loads that had been identified as attractive. Losing a single load in a chain of several ones may turn a profitable bundle into a costly blunder. Thus, one needs to define sophisticated *recourse strategies* capable of addressing the various possible outcomes of a series of related simultaneous or sequential auctions. The only way to fully address this issue is by moving to fairly complex stochastic optimization models, which is probably more easily done in the context of tightly coupled advisors than of independent ones (because in the first case, one would already be working in a stochastic environment). At this time, it is certainly an open challenge to be able to come up with advisors capable of addressing this contingency issue in a simple, yet effective fashion. It is important to point out that this difficulty is compounded by the setting of continuous markets (a situation that is quite likely to be encountered in many real-life freight exchanges) that make any type of combinatorial bidding impossible and thus maximize the exposure risk. The development of advisors specifically aimed at such markets is probably one of the major priorities in this field.

Significant research efforts are required in all these areas. The development of tools for model and strategy evaluation, as well as market analysis, is also a priority (see Ağrali et al., 2008, for a recent effort in this direction). Simulation appears as the methodology of choice in this context (Mes et al., 2007). A fascinating question that will also have to be addressed is whether the access to such electronic market places will reduce the stochasticity of operations and reduce the need for sophisticated look-ahead capabilities. The contemplated simulators would help address this issue as well.

7. Conclusions and perspectives

This paper aims to assess ITS achievements with respect to the transportation of freight and to identify challenges, opportunities, and promising research and development directions.

We examined the Freight ITS field from several complementary points of view: enabling technologies including Electronic Data Interchange, Commercial Vehicle Operations including border-crossing issues, Advanced Fleet Management Systems, the City Logistics concept for integrated urban freight management, and the links and convergence of Freight ITS and e-business. Throughout the presentation, we attempted to illustrate how the introduction of better decision-support software may very significantly improve the ultimate performance of Intelligent Freight-Transportation Systems.

Similar to many other ITS areas, Freight ITS development proceeds along three major, parallel but complementary, directions. The first concerns vehicular and infrastructure developments. The second direction concerns the electronics, location, tracking, and communication hardware, as well as the associated information-technology software. The third targets the *methodologies* – models and algorithms – required to process the data and transform it into timely and meaningful information and intelligent advice for advanced system and fleet planning, as well as management, operations, and control systems. The ultimate performance and long-term success of ITS depends on a balanced and harmonious integration of these aspects.

It appears, however, that governments and industry privileged up to now the hardware aspect to the detriment of the methodological one. In many cases, data provided by very sophisticated devices and relayed through advanced communication technologies are still being processed and acted upon by the human operators with little, if any, decision-support tools. There is thus a challenge to drastically increase the *intelligence* of ITS.

The various applications described in this paper illustrate the key role *operations research* models and methods play in the analysis of ITS needs and projects, as well as in the development of the software component of ITS. Such methodologies transform the huge amount of data provided by ITS technologies into useful information that may be either distributed to the various ITS users or transformed into operating policies and instructions. Operations research-based data processing and decision-support systems may explore and evaluate the behaviour of the transportation system under various conditions and develop contingency plans, predict the state of the system over the next time periods, generate general or user-tailored itineraries or guidance instructions, plan operations and assist the real-time management of fleets. Many challenges and opportunities for research and development may still be identified, however.

An important research field that should be explored addresses the exchanges and integration of Freight ITS deployed at border crossings and ports, the Advanced Traffic Management and Advanced Traveller Information Systems of the corresponding cities and regions, and the AFMS of the shippers and carriers that use the systems. This involves not only the integration of electronics and communication systems, but also those of the planning and scheduling activities. Being pre-approved means nothing if one must still wait for hours together with other pre-approved vehicles because everybody desires to cross simultaneously. This field belongs to the broader research domain focusing on the issues related to the management of ITS and of security-equipped borders and ports. The efficiency of these facilities is tributary of their design and management methods and processes. The whole field is not yet sufficiently addressed, and the operations research community may make a significant contribution.

Research and development efforts are currently under way in several AFMS areas. The methodological developments of recent years in the various fields of operations research, combined to recent advances in computer science, in particular in parallel and distributed computing, put the required models and methods within our reach. More efforts are still needed, however, in particular relative to the real-time allocation of resources and management of operations, including real-time fleet management and vehicle re-routing. The issues are different but equally challenging whether urban or interurban transportation is considered, or whether the real-time decisions depend on the congestion and demand conditions only, or must account for and coordinate with the decisions of other agents (e.g., customs or port operations). The determination of appropriate trade-offs between accuracy of results and response time in real-time settings constitutes a particularly challenging issue in these contexts.

Challenging research issues are also related to the development of the next generation of planning models and methods for carrier or shipper operations that reflect the new technologies and operating policies of carriers and integrate the stochastic and dynamic aspects of ITS. Equally challenging are the issues related to the planning and management of integrated logistics networks within the context of ITS, carrier AFMS, and e-business practices. In both cases, one must address the representation of the characteristics and behaviour of particular system components (e.g., terminals or cooperating firms) within an integrated planning model of the overall system. Identifying the "correct" trade-off among the accuracy of the component and system representations, the difficulty of the corresponding formulation, and the efficiency of solution methods is a particularly challenging issue, as is the representation of operational uncertainty into medium and long-term planning models and decision-support systems.

