Advanced methodological researches concerning ITS in freight transport

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Abstract

This paper analyzes methods and models for ITS applications in freight transport. A new interpretation is provided, which collects and groups studies into five macro-categories, according to the spatial context in which the supply chain works. The analysis is based on the approaches adopted by different authors: statistical surveys, “what if” and “what to” analyses and project proposals.

1. Introduction

The term ITS, “Intelligent Transportation System”, refers to integrated telematics, communication, control and automation technologies that significantly contribute to improve the quality of transport services.

At the end of last century, studies about ITS applications were mainly focussed on urban public transport. Then, the topic has developed to include all transport modes and levels, for both passengers and goods, and to take into account the material flow, i.e. the handling and storage of physical entities, and the information flow, which takes place at the different business levels and may support the decision-making process.

ITS availability have led to new problems and new management tools, encouraging sector research on new themes, such as real time congestion control or dynamic navigation. These problems have been tackled by several scientists through specific models.
This paper reviews ITS classifications for freight transport and logistics, which are useful to analyze the methodologies and models shown in the final part of the paper, and then presents the results of a survey aimed to collect, classify and examine models and methodological tools related to ITS applications.

The first section of this paper illustrates a theoretical framework of the studies concerning ITS applications in freight transport by reviewing literature classifications. At the end of such a review, a classification proposed by the authors has been used as a landmark to provide a specific interpretation of the analysis elaborated. In particular, studies have been classified into five main categories, according to the spatial operational context of a supply chain. Models have been distinguished in relation to territorial, urban, warehouse, industrial and intermodal freight transport. Research works are presented considering the approaches adopted by the authors (statistical, “what to” and “what if” analyses and project proposals).

2. General review of studies concerning ITS applications

ITS include the latest technologies, infrastructure, and services as well as the operations, planning and control methods that are used for the transportation of passengers and freight (Crainic et al., 2009). Over the last 15 years, there has been an interesting R&D activity aimed to improve the performances of transport systems, in order to achieve a wide range of objectives, such as congestion and security control, the enhancement of the efficiency and effectiveness of transport systems, the interaction between different mobility components.

There exist many ITS studies in literature. A complete framework is provided by the Research and Innovative Technology Administration of the U.S. Department of Transportation, which has conducted an accurate analysis of ITS and proposed a classification based on the concepts of Intelligent Infrastructure and Intelligent Vehicle and on their integration. The European Commission has defined a unified ITS architecture by organizing them into seven functional categories: traffic and mobility management systems; user information systems; public transport management systems; fleet and freight management systems; automatic payment systems; advanced control vehicle systems for safe transport; emergencies and accidents management systems.

There are also many more or less specialized scientific and technical reports on ITS.

2.1. ITS in freight transport

The topic of ITS has been discussed in the field of freight transport since the ‘90s. However, specialist literature has advanced in the last ten years. ITS are seen as “the combined application of Information and Communication Technologies, its related infrastructure, and the necessary legislative/policy framework, in order to optimize transport efficiency and operational sustainability in the future”. Giannopoulos (2009) has classified ITS into seven macro-categories: e-business oriented systems; freight operation; intermodal transport operating systems; site-specific ICT systems; transport and other Public Administrations related systems; city logistics and e-freight.

The U.S. Department of Transportation (RITA, 2005) has also dealt with the topic of ITS in freight transport and has identified five groups of technologies: asset tracking, to monitor the freight car position and status; on-board status, to monitor the freight car operating parameters, load conditions and tampering attempts; gateway facilitation, to simplify and speed up terminal operations; freight status information, to facilitate the exchange of information about the goods flow; and network status information, to monitor the status of flows on road sections, weather conditions and accidents.

