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Trends in transportation and logistics

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A B S T R A C T

Problems in transportation and logistics had to be tackled long before computers and Operational Research (OR) became available to support decision making. After the first optimization models were developed, OR has substantially contributed in making transportation systems efficient and companies with complex transportation and logistics problems competitive. Over the years, technology has evolved and the same has done OR. In this paper, the history of problems and OR contributions in transportation and logistics will be shortly reviewed together with the evolution of technology. Then, the future trends in this area will be discussed together with potential OR contributions.

1. Introduction

Problems in transportation and logistics had to be tackled long before computers were invented and Operational Research (OR) became a discipline aimed at developing models and techniques to support decision making.

After the first optimization models were developed, OR has substantially contributed in making transportation systems efficient and companies with complex transportation and logistics problems competitive. OR, as a *system science*, has captured the complexities of problems and the interactions among parts of a system to improve the quality of decision making. The OR methods have been dependent on data availability and in most cases have relied on computers. The availability of more data and of more computational capacity have made the OR methods more powerful.

Over the years, technology has evolved and the same has done OR. The internet, technological developments, the individual use of information and communication devices, the widespread availability of massive amounts of data have created new challenges and opportunities to transportation and logistic systems, and to researchers in OR as well.

The aim of this paper is to show that, over time, the contributions of OR to transportation and logistics have evolved, following the evolution of problems in the area and technology, and that the recent trends are creating exciting opportunities.

In Section 2 the history of problems and OR contributions in transportation and logistics will be sketched out, together with the evolution of technology, to outline that problems in the area, technology and OR are strongly interconnected. Major general technological phenomena, namely big data and internet of things, are shortly presented in Section 3. Problems in logistics and supply chain management are mainly related to the transportation of goods and are generally treated separately from problems concerning mobility, that is the transportation of people. The trends in logistics and supply chain management will be discussed, together with potential OR contributions, in Section 4, whereas the trends in mobility problems will be discussed in Section 5. Some conclusions will be finally drawn in Section 6.

2. The history of transportation and logistics

The history of problems in transportation and logistics is deeprooted. Only recently OR has contributed to their solution, accompanied by the birth and growth of computerized systems.

2.1. Transportation and logistics

The history of transportation and logistics is as long as the history of mankind, but has been marked by recent milestones. The railroad was discovered at the beginning of the nineteenth century, the airplane in 1903. In maritime transportation, the invention of the sea container is dated 1956 and has impacted sea transport dramatically. Nowadays logistics, and the broader concept of supply chain management, is mainly intended as a business function that has the scope to make goods available where and when needed and in the needed quantities. Transportation management can be seen as part of logistics, when referred to the business processes. However, not only goods but also people need to be transported. In the old times people used to walk or travel by horse

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or carriage or ship. Nowadays different transportation means are available with different levels of cost and comfort.

Traditionally, freight transportation problems have been independent of people transportation problems. Moreover, whereas freight transportation is a relevant problem in the private sector, people transportation problems have been mostly - with the exception of airlines - faced by the public sector that is responsible for the public transportation (mass transit) system and for the design of the infrastructure for the movement of private vehicles. Fleets of vehicles, mainly buses and trains, have needed to be coordinated in terms of routes, schedules, crew and OR has offered fundamental contributions to the optimization of these systems.

2.2. Operational research

Transportation and logistics problems have been studied for a long time by researchers and practitioners in operational research. In fact, the first contribution dates back to 1930 and is due to Tolstoı, as reported by Schrijver (2002). It is a model for the solution of a practical problem related to the transportation of salt, cement, and other cargo between sources and destinations along the railway network of the Soviet Union. The author studied the transportation problem and described various solution approaches and the now well-known idea that an optimal solution does not have any negative-cost cycle in its residual graph. As mentioned in Schrijver (2002), Tolstoı might have been the first to observe that the cycle condition is necessary for optimality. A large - for that time - size instance with 10 origins and 68 destinations was solved taking advantage of the structure of the railway network. Later, the transportation problem was formulated by Hitchcock (1941), and a cycle criterion for optimality was considered by Kantorovich (1942).