City Logistics – the integrated management of freight movements within urban areas – constitutes a fascinating and quite young research domain. City Logistics brings new concepts, environments, and challenges to freight transportation. Operations research models and methods are needed to address these challenges and to assist the design, evaluation, planning, and real-time management of operations of City Logistics systems.

All problems and applications mentioned in this paper require modelling efforts and the development of appropriate solution methods. Regarding the former, of particular relevance is the need to focus not only on the physical components of the systems considered and the associated flows of physical resources, but also on the adequate representation of the associated information and decision flows. Of particular interest with respect to the latter is the ability to address large instances of formulations including integer-valued decision variables, nonlinear objective functions and constraints, and uncertain data.

The computational efficiency of our solution methods may be significantly enhanced through parallel and distributed computing. The integration of exact algorithms and meta-heuristics into co-operative search methods, and the development of co-operation mechanisms based on mathematical programming principles, decomposition methods in particular are promising research directions. A different research perspective is offered by the computing capabilities naturally distributed in ITS. Answering questions like "what is the correct arbitration between central processing and the utilisation of the computing power of local traffic controllers, on-board computers, and the next generation of transponder devices and how can one take advantage of these devices" will certainly prove challenging but may help addressing several issues in real-time Freight ITS operations.

The "natural" technology-transfer instrument for operations research is the embedding of our models and methods into decision-support systems, which, directly or indirectly, are linked to the information-management system(s) of the firm. Several issues challenge our profession in this respect and we recall some of them here. Differences usually exist among the data in the information system, data required by the optimization, and the information that exists in the minds of human dispatchers and controllers. The latter communicate intensively with customers and equipment operators and base their decisions on a more nuanced status of the system, taking into account un-written traditions and preferences, as well as nuances in expressing instructions (e.g., "it would be nice to pick up this load before..."), than the one available to optimization. How much of this information can or should be automated? Given the amount which is not automated, how should the optimization models and the planning procedures be modified for best system-human integration and results? A related issue concerns the scope of the models we develop. Many research results address stylized problem settings, which are far from the complexity of problems in the field. The fact than many optimization-based systems are built to "assist" decision-making rather than directly "decide" is a partial answer to these issues. Only partial, however, and working on mode detailed models and solution methods that may be deployed and used in the field is one of the main challenges to our profession.

The emergence and rapid growth of electronic business both challenges and offers freight carriers great opportunities for improved operations and profits. The convergence of information, communication, and decision technologies used in CVO and AFMS and in advisors for e-markets constitutes a significant advantage in this context. Significant research is still required in this area, however, in particular in order to develop efficient and comprehensive advisors. Three particularly challenging aspects of this issue are the (1) enhancement of the modeling capabilities and the efficiency of solution methods for the complex, stochastic and dynamic formulations related to identifying profitable bundles; (2) development of methodologies to address the contingency issues when bundles have to be negotiated in parallel or non-combinatorial markets; (3) determination of bidding strategies (e.g., estimation of probabilities of winning, of competitor behaviour, and price and bid modification) in various settings, parallel and continuous markets in particular. Strongly related to this is the area of coordination of various information sources, agents, and negotiations.

Freight ITS change the way transportation activities are performed. This is exactly what is expected. On the other hand, however, freight vehicles interact with private and public vehicles carrying passengers. Moreover, Freight ITS, CVO systems for example, also interact strongly with logistics activities and industrial value chains. These impacts are not well understood, nor are the relations among ITS systems, environmental and sustainable development policies, and logistic chains. One lacks the knowledge and tools to evaluate and compare alternate systems, policies, and investments. One should be able to evaluate these interactions and the impact of Freight ITS on the general mobility within a given zone or on the logistic activities of particular industrial sectors. The development of such urban/regional planning systems, which reflect the utilization of CVO and AFMS technologies, require a multi-disciplinary effort: a thorough representation of the economic, operations, and information and decision technologies used by the various actors, sophisticated optimization and simulation methodologies, parallel or distributed computing environments. The resulting systems would be used not only for policy assessment but also for experimentation and training at the university and industry levels.

Acknowledgements

The authors wish to thank the anonymous referees for their comments and suggestions, which resulted in a better paper. This work was partly supported by the Bell University Laboratories, the Fonds québécois de la recherche sur la nature et les technologies (FQRNT), and the Natural Sciences and Engineering Research Council of Canada (NSERC). Special recognition is extended to Dr. Denis Lebeuf for his extensive contributions to the project. During the span of this project, Dr. Teodor Gabriel Crainic was Adjunct Professor with the Department of Computer Science and Operations Research, Université de Montréal, and the Department of Economics and Business Administration, Molde University College, Norway.