Many scientists have focussed their research on the concept of “smart goods”, i.e. ITS components that, when applied directly to the goods to be transferred, allow to obtain important information, such as the identity of the product or its position (Lumsden and Stefansson, 2007; Holmqvist and Stefansson, 2006).
The authors (Gattuso and Pellicanò, 2012) have proposed an ITS classification in freight transport following a tree diagram (Figure 1). It is possible to find four levels of characterizing attributes. The first corresponds to the particular type of supply chain. The second level of classification concerns the spatial context: goods can be in motion on an infrastructural link or standing in a certain site. It is also necessary to define the spatial scale of a supply chain. ITS can have an extra-urban (territorial logistics) or urban (city logistics) range. When the goods are at the node, it is possible to identify warehouse area, an industrial area and an interchange platform. The third level concerns load units. ITS can be applied directly to the goods, to the vehicle or to the handling units. If the goods are on an infrastructural link, both goods and vehicles can be considered as load units. On the contrary, if they are at a node, handling units should be also considered. The last level defines the specific services for each type of goods or vehicle. In particular, the following 17 types of services were identified: Scheduling; Routing; Planning of service area activities; Management control; Orders transmission; Documents transport digitalization; Monitoring the order working progress; Consignment confirmation; Business plans acquisition; Activities execution support and re-planning; Activities reporting; Tracking and tracing; Operating parameters monitoring; Satellite antitheft; Access control; Picking; Sorting.

3. Research and literature models

The proposed architecture provides a useful landmark for the analysis of ITS applications models and methods in freight transport and logistics. In particular, considering the spatial context, it is possible to divide the study into the following five main categories: freight transport on a territorial scale; freight transport on an urban scale; freight handling at the warehouse, in the industrial area and at the intermodal platforms.

3.1. Territorial freight transportation

The following approaches were identified in the study of ITS applications to territorial freight transport: statistical analyses, “what to” (optimization), “what if” (simulation) analysis and project proposals.

The authors who have followed a statistical approach have examined the main features of ITS development in freight transport systems. They have highlighted the growing need for integrated planning and control, which should be achieved through intelligent solutions able to improve the information exchange among stakeholders and enhance the efficiency of transport and supply chain.

Noteworthy is the contribution of Dehning et al. (2007) who have used a statistical approach to measure the impact of ITS on transport companies. They introduced a general linear model (GLM) to verify if changes were
significant and compared the system parameters before and after the introduction of technologies. In particular, they showed that performances were improved in the case of a hi-tech company.

Other studies have focussed on procedures of freight transport and logistics optimization. Dorer and Calisti (2005) have proposed a dynamic transport optimization model. They used an agent-based solution (LS/ATN) which took into account some key actions, such as the automatic support for shippers (including the management of unexpected events); the increased use of the freight car capacity through the optimal allocation of orders to trucks; the complete integration of computer services; the combination of the different types of logistic networks; the increased transparency and visibility throughout the network; and the combination of different transport modes.

Some authors have studied the optimization of vehicular routing through ITS. Santos et al. (2011) have proposed an intelligent web-based spatial decision support system (wSDSS) in order to generate optimized routes to solve the routing problem. The wSDSS incorporated Google Maps (cartography and network data), a database, a heuristic system developed to generate paths and routes of vehicles. The system considered the real features of freight transport, such as vehicle capacity, time constraints, network constraints, e.g. one-way and no-entry streets. Furthermore, the wSDSS could be used for “what-if” analysis and easily adapted in many real situations. Figure 2 shows the algorithm they used. Other authors have developed tools to solve specific problems, such as vehicles and goods tracking and tracing, computerized platform enabling to identify drivers and their travel itinerary through a wireless system and to ensure an adequate level of transport parameters during the trip.

A few studies have proposed tools for the information flow management in freight transport. A standard-based model has been suggested by Hribernik et al. (2010) to connect the information flow to the material flow in logistic processes. The information flow was modelled as a multi-agent system (MAS) with features of autonomous control of logistic processes, whereas the material flow consisted of real objects. This study led to the creation of an intelligent system, an “Internet of Things” (IoT) for logistics, in which the supply chain products (things) were able to process information, communicate with each other and make decisions. Other authors, such as Dalmolen et al. (2012), Grakovski et al. (2008), have proposed advanced systems for data exchange among stakeholders in the supply chain.

Among the authors who have adopted a simulation approach, Zacharewicz et al. (2011) have constructed a platform to simulate the routing of products through RFID combined with geo-location and mobile technology.
The approach was based on Generalized Discrete Event Specification (G-DEVS) and HLA (High Level Architecture) models and assumed that:

- a supplier manages a set of resources $r$ to perform products $p$;
- each resource has entry stocks (storage of components) and exit stocks (storage of finished products);
- suppliers of the considered suppliers are considered as perfect (no late delivery, wrong quantity of products);
- backorders only concern products delivered to customers.