The history of the contributions of OR to transportation and logistics followed the evolution of the problems in the area and at the same time the developments in the information and communication technologies (ICT). The major phases of this history can be sketched as:

1960s and 70s: *Transportation science* emerged. *Transportation* meant traffic and public transportation, whereas *logistics* was a young field that referred to physical distribution and inventory management. In the same period, different programming languages were developed. The first FORTRAN compiler was delivered, in fact, in 1957. In the sixties 40 FORTRAN compilers became available. FORTRAN was developed for scientific and engineering applications and dominated this area of programming for over half a century. Besides FORTRAN, other languages were developed: in 1968 Logo, in 1970 Pascal, in 1972 C, Smalltalk, Prolog, in 1978 SQL;

1980s: It is the period of the study of trucking (common carriers and private fleets). In this decade rail and sea transportation emerged. Air transportation also emerged as a distinct research area. During the early 1980s, home computers were developed for household use, with software for personal productivity, programming and games;

1990s: *Transportation* included passenger and freight transportation. *Logistics* developed with a focus on operations and shippers into *supply chain management*. *Transportation and logistics* emerged to cover a broader variety of problems. Since the mid-1990s, the internet has had a revolutionary impact on culture and commerce, including the rise of near-instant communication by electronic mail, instant messaging, and the World Wide Web with its discussion forums, blogs, social networking, and online shopping sites;

2000/2010: *Transportation and logistics* covers a continuously growing number of applications. The traditional barrier between freight and passenger transportation seems to become thinner and thinner. The mobile apps (that stands for applications) are made available through digital distribution platform to mobile devices such as smartphones and tablets.

The research in transportation and logistics has not only produced an advance of knowledge, with academic results measurable in papers published and conferences organized. Having always been driven by real problems, the research has produced models and algorithms that have been embedded in software packages, used by companies in the private and public sectors. Two surveys published in OR/MS Today, one on software for supply chain management (Aksoy & Derbez, 2003), and one specifically for vehicle routing problems (Partyka & Hall, 2014), witness this impact. The two surveys are accompanied by a summary of the problems addressed in the software and the corresponding OR tools, from facility location to warehouse management, from lot sizing to production scheduling, from supply chain network design to inventory management, from fleet management to vehicle routing (see also the recent books Toth & Vigo (2014) and Corberán & Laporte (2015)).

3. Big data and internet of things

The most recent technological advances are related to the explosion of digital data, the so called *big data*, and to the expansion of the concept of internet to the so called internet of Things (IoT), also called the internet of objects.

The number of searches in Google for ‘big data’ has exceeded in 2013 the number of searches for ‘supply chain management’ (see Waller & Fawcett, 2013). This does not imply that data is more important than supply chain management but certainly is a signal of the growing perception that the availability of massive quantities of data is relevant to businesses and to services, to the private and to the public sectors, to companies and to institutions.

What makes big data different from traditional data? In McAfee and Brynjolfsson (2012) three main differences are identified: volume, velocity and variety. ‘More data cross the internet every second than were stored in the entire internet just 20 years ago’ (McAfee & Brynjolfsson, 2012). The speed of data creation is for many applications extremely important, possibly more important than the volume of data. Big data takes a variety of forms, from messages to images, global positioning system (GPS) signals from cell phones, readings from sensors. The social networks, smartphones and mobile devices are sources of big data and provide enormous amounts of data related to people, activities, locations. Smartphones and mobile devices have become so ubiquitous that it is easy to forget that they did not exist less than ten years ago. Because of big data, managers and decision makers can know more and transform that knowledge into improved decision making and performance.

Data-driven decisions are better decisions. This is an obvious concept to operational researchers. However, the big data is creating a new broad range of opportunities for operational researchers, in particular in the field of transportation and logistics. In fact, while big data is an extremely popular expression and data scientists are requested by an increasing number of companies (see Davenport & Patil, 2012), acquiring big data is far from being sufficient. Big data is the input to advanced quantitative tools that can lead companies and institutions to better decisions (see Barton & Court, 2012).

The big data phenomenon is related to, and also partially caused by, the IoT (see, for example, Atzori, Iera, & Morabito, 2010 and Gubbi, Buyya, Marusic, & Palaniswami, 2013) which is the network of physical objects or 'things' embedded with electronics, software, sensors, and network connectivity, which enables these objects to collect and exchange data. The IoT allows objects to be sensed and controlled remotely across an existing network infrastructure, creating opportunities for more direct integration between the physical world and computer-based systems. The IoT encompasses smart grids, smart homes, intelligent transportation and smart cities. In the IoT each thing is identified by its embedded technology and is able to inter-operate within the existing Internet infrastructure. The IoT will increase the ubiquity of the Internet and lead to a highly distributed network of devices communicating with human beings as well as with other devices. The IoT is expected to generate in the future larger amounts of data than available nowadays.

Big data and IoT are opening tremendous opportunities for a large number of novel applications and research projects.