References

Abrache, J., Crainic, T.G., Gendreau, M., 2004. Design issues for combinatorial auctions. 4OR 2 (1), 1–33.
Abrache, J., Crainic, T.G., Gendreau, M., Rekik, M., 2007. Combinatorial auctions. Annals of Operations Research 153 (1), 131–164.
Ağrali, S., Tan, B., Karaesmen, F., 2008. Modeling and analysis of an auction-based logistics market. European Journal of Operational Research 191 (1), 272–294.
Allen, J.B., Crum, R.M., Brauschweig, D.C., 1992. The US motor carrier industry: the extent and nature of EDI use. International Journal of Physical Distribution and Logistics Management 22 (8), 27–34.
Ambrosini, C., Routhier, J.-L., 2004. Objectives, methods and results of surveys carried out in the field of urban freight transport: an international comparison. Transport Reviews 24 (1), 57–77.
An, N., Elmaghraby, W., Keskinocak, P., 2004. Bidding in combinatorial auctions. In: Proceedings of the Institute of Industrial Engineers (IIE) Annual Conference, Houston, Texas, May 15–19.
An, N., Elmaghraby, W., Keskinocak, P., 2005. Bidding strategies and their impact on revenues in combinatorial auctions. Journal of Revenue and Pricing Management 3 (4), 337–357.
Arendt, F., Speidel, V., 1999. Speeding-up the link between road and sea transport. In: CD-ROM, ITS in Europe'99, Amsterdam.
Armacost, A.P., Barnhart, C., Ware, K.A., Wilson, A.M., 2004. UPS optimizes its air network. Interfaces 34 (1), 15–25.
Attanasio, A., Bregman, J., Ghiani, G., Manni, E., 2007. Real-time fleet management at eCourier Ltd. In: Zeimpekis, V., Tarantilis, C.D., Giaglis, M.G., Minis, I. (Eds.), Dynamic Fleet Management: Concepts, Systems & Case Studies. Springer, New York, NY, pp. 219–238.
Barceló, J., Grzybowska, H., Pardo, S., 2007. Vehicle routing and scheduling models, simulation and city logistics. In: Zeimpekis, V., Tarantilis, C.D., Giaglis, G.M., Minis, I. (Eds.), Dynamic Fleet Management Concepts – Systems, Algorithms & Case Studies. Springer, pp. 163–195.
Barnhart, C., Kim, D., 1995. Routing models and solution procedures for regional less-than-truckload operations. Annals of Operations Research 61, 67–90.
Bektaş, T., Crainic, T.C., 2008. A brief overview of intermodal transportation. In: Taylor, G.D. (Ed.), Logistics Engineering Handbook. Taylor and Francis Group, Boca Raton, FL, pp. 1–16 (Chapter 28).
Benjelloun, A., Crainic, T.G., 2008. Trends, challenges, and perspectives in city logistics. In: Proceedings of the Transportation and Land Use Interaction 2008, Bucharest, Romania, 23–25 October.
Benjelloun, A., Bigras, Y., Crainic, T.G., 2008. Towards a taxonomy of city logistics systems. Publication CIRRELT, Interuniversity Research Center on Enterprise Networks, Logistics and Transportation, Université de Montréal.
Bent, R., Van Hentenryck, P., 2004. Scenario-based planning for partially dynamic vehicle routing with stochastic customers. Operations Research 52 (6), 977–987.
Branke, J., Middendorf, M., Noeth, G., Dessouky, M., 2005. Waiting strategies for dynamic vehicle routing. Transportation Science 39 (3), 298–312.
Bodin, L., Maniezzo, V., Mingozzi, A., 2003. Street routing and scheduling problems. In: Hall, R.W. (Ed.), Handbook of Transportation Science, second ed. Kluwer Academic Publishers, Norwell, MA, pp. 413–440.
Boerkamps, J., van Binsbergen, A., 1999. GoodTrip – a new approach for modelling and evaluating urban goods distribution. In: Taniguchi, E., Thompson, R.G. (Eds.), City Logistics I, 1st International Conference on City Logistics. Institute of Systems Science Research, Kyoto, pp. 175–186.
Bozzo, R., Derito, A., Nurchi, R., Ackroyd, N., 2001. MOCONT: a new system for container terminal monitoring and control. In: Proceedings of the Intelligent Transportation System Conference, Oakland, CA, August 2001, CD-ROM.
Caplice, C., Sheffi, Y., 2003. Optimization-based procurement for transportation services. Journal of Business Logistics 24 (2), 109–127.
Cascetta, E., 2001. Transportation Systems Engineering: Theory and Methods. Kluwer Academic Publishers, Dordrecht, The Netherlands.
Chang, T.-S., Crainic, T.G., Gendreau, M., 2002a. Dynamic advisors for freight carriers for bidding in combinatorial auctions. In: Proceedings of the 5th International Conference on Electronic Commerce Research (ICECR-5). CD ROM, Centre de recherche sur les transports, Montréal, Canada.
Chang, T.-S., Crainic, T.G., Gendreau, M., 2002b. Dynamic bidding strategies in on-line sequential auctions. In: Proceedings of the 5th International Conference on Electronic Commerce Research (ICECR-5). CD ROM, Centre de recherche sur les transports, Montréal, Canada.
Christiansen, M., Fagerholt, K., Nygreen, B., Ronen, D., 2007. Maritime transportation. In: Barnhart, C., Laporte, G. (Eds.), Transportation, Handbooks in Operations Research and Management Science, vol. 14. North-Holland, Amsterdam, pp. 189–284.
Crainic, T.G., 2000. Network design in freight transportation. European Journal of Operational Research 122 (2), 272–288.
Crainic, T.G., 2003. Long haul freight transportation. In: Hall, R.W. (Ed.), Handbook of Transportation Science, second ed. Kluwer Academic Publishers, Norwell, MA, pp. 451–516.
Crainic, T.G., 2008. Parallel solution methods for vehicle routing problems. In: Golden, B., Raghavan, S., Wasil, W. (Eds.), The Vehicle Routing Problem: Latest Advances and New Challenges. Springer, pp. 171–198.
Crainic, T.G., Bilegan, I.-C., Gendreau, M., 2006. Fleet management for advanced intermodal services – final report for Transport Canada. Publication CRT-2006-13. Centre de recherche sur les transports, Université de Montréal.
Crainic, T.G., Florian, M., 2008. National planning models and instruments. INFOR 46 (4).
Crainic, T.G., Gendreau, M., 2003. Advanced fleet management systems and advisors: converging decision technologies for ITS and E-Business. In: CD-ROM 10th World Congress on Intelligent Transport Systems, Madrid.
Crainic, T.G., Gendreau, M., Lebeuf, D., 2000. Making intelligent transportation systems more intelligent: the contribution of operations research. In: CD-ROM 7th World Congress on Intelligent Transport Systems, Torino, Italia.
Crainic, T.G., Gendreau, M., Lebeuf, D., 2001. Intelligent transportation systems: an historic assessment and the role of operations research. Publication CRT-2001–26, Centre de recherche sur les transports, Université de Montréal.
Crainic, T.G., Kim, K.H., 2007. Intermodal transportation. In: Barnhart, C., Laporte, G. (Eds.), Transportation, Handbooks in Operations Research and Management Science, vol. 14. North-Holland, Amsterdam, pp. 467–537.
Crainic, T.G., Laporte, G., 1997. Planning models for freight transportation. European Journal of Operational Research 97 (3), 409–438.
Crainic, T.G., Ricciardi, N., Storchi, G., 2004. Advanced freight transportation systems for congested urban areas. Transportation Research Part C: Emerging Technologies 12 (2), 119–137.
Crainic, T.G., Ricciardi, N., Storchi, G., 2007. Models for evaluating and planning city logistics transportation systems. Publication CIRRELT-2007-65, Interuniversity Research Centre on Enterprise Networks, Logistics, and Transportation, Université de Montréal.
Crainic, T.G., Speranza, M.G., 2008. Logistics and the Internet. In: Taylor, G.D. (Ed.), Logistics Engineering Handbook. Taylor and Francis Group, Boca Raton, FL, pp. 1–14 (Chapter 24).