The proposed model defines an optimal manufacturing plan through the minimization of three components: storage costs, production backorder and transport delay:

$$
\min \left[ \sum_{p} \sum_{t} \left( i^r_{p,t} \cdot CS^r_p + f^r_{p,t} \cdot CP^r_p + b^r_{p,t} \cdot CB^r_p \right) \right]
$$

Storage costs are the product of the inventory level of product $p$ at the end of period $t$, resource $r$ ($i^r_{p,t}$) and unitary inventory mean cost ($CS^r_p$). The production backorder is the product of the production quantity of product $p$, to launch on resource $r$ during the period $t$ ($f^r_{p,t}$), and the unitary production mean cost ($CP^r_p$). The transport delay is the product between the final customers’ backorders of product $p$, delivered by resource $r$ at the end of period $t$ ($b^r_{p,t}$), and the unitary backorder cost ($CB^r_p$).

### 3.2. Urban freight transportation

In literature, the role of ITS in urban freight transport has been investigated through empirical analysis and statistical surveys as well as through models and analytical-design methods.

An advanced computerized system, which may integrate freight transport, is a key factor to enhance the development of urban logistics, economic and environmental sustainability and the performances of the system (He and Chen, 2012; Čišařová and Široký, 2009).

ITS are essential tools for planning and controlling goods distribution in urban areas. Studies show that the quantitative data obtained through intelligent systems, such as GPS, allow to acquire key information for the optimization of goods distribution that are by far preferable to the qualitative data obtained through traditional methods, such as interviews (Comendador et al. 2012). According to Hesse (2002), the increasing importance of e-commerce is due to the structural change in the sector of distribution. As a matter of fact, it improves the system performances in terms of distances, emissions and energy consumption.

The study of ITS has been also addressed with modelling approaches. Taniguchi et al. (2012) have developed an overview of city logistics management models by classifying them into optimization models and simulation models. Intelligent agents can be a useful tool for solving optimization problems in dynamic environments, such as the drayage problem when service time durations are highly uncertain; the definition of optimal paths for delivery vehicles in road networks; and dynamic vehicle routing and scheduling (Máhr et al. 2010).

Ngai et al. (2007) have proposed a model for the adoption of logistics information systems (LIS) that analyzes the relationships within the organizational context of the supply chain, the benefits deriving from the adoption of LIS and their limits. Moreover, in order to calibrate the proposed model, they reported some results from a survey on the use of ITS by companies.

Kim and Sohn (2009) have suggested a model to estimate the management costs of a RFID system which may be applied to urban freight transport in order to support decision-making and help companies choose the most beneficial and cost-effective RFID system. The cost elements consist of three parts: fixed cost, variable cost and yield loss cost. Furthermore, it is necessary to consider the loss of yield defined as the efficient operation cost of the RFID system. Gonzalez-Feliu and Salanova (2012) have studied the information exchange among the stakeholders highlighting the opportunities for collaboration through a simulation approach. The authors identified two types of fundamental technologies: transportation management systems (TMS), which are related to planning and allow properly integrating transport and supply chain; and the management tools for vehicle
routing and scheduling. Prindezis and Kiranoudis (2005) have presented a logistics management system based on the use of the Internet to coordinate and spread activities and information. The system architecture was based on special meta-heuristic methods and included features of interactive communication between peripheral software tools. A dynamic vehicle routing and scheduling model for city logistics has been developed by Taniguchi and Shimamoto (2004). A dynamic traffic simulation allowed updating the travel time in relation to real-time measurements. The model determined the optimal solution by minimizing total transportation costs $C(t_0, X)$, which were composed of three components: the fixed cost of vehicles; the vehicle operating costs, which are proportional to the time travelled; and the early arrival and delay penalty for designated pickup/delivery time at customers. The model was formalized by the following expression:

$$\min C(t_0, X) = \min \left[ \sum_{i=1}^{m} c_{f,i} \cdot \delta(x_i) + \sum_{i=1}^{m} C_{t,i}(t_{i,0}, x_i) + \sum_{i=1}^{m} C_{p,i}(t_{i,0}, x_i) \right]$$

where:

- $t_0$ is the carrier departure time for all vehicles from the depot;
- $X$ is the allocation and order of visited customers for all vehicles;
- $c_{f,i}$ is the fixed cost for vehicle $i$;
- $\delta(x_i)$ is the decision-making variable, which is 1 if vehicle $i$ is used, 0 otherwise;
- $x_i$ is the allocation and order of the customers visited by an $i$-th vehicle;
- $C_{t,i}(t_{i,0}, x_i)$ is the operating cost for vehicle $i$;
- $C_{p,i}(t_{i,0}, x_i)$ is the penalty cost for vehicle $i$;
- $m$ is the maximum number of vehicles available.