4. Trends in supply chain management

The aim of this section is to outline new trends and research opportunities in supply chain management. The environment for supply chain activities is changing and experts predict that many changes will occur in the near future. In Stank, Autry, Daugherty, and Closs (2015) ten trends were identified as influential in the near future of the supply chain management industry. We shortly summarize here the trends that are most relevant to OR:

- Systemic focus: Optimization of the entire supply chain network, customer value co-creation.
- Information synthesis: Information is holistically shared, joint interpretation to improve performance.
- Collaborative relationships: Joint accountability and rewards, total system value creation.
- Demand shaping: Proactively influencing demand, total system value creation.
- Transformational agility: Constantly changing conditions.
- Flexible network integration: Dynamic selection of partners upstream and downstream.
- Global optimization.

Three major directions for research can be derived from these trends: a systemic, a collaborative and a dynamic direction. In the following we discuss the research opportunities associated with each of these.

4.1. Systemic direction

Operational research has contributed to decision making in several areas of supply chain management. The systemic direction suggests that better solutions to problems can be identified when broader parts of the supply chain are jointly modeled and optimized. In fact, several research efforts have already been made in recent years in this direction.

As an example, in the area of vehicle routing, several papers have studied more global problems with respect to the classical routing problems aimed at finding the routes of vehicles only, given locations, demands of customers, time windows. Integrated vehicle routing problems is the expression increasingly used to denote the class of problems where the routing decisions are tackled together with other decisions (as outlined by the special issue edited by Bektaş, Laporte, & Vigo, 2015). Location-routing problems jointly optimize location and routing. Inventory-routing problems combine routing and inventory management. Production-routing problems integrate production, routing, and usually also inventory decisions. Multi-echelon routing problems optimize the routes of vehicles in distribution systems comprising two or more echelons. Routing problems with loading constraints simultaneously optimize the routing of vehicles and the loading of goods on them.

Integrated vehicle routing problems combine problems that are usually NP-hard by themselves (routing problems are among the hardest combinatorial problems). However, solving the problems independently, even by means of exact methods, leads to a sub-optimal solution for the integrated problem. One of the first papers that showed the benefits of integrated decisions is due to Chandra and Fisher (1994). More recently, Archetti and Speranza (2016) compared the heuristic solution of an inventory-routing problem with the solution obtained by sequentially and optimally solving the inventory management and the routing problems. The sequential solution models a traditional management style of a supply chain where customers control their optimal inventory management policy and decide order times and quantities. Only afterwards, the supplier organizes an optimal distribution that, however, has to take customer times and quantities as constraints. The inventory-routing problem models instead a more recent integrated management policy, called Vendor Managed Inventory (VMI), where the supplier is responsible for the distribution as well as the inventory at its customers (see, for example, the review of VMI by Marquès, Thierry, Lamothe, & Gourc, 2010). The research direction towards more integrated problems is consistent with the trends sketched above. More integrated optimization problems model more integrated management styles of supply chains, contribute to exploit the advantages of the integration and can quantify the benefits. In Archetti and Speranza (2016) the results of computational tests show that solutions of the inventory-routing problem allow average savings of 10%, with average savings on inventory and transportation costs of 15% and 9%, respectively. Thus, if a heuristic is used for the solution of the integrated problem that generates an average error of less than 10%, the integration offers benefits with respect to the sequential solution, even if optimal, of the individual problems.

4.2. Collaborative direction

The trends include collaborative relationships. Collaboration in supply chain management has been widely discussed (see, for example, Barratt, 2004, Holweg, Disney, Holmström, & Småros, 2005 and Fawcett, Fawcett, Watson, & Magnan, 2012) and many strategies have been suggested, including, among the most popular ones, VMI and Collaborative Planning, Forecasting and Replenishment (CPFR) initiatives. Collaboration can be seen as a tool that enables integration and global optimization of a supply chain. It is beyond the scope of this paper to explore the complexities of the implementation of collaboration initiatives and discuss when and why collaboration can be effective in practice. The goal here is to start from the observation that collaboration is a trend in supply chain management, enabled by the technology and stimulated by increased competition and expected benefits, and to argue that new optimization problems arise when decision making takes place in a collaborative environment. Collaboration initiatives may fail for several reasons and the lack of exploitation of the potential benefits is one of those reasons. Here is where OR can contribute.

The challenges of integrating internal and external operations are known (see, for example, Holweg et al., 2005). In this section for collaboration we intend external collaboration, that is collaboration with companies that are external to the supply chain. Collaboration inside the supply chain can be seen as falling in the systemic direction.

Partners of a collaboration initiative decide to work together because they expect to improve the performance of their own business through collaboration. Whereas collaboration will change their behavior and imply interactions among partners in a joint effort towards integration, each partner will be focused on its own business more than on a global performance. Thus, integration must be mediated with individual interests to make the collaboration initiative successful. This essential concept in collaboration may make models for decision support in collaboration initiatives different from models for global optimization.