Crum, M.R., Johnson, A.D., Allen, J.B., 1998. A longitudinal assessment of EDI use in the US motor carrier industry. Transportation Journal 38, 15–28.
Dablanc, L., 2007. Goods transport in large european cities: difficult to organize, difficult to modernize. Transportation Research Part A: Policy and Practice 41 (3), 280–285.
de Vries, S., Vohra, R., 2003. Combinatorial auctions: a survey. INFORMS Journal on Computing 15 (3), 184–309.
Dürr, E., Giannopoulos, G.A., 2003. SITS: a system for uniform intermodal freight transport information exchange. International Journal of Transport Management 1 (3), 175–186.
Elmaghraby, W.J., Keskinocak, P., 2004. Combinatorial auctions in procurement. In: Harrison, T.P., Lee, H.L., Neale, J.J. (Eds.), The Practice of Supply Chain Management: Where Theory and Application Converge. Springer, New York, NY, pp. 245–258.
Emmelhainz, M.A., 1990. Electronic Data Interchange: A Total management Guide. Van Nostrand Reinhold, New York.
EPA, 2006. Greenhouse Gas Emissions from the U.S. Transportation Sector 1990–2003, Office of Transportation and Air Quality, United States Environmental Protection Agency.
Ergun, O., G. Kuyzu, G., Savelsbergh, M., 2007. Bid price optimization for simultaneous truckload transportation auctions. Working Paper, H. Milton Stewart school of Industrial Engineering, Georgia Institute of Technology.
Figliozzi, M.A., 2007. Analysis of the efficiency of urban commercial vehicle tours: data collection, methodology and policy implications. Transportation Research Part B: Methodological 41 (9), 1014–1032.
Figliozzi, M., Mahmassani, H.S., Jaillet, P., 2002. Modelling online transportation market performance under real-time carrier bidding strategies. In: Proceedings of the 5th International Conference on Electronic Commerce Research (ICECR-5). CD ROM, Centre de recherche sur les transports, Montréal, Canada.
Figliozzi, M., Mahmassani, H.S., Jaillet, P., 2003. A framework for the study of carrier strategies in an auction based transportation marketplace. Transportation Research Record 1854, 162–170.
Figliozzi, M., Mahmassani, H.S., Jaillet, P., 2004. Competitive performance assessment of dynamic vehicle routing technologies using sequential auctions. Transportation Research Record 1882, 10–18.
Figliozzi, M.A., Mahmassani, H.S., Jaillet, P., 2005. Impacts of auction settings on the performance of truckload transportation marketplaces. Transportation Research Record 1906, 89–96.
Figliozzi, M.A., Mahmassani, H.S., Jaillet, P., 2006. Quantifying opportunity costs in sequential transportation auctions for truckload acquisition. Transportation Research Record 1964, 247–252.
Fleischmann, B., Gnutzmann, S., Sandvoss, E., 2004. Dynamic vehicle routing based on online traffic information. Transportation Science 38 (4), 420–433.
Florian, M., 2008. Models and software for urban and regional transportation planning: the contribution of the center for research on transportation. INFOR 46 (1), 29–50.
Friedrich, M., Haupt, T., Nökel, K., 2003. Freight modelling: data issues, survey methods, demand and network models. Publication, Institut für Straßen – und Verkehrswesen Lehrstuhl für Verkehrsplanung und Verkehrsleittechnik, Stuttgart University.
Fu, L., Henderson, J., Hellinga, B., 2003. Inventory of intelligent transportation systems (ITS) projects in Canada. ITS-STI Canada.
Garrido, R.A., 2007. Procurement of transportation services in spot markets under a double-auction scheme with elastic demand. Transportation Research Part B: Methodological 41 (9), 1067–1078.
Gendreau, M., Badeau, P., Guertin, F., Potvin, J.-Y., Taillard, É.D., 1996. A solution procedure for real-time routing and dispatching of commercial vehicles. In: Third Annual World Congress on Intelligent Transportation Systems, CD-ROM.
Gendreau, M., Guertin, F., Potvin, J.-Y., Séguin, R., 2006. Neighborhood search heuristics for a dynamic vehicle dispatching problem with pick-ups and deliveries. Transportation Research Part C: Emerging Technologies 14 (3), 157–174.