The model was based on the following assumptions: a vehicle must depart from the depot and return to the depot at the end of the tour and can come back to the depot during the tour; a vehicle visits each customer exactly once; the demand conditions are that the load of a customer should be carried by a vehicle in a single visit and that the total load of a vehicle cannot exceed the capacity of the vehicle; the first departure time from the depot and the last arrival time at the depot during the tour must be within the designated time period.

### 3.3. Warehousing freight handling

The ITS impact topic on the goods movement in a warehouse has been addressed by several authors, according to a statistical approach. Eckhardt and Rantala (2012), Evangelista et al. (2009) have investigated the ICT role in the field logistics and their effects in the supply chain. Other studies have focussed on optimization procedures such as resources allocation or the products picking to increase and improve the management performance of the logistics platform (Petrucci et al., 2010; Poon et al., 2009).

Suchánek and Buckí (2011) have used a heuristic approach to optimize the location choice of the warehouse minimizing transportation costs in the context of electronic commerce. This position is defined considering the optimal distances between the participating companies and customers expected. The goal is to minimize the following function, given by the sum of the costs of storage and distribution costs:

$$\min \left( \sum_{m=1}^{M} \sum_{n=1}^{N} x_{m,n} \cdot a_{m,n} + \sum_{m=1}^{M} b_m \cdot y_m \right)$$

where:

- $a_{m,n}$ is the supply cost of the $n$-th shop from the $m$-th warehouse;
- $b_m$ is the warehouse operating cost in the $m$-th point;
- $x_{m,n}$, $y_m$ are decision variables;
- $m$ is the number of places for the warehouses location, $m = 1, ..., M$;
- $n$ is the number of shops given, $n = 1, ..., N$. 

The intelligent systems application to the warehouse activities has led to the design of intelligent operations management tools (Hildebrandt et al., 2010). Choy et al. (2003) have proposed an intelligent management system of supplier relationships (ISRMS) allowing manufacturers to select the most suitable suppliers according to the needs. Chow et al. (2006) have proposed the design of a system resource management through a RFID-based technology (RFID-RMS) exploiting a code procedures, to support companies in the resources use in the warehouse operations management, activities information management that involve saving time and costs.

Other authors have followed a simulation approach. Some studies have explained how the implementation of RFID technology can increase the visibility of information at various layers of the supply chain which through a software business-process, allowing members to gather precise information on real demand and improve replenishment processes.

3.4. Industrial freight handling

ITS applications in the industrial freight transport have been analyzed by various authors by following a statistical approach. Some of them have investigated how industrial and commercial processes were changed by the arrival of ITS and how such intelligent systems impacted on the staff’s skills. In particular, a study by Hidalgo and Albors (2010) have shown that the use of ICT in European Transport and logistics companies greatly improved the sector’s performance, as shown in Table 1.

Table 1. Use of ICT solutions for TLS Industry

| Sectors      | MMS | CHT | FCS | ITMS | ITS |
|--------------|-----|-----|-----|------|-----|
| Weighting    |     |     |     |      |     |
| Empl.%       | 32  | 15  | 16  | 5    | 29  |
| Firms %      | 17  | 12  | 12  | 4    | 16  |
| Empl.%       | 29  | 10  | 12  | 4    | 16  |
| Firms %      | 16  | 7   | 10  | 6    | 10  |

MMS: Maintenance management system; CHT: Cargo handling technology; FCS: Fleet control system; ITMS: Intermodal transportation management system

Another approach adopted by researchers is related to the optimization of industrial practices through ITS. Giannikas and McFarlane (2012) have introduced intelligent systems to improve logistics processes and activities supporting production. Doishita et al. (2010) have followed a “what to” approach to solve the problem of routing through decision support systems. Dabbene and Gay (2011) have examined innovative criteria and methodologies for measuring and optimizing the traceability system performance. Their approach consisted in an optimization problem expressed as a mixed linear programming. An interesting topic has been developed by Li et al. (2006), who have proposed an innovative planning model for the perishable products supply chain. Their goal was to minimize the product value loss and maximize profits for the partners of the supply chain. Each product unit was equipped with an RFID system which determined its quality state and sent this information to optimize products allocation.