Gendreau, M., Guertin, F., Potvin, J.-Y., Taillard, É.D., 1999. Tabu search for real-time vehicle routing and dispatching. Transportation Science 33 (4), 381–390.
Gendreau, M., Laporte, G., Potvin, J.-Y., 2002. Metaheuristics for the capacitated VRP. In: Toth, P., Vigo, D. (Eds.), The Vehicle Routing Problem, SIAM Monographs on Discrete Mathematics and Applications. SIAM, Philadelphia, PA, pp. 129–154.
Gendreau, M., Laporte, G., Semet, F., 2001. A dynamic model and parallel tabu search heuristic for real-time ambulance relocation. Parallel Computing 27 (12), 1641–1653.
Gendreau, M., Potvin, J.-Y., 1998. Dynamic vehicle routing and dispatching. In: Crainic, T.G., Laporte, G. (Eds.), Fleet Management and Logistics. Kluwer Academic Publishers, Norwell, MA, pp. 115–126.
Gentile, G., Vigo, D., 2007. Movement generation and trip distribution for freight demand modelling applied to city logistics. Technical Report, Università di Bologna.
Giannopoulos, G.A., 1996. Mobile data communication and electronic data interchange, technology in road freight operations in Europe: an evaluation of some pilot applications. In: 75th Annual TRB Meeting, Washington.
Giannopoulos, G.A., 2001. Implications of European transport telematics on advanced logistics and distribution. Transport Logistics 1 (1), 302–320.
Giannopoulos, G.A., 2004. The application of information and communication technologies in transport. European Journal of Operational Research 152 (2), 302–320.
Giannopoulos, G.A., McDonald, M., 1997. Developments in transport telematics applications in Japan: traffic management, freight and public transport. Transport Reviews 17 (1), 37–59.
Giannopoulos, G., Shinakis, M., 1999. The AEI and EDI experience at the Port of Piraeus. In: CD-ROM, ITS in Europe'99, Amsterdam.
Glover, F., Laguna, M., 1997. Tabu Search. Kluwer Academic Publishers, Norwell, MA.
Godfrey, G., Powell, W.B., 2002a. An adaptive dynamic programming algorithm for single-period fleet management problems I: single period travel times. Transportation Science 36 (1), 21–39.
Godfrey, G., Powell, W.B., 2002b. An adaptive dynamic programming algorithm for single-period fleet management problems II: multiperiod travel times. Transportation Science 36 (1), 40–54.
Golob, T., Regan, A.C., 2000a. Freight industry attitudes towards policies to reduce congestion. Transportation Research Part E: Logistics and Transportation 36 (1), 55–77.
Golob, T., Regan, A.C., 2000b. Trucking industry perceptions of congestion problems and potential solutions in maritime intermodal operations in California. Transportation Research Part A: Policy and Practice 34 (8), 587–605.
Golob, T.F., Regan, A.C., 2001a. Impacts of information technology on personal travel and commercial vehicle operations: research challenges and opportunities. Transportation Research Part C: Emerging Technologies 9 (2), 87–121.
Golob, T., Regan, A.C., 2001b. Impacts of highway congestion on freight operations, perceptions of trucking industry managers. Transportation Research Part A: Policy and Practice 35 (7), 577–599.
Golob, T.F., Regan, A.C., 2002a. Trucking industry adoption of information technology: a multivariate discrete choice model. Transportation Research Part C: Emerging Technologies 10 (3), 205–228.
Golob, T.F., Regan, A.C., 2003. Traffic congestion and trucking managers' demand for routing and scheduling software. Transportation Research Part E: Logistics and Transportation 39 (1), 69–73.
Golob, T.F., Regan, A.C., 2005. Trucking industry preferences for traveler information for drivers using wireless internet-enabled devices. Transportation Research Part C: Emerging Technologies 13 (3), 235–250.
Gragnani, S., Valenti, G., Valentini, M.P., 2004. City logistics in Italy: a national project. In: Taniguchi, E., Thompson, R.G. (Eds.), Logistics Systems for Sustainable Cities. Elsevier, pp. 279–293.
Günther, H.-O., Kim, K.H., 2005. Container Terminals and Automated Transport Systems. Springer, Berlin.

Ichoua, S., Gendreau, M., Potvin, J.-Y., 2006. Exploiting knowledge about future demands for real-time vehicle dispatching. Transportation Science 40 (2), 211–225.
Ichoua, S., Gendreau, M., Potvin, J.-Y., 2007. Planned route optimization for real-time vehicle routing. In: Zeimpekis, V., Tarantilis, C.D., Giaglis, G.M., Minis, I. (Eds.), Dynamic Fleet Management: Concepts, Systems & Case Studies. Springer, New York, NY, pp. 1–18.
Hook, P., 1998. Built to serve. ITS International, September/October, pp. 75–76.
ITF, 2008. Transport and energy: the challenge of climate change – research findings. In: International Research Forum, Leipzig 2008, OECD/ITF. <http://www.internationaltransportforum.org/>.
Johnson, A.D., Allen, J.B., Crum, M.R., 1992. The state of EDI usage in the motor carrier industry. Journal of Business Logistics 13 (2), 43–68.
Kohler, U., 1997. An innovating concept for city-logistics. In: Proceedings of the 4th World Congress on Intelligent Transportation Systems, Berlin, CD ROM.
Kohler, U., 2001. How to change urban traffic with city logistics. In: Schnieder, E., Becker, U. (Eds.), Control in Transportation Systems 2000 – Proceedings of the 9th IFAC Symposium, vol. 1. Pergamon, Oxford, pp. 199–201.
Kuo, A., Miller-Hooks, E., 2008. Combinatorial auction of track capacity in freight spot markets. Publication, Department of Civil & Environmental Engineering, University of Maryland.
Kwon, R.H., Anandalingam, G., Ungar, L.H., 2005. Iterative combinatorial auctions with bidder-determined combinations. Management Science 51 (3), 407–418.
Lee, C.-G., Kwon, R.H., Ma, Z., 2007. A carrier's optimal bid generation problem in combinatorial auctions for transportation procurement. Transportation Research Part E: Logistics and Transportation 43 (2), 173–191.
Lee, D.H., Song, L., Wang, H.Q., 2008. An optimization approach to security operations toward sustainable seaport. International Journal of Sustainable Transportation 2 (2), 115–133.
Lee-Partridge, J., Teo, T., Lim, V., 2000. Information technology management: the case of the Port of Singapore authority. Journal of Strategic Information Systems 9 (1), 85–99.
Ledyard, J.O., Olson, M., Porter, D., Swanson, J.A., Torma, D.P., 2002. The first use of a combined value auction for transportation services. Interfaces 32 (5), 4–12.
Lewis, B.M., Erera, A.L., White III, C.C., 2002. Efficient container security operations at transshipment seaports. In: Proceedings of the Inaugural Annual Intelligent Transportation Society (Singapore) Symposium, September 5–6, Singapore.
Lewis, B.M., Erera, A.L., White III, C.C., 2003. Optimization approaches for efficient container security operations at transshipment seaports. Transportation Research Record 1822, 1–8.
Ma, Z., 2008. Combinatorial auctions for truckload transportation procurement. Ph.D. Thesis, Graduate Department of Mechanical & Industrial Engineering, University of Toronto.
McMillan, J., 1994. Selling spectrum rights. Journal of Economic Perspectives 8, 145–162.
Mes, M., van der Heidjen, M., van Harten, A., 2007. Comparison of agent-based scheduling to look-ahead heuristics for real-time transportation problems. European Journal of Operational Research 181 (1), 59–75.
Mintsis, G., Basbas, S., Papaioannou, P., Taxiltaris, C., Tziavos, I.N., 2004. Applications of GPS technology in the land transportation system. European Journal of Operational Research 152 (2), 399–409.
Mitrović-Minić, S., Krishnamurti, R., Laporte, G., 2004. Double-horizon based heuristics for the dynamic pickup and delivery problem with time windows. Transportation Research Part B: Methodological 38 (8), 669–685.
Mitrović-Minić, S., Laporte, G., 2004. Waiting Strategies for the dynamic pickup and delivery problem with time windows. Transportation Research Part B: Methodological 38 (7), 635–655.
MLITT, 2007. ITS handbook Japan 2006–2007, Highway Industry Development Organization. Road Bureau, Ministry of Land, Infrastructure, Transport and Tourism, Japan <http://www.its.go.jp/ITS/topindex/topindex_g02_handbook.html> (July 2008).
MLITT, 2008. Comprehensive plan for ITS in Japan. Road Bureau, Ministry of Land, Infrastructure, Transport and Tourism, Japan. <http://www.its.go.jp/ITS/topindex/topindex_g06_2.html> (July 2008).