Other authors have addressed the issue through the design and implementation of innovative systems. In the industrial sector, agri-food traceability has become increasingly important as a mechanism to enhance the level of coordination between producers and firms and between firms and retailers. Recently, technological advances have led to the design of ITS tools, such as barcodes and RFID for data acquisition and storage, databases, web-based systems and innovative tracking systems, with a view to reducing management costs.

3.5. Intermodal freight transportation

The study of ITS applications in the intermodal platforms has been examined through various approaches.
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Coronado Mondragon et al. (2012a), Abajo (2009), Carrasco-Gallego and Moreno-Romero (2010) have elaborated statistical analyses of the economic and environmental impacts of ITS applications. Innovative solutions may support operators in the organization of terminal activities and accelerate intermodal transport by reducing handlings times and costs at the terminal. Coronado Mondragon et al. (2012b) have elaborated an overview of ITS developments in port operations through a case study analysis. They illustrated the role and contribution of ITS in multimodal logistics and focussed on wireless vehicular networks as Dedicated Short Range Communication.

Other authors have adopted optimization approaches to solve the specific problems of the sector. Flotzinger et al. (2010) and Dullaert et al. (2009) have addressed the problem through the development of intelligent systems, such as automation systems for intermodal activities, software and hardware for operations management. The study by Sirikijpanichkul et al. (2007) has introduced an integrated agent-based model to evaluate the location of a hub for road-rail freight transport, assuming four dominant agents: hub owners, transport infrastructure providers, hub users and the communities. Other authors have proposed innovative tools to improve the performance of intermodal transport. Some of them have defined intelligent platforms equipped with advanced systems to improve the intermodal terminal productivity, to plan the node activity, to monitor the logistic processes and to facilitate the information and data exchange. Rados et al. (2012), Siror et al. (2011) have focussed on the design of an intelligent port with ambient-intelligence technologies, web-based applications and RFID. Asosheh et al. (2008) have analyzed different methods for tracking shipping containers by means of satellite systems, RFID and GSM mobile communications.

An interesting study has been conducted by Andrzejewski (2010), which focussed attention on the problem of the modal choice freight transport decision-makers have to face in the phase of delivery planning. This is the reason why ITS applications are an excellent decision support tool. The author proposed a software programme to support the transport mode choice from an origin to a destination, also comparing the time and cost of the different alternatives. Furthermore, he presented a prototype of e-logistics platform as a potential tool to support small and medium-sized enterprises in their modal choices.

Amborski et al. (2005), Ballis and Golias (2004) have followed a simulation approach assuming changes in operational scenarios with the purpose to improve the logistic processes of intermodal platforms. Boile et al. (2006) have designed a conceptual framework that aimed to facilitate cooperation and collaboration between regional partnerships and stakeholders so as to improve port competitiveness through a methodology based on micro-simulation tools and real-time information obtained through processing and control technologies.

4. Conclusions

The introduction of ITS as an innovative tool for the management of freight transport activities has directed sector studies towards new research themes through methodological and modelling approaches.

After a brief general overview of the topic, different studies for ITS applications in freight transport have been analyzed, providing a new interpretation, which collects and groups studies into five macro-categories, according to the spatial context in which the supply chain works.

An architecture has been proposed for the models and methodologies analysis based on freight transport on a territorial scale; freight transport on an urban scale; freight handling at the warehouse, in the industrial area and at the intermodal platforms. Case studies are presented considering the approaches used by the authors: statistical analyzes, “what to” (optimization), “what if” (simulation) analysis and project proposals.

The specialized literature studies are important in order to understand how ITS can help to improve the different aspects of logistics. The current research is addressed on the development of models, algorithms and methodologies for specific applications in the field of agri-food logistics, considering the management characteristics and constraints of goods kinds, typically perishable, and the opportunities resulting from the use of new technologies such as ICT, thermal control, handling units control.
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