OECD, 2003. Delivering the goods: 21st century challenges to urban goods transport. Organisation for Economic Co-operation and Development, OECD Publishing. <http://www.oecdbookshop.org>.
Park, S., Rothkopf, M.H., 2005. Auctions with bidder-determined allowable combinations. European Journal of Operational Research 161 (2), 399–415.
Patier, D., 2002. La logistique dans la ville. CELSE Editeur, Paris.
Potvin, J.-Y., Xu, Y., Benyahia, I., 2006. Vehicle routing and scheduling with dynamic travel times. Computers & Operations Research 33 (4), 1129–1137.
Powell, W.B., 1988. A comparative review of alternative algorithms for the dynamic vehicle allocation problem. In: Golden, B.L., Assad, A.A. (Eds.), Vehicle Routing: Methods and Studies. North-Holland, Amsterdam, pp. 249–292.
Powell, W.B., 2003. Dynamic models of transportation operations. In: Graves, S., de Kok, A.G. (Eds.), Supply Chain Management, Handbooks in Operations Research and Management Science, vol. 11. North-Holland, Amsterdam, pp. 677–756.
Powell, W.B., Bouzaïene-Ayari, B., Simaõ, H.P., 2007. Dynamic models for freight transportation. In: Barnhart, C., Laporte, G. (Eds.), Transportation, Handbooks in Operations Research and Management Science, vol. 14. North-Holland, Amsterdam, pp. 285–365.
Powell, W.B., Jaillet, P., Odoni, A., 1995. Stochastic and dynamic networks and routing. In: Ball, M., Magnanti, T.L., Monma, C.L., Nemhauser, G.L. (Eds.), Network routing, Handbooks in Operations Research and Management Science, vol. 8. North-Holland, Amsterdam, pp. 41–295.
Powell, W.B., Marar, A., Gelfand, J., Bowers, S., 2002a. Implementing operational planning models: a case application from the motor carrier industry. Operations Research 50 (4), 571–581.
Powell, W.B., Shapiro, J., Simaõ, H.P., 2002b. An adaptive, dynamic programming algorithm for the heterogeneous resource allocation problem. Transportation Science 36 (2), 231–249.
Powell, W.B., Sheffi, Y., Nickerson, K.S., Butterbaugh, K., Atherton, S., 1992. Maximizing profits for North American Van Lines' Truckload Division: A new framework for pricing and operations. Interfaces 18 (1), 21–41.
Powell, W.B., Topaloglu, H., 2003. Stochastic programming in transportation and logistics. In: Ruszczynski, A., Shapiro, A. (Eds.), Stochastic Programming, Handbooks in Operations Research and Management Science, vol. 10. North-Holland, Amsterdam, pp. 555–635.
Powell, W.B., Topaloglu, H., 2005. Fleet management. In: Wallace, S., Ziemba, W. (Eds.), Applications of Stochastic Programming, Math Programming Society – SIAM Series in Optimization. SIAM, Philadelphia, PA, pp. 185–216.
Powell, W.B., Towns, M.T., Marar, A., 2000. On the value of optimal myopic solutions for dynamic routing and scheduling problems in the presence of user noncompliance. Transportation Science 34 (1), 67–85.
Rassenti, S.J., Smith, V.L., Bulfin, R.L., 1982. A combinatorial auction mechanism for airport time slot allocation. Bell Journal of Economics 13 (2), 402–417.
Ratliff, H.D., 1995. Logistics management: integrate your way to an approved bottom line. IIE Solutions 27 (10), 31–33.
Reagan, A.C., Mahmassani, H.S., Jaillet, P., 1995. Improving the efficiency of commercial vehicle operations using real-time information: potential uses and assignment strategies. Transportation Research Record 1493, 188–198.
Reagan, A.C., Mahmassani, H.S., Jaillet, P., 1996a. Dynamic decision making for commercial vehicle operations using real-time information. Transportation Research Record 1537, 91–97.
Reagan, A.C., Mahmassani, H.S., Jaillet, P., 1996b. Dynamic dispatching strategies under real-time information for carrier fleet management. In: Lesort, J.B. (Ed.), Transportation and Traffic Theory. Pergamon, pp. 737–756.
Reagan, A.C., Mahmassani, H.S., Jaillet, P., 1998. Evaluation of dynamic fleet management systems: a simulation framework. Transportation Research Record 1645, 176–184.
Reid, P., Myers, R., 1996. TruckScan – automating and improving roadside checking. Traffic Technology International.
Rothkopf, M.H., Park, S., 2001. An elementary introduction to auctions. Interfaces 31 (6), 83–97.

Rothkopf, M.H., Pekec, A., Harstad, R.M., 1988. Computationally manageable combinatorial auctions. Management Science 44, 1131–1147.
Roy, J., Bigras, Y., Crainic, T.G., 1997. New information technologies and freight transportation. In: Roller, D. (Ed.), Proceedings of the 30th International Symposium on Automotive Technology and Automation, ATT/ITS Conference. ISATA, Florence, pp. 291–298.
Ruske, W., 1994. City logistics – solutions for urban commercial transport by Cooperative Operations Management. In: OECD Seminar on Advanced Road Transport Technologies. Omiya, Japan.
Russo, F., Comi, A., 2004. A state of the art on urban freight distribution at European scale. In: Presented at ECOMM 2004, Lyon. Available from The European Conference on Mobility Management <http:www.epomm.org/>.
Séguin, R., Potvin, J.-Y., Gendreau, M., Crainic, T.G., Marcotte, P., 1997. Real-time decision problems: an operational research perspective. Journal of the Operational Research Society 48 (2), 162–174.
Sheffi, Y., 2004. Combinatorial auctions in the procurement of transportation services. Interfaces 34 (4), 245–252.
Slevin, J., 1999. PrePass and NORPASS. ITS World, July/August, pp. 12–13.
Song, J., Regan, A., 2004. Combinatorial auctions for transportation service procurement: the carrier perspective. Transportation Research Record 1833, 40–46.
Song, J., Regan, A., 2005. Approximation algorithms for the bid construction problem in combinatorial auctions for the procurement of freight transportation contracts. Transportation Research Part B: Methodological 39 (10), 914–933.
Spivey, M.Z., Powell, W.B, 2004. The dynamic assignment problem. Transportation Science 38 (4), 399–419.
Sunstrum, A.L., Howard, F.H., 1996. Strategic alliances enabled by electronic commerce. In: Proceedings of the 31st Annual Meeting of the Canadian Transportation Research Forum, Winnipeg, Canada, pp. 252–265.
Steenken, D., Voss, S., Stahlbock, R., 2004. Solution container terminal operation and operations research – a classification and literature review. OR Spectrum 26 (1), 3–49.
Taniguchi, E., van der Heijden, R.E.C.M., 2000. An evaluation methodology for city logistics. Transport Reviews 20 (1), 65–90.
Taniguchi, E., Kawakatsu, S., Tsuji, H., 2000. New co-operative system using electric vans for urban freight transport. In: Sucharov, L.J., Brebbia, C.A. (Eds.), Urban Transport and the Environment for the 21st Century VI. WIT Press, Southampton, pp. 201–210.
Taniguchi, E., Noritake, T., Yamada, T., Izumitani, T., 1999a. Optimal size and location planning of public logistics terminals. Transportation Research Part E: Logistics and Transportation 35 (3), 207–222.
Taniguchi, E., Thompson, R.G., Yamada, T., van Duin, J.H.R., 2001a. City Logistics: Network Modelling and Intelligent Transport Systems. Pergamon, Amsterdam.
Taniguchi, E., Thompson, R.G., 2002. Modeling city logistics. Transportation Research Record 1790, 45–51.
Taniguchi, E., Yamada, T., Tamagawa, D., 1999. Modelling advanced routing and scheduling of urban pickup/delivery trucks. In: World Congress on ITS, Toronto, Canada, CD-ROM.
Taniguchi, E., Yamada, T., Tamaishi, M., 2001b. Dynamic vehicle routing and scheduling with real time informations. In: Taniguchi, E., Thompson, R.G. (Eds.), City Logistics II, Second International Conference on City Logistics. Institute of Systems Science Research, Kyoto, pp. 111–125.
Thompson, R.G., 2004. Intelligent vehicle routing and scheduling. In: Taniguchi, E., Thompson, R.G. (Eds.), Logistics Systems for Sustainable Cities. Elsevier, pp. 97–109.
Thompson, R.G., Taniguchi, E., 2001. City logistics and transportation. Handbook of Logistics and Supply-chain Management. Elsevier, Amsterdam. pp. 393–405.
Toth, P., Vigo, D., 2002. The vehicle routing problem. SIAM Monographs on Discrete Mathematics and Applications. SIAM, Philadelphia, PA.
Topaloglu, H., 2006. A parallelizable dynamic fleet management model with random travel times. European Journal of Operational Research 175 (2), 782–805.
TRB, 2002. Deterrence, protection, and preparation: the new transportation security initiative. Special Report 270, Transportation Research Board, National Research Council, Washington, DC.
Udo, G.J., Pickett, G.C., 1994. EDI conversion mandate: the big problem for small businesses. Industrial Management 36 (2), 6–9.
van Duin, J.H.R., 1997. Evaluation and evolution of the city distribution concept. In: Urban Transport and the Environment for the 21st Century III. WIT Press, Southampton, pp. 327–337.
Zeimpekis, V., Tarantilis, C.D., Giaglis, M.G., Minis, I. (Eds.), 2007. Dynamic Fleet Management: Concepts, Systems, Algorithms & Case Studies. Springer, New York, NY.
Walsh, W.E., Wellman, M.P., Ygge, F., 2000. Combinatorial auctions for supply chain formation. In: Proceedings of the ACM Conference on Electronic Commerce. ACM, pp. 260–269.
Walton, L.W., 1994. Electronic data interchange (EDI): a study of its usage and adoption within marketing and logistics channels. Transportation Journal 34 (2), 37–45.
Yang, J., Jaillet, P., Mahmassani, H.S., 1999. On-line algorithms for truck fleet assignment and scheduling under real-time information. Transportation Research Record 1667, 107–113.
Yang, J., Jaillet, P., Mahmassani, H.S., 2004. Real-time multi-vehicle truckload pick-up and delivery problems. Transportation Science 38 (2), 135–148.
WR1. http://www.customs.ustreas.gov/xp/cgov/border_security/ Customs and Border Protection, Department of Homeland Security.
WR2. www4.norpass.net NORPASS.
WR3. www.prepass.com PrePass.
WR4. www.ertico.com ERTICO.
WR5. http://ec.europa.eu/dgs/energy_transport/index_en.html. Directorate General for Energy and Transport, European Community.
WR6. www.citylogistics.org. The Institute for City Logistics, Kyoto University.
WR7. www.transports-marchandises-en-ville.org. City Logistics issues and projects, mostly in France.
WR8. www.bestufs.net. Best Urban Freight Solutions.
WR9. www.itree.com.au. TruckScan system, Australia.