As an example, let us consider collaboration among carriers. Statistics show (see Giachino, 2010) that approximately 90% of freight travels on road and that in all European countries the percentage of empty trucks traveling on road and contributing to traffic, pollution, accidents is between 15% and 30%. The average load of a truck is much lower than its capacity and particularly low in city distribution. The number of trucks on road is much higher than it should be. Several causes of these negative statistics can be identified. Among these, we certainly have the size of carriers, the dispersion of customers, the short lead time between order and delivery times, caused in particular by the increasing volumes generated by e-commerce activities. Collaboration among carriers may improve the statistics and generate economic benefits for the carriers involved as well as social and environmental benefits.

To illustrate the concept, let us consider the problem studied by Fernández, Fontana, and Speranza (2016), where a collaboration scheme is adopted by a group of carriers. Each carrier may decide to serve a subset of its customers and to share the other customers with other carriers. If a customer is shared it may be served by any of the carriers of the group. A carrier will choose to serve customers with high volumes or conveniently located or valuable for any other reason. A customer with low demand, and far from the depot and from other customers will be likely shared. The profit coming from a shared customer will be partly collected by the carrier 'owning' the customer and partly by the carrier actually serving the customer. The revenue sharing agreement is part of the collaboration scheme. In the solution where the sum of the costs of all carriers is minimized, each carrier will serve its customers, some of the customers shared by other carriers, and possibly some of its own shared customers that may become convenient when combined with customers shared by others. This solution will generate savings with respect to the total cost of the solution where carriers do not collaborate. However, such solution may be such that the profit of a carrier is lower than its profit without collaboration. Such a situation is likely to be unacceptable to a carrier, especially if not experienced only occasionally, and may make the collaboration fail. In Fernández et al. (2016) a model is, thus, suggested where the profit of each carrier is constrained to be not lower than the profit that would be gained without collaboration. In this way, the collaborative solution will be beneficial to each individual carrier. Computational results show that the total profit increase in a solution where carriers collaborate, with the individual profit guarantee, is on average 7% higher than the total profit without collaboration. The results also show that the profit increase strongly depends on the location and demand of customers, ranging from small positive values to up to 85%.

4.3. Dynamic direction

The transformational agility and the constantly changing conditions listed as trends are caused by the continuously changing flow of data about customers, purchases, deliveries, locations, inventories. This in turn makes the problems intrinsically much more dynamic than they used to be. Systems should become more reactive to changes and provide more effective responses to customers whose demand is becoming more and more variable over time, due to the increasing volumes of e-commerce. This latter trend makes the demand also difficult to predict. As planning activities based on forecasting will remain essential in supply chain management, especially in the upper parts of the supply chains (see Simchi-Levi, Kaminsky, & Simchi-Levi, 2004), models should also capture all the possible, uncertain, information available on future outcomes.

Most classical optimization models assume that all relevant information is available at the moment a model is built, that the model is then run and the solution obtained entirely implemented. This was a realistic assumption in a world where it was very time consuming and costly to collect data and where the data were updated rarely. This assumption is becoming less and less acceptable, because solutions need to be revised shortly, before being completely implemented. Although dynamic problems in transportation have been discussed for a long time (for example, by Psaraftis, 1995), research on dynamic and stochastic vehicle routing problems received increasing interest only in the last decade (see the recent survey by Ritzinger, Puchinger, & Hartl, 2015). In fact, in Ritzinger et al. (2015) the importance of appropriately modeling dynamic events and simultaneously incorporating information about the uncertainty of future events is outlined.

Several research opportunities related to the dynamic direction in supply chain management are discussed in Waller and Fawcett (2013). Moreover, the data is continuously changing and long computational times become less and less acceptable. How much computational effort is worth investing in a model whose solution will only be partially implemented? When a change in the data should imply a rerun of a model? Or what changes in the data make the rerunning of a model beneficial? The need to run a model frequently because of the continuous update of data creates other relevant research issues. Can we take advantage of the work done by an algorithm for the solution of an optimization problem to speed up the solution of the next problem, where some data, but not all, have changed?

5. Trends in transportation

Although private cars remain the dominant transportation mode for the large majority of people, the set of mobility options is growing. Startups in this sector establish themselves within a short time. Uber, Grabtaxi, BlaBlaCar, Zipcar are only some of the names corresponding to companies that offer an alternative transportation mode to people, some for short, others for long distances. Young people tend to use these new options and to delay the purchase of a car and the acquisition of a driving licence.

In Porter, Linse, and Barasz (2015) six major trends in people transportation are presented that will change the way we move:

- Autonomous vehicles: Hands-free and feet-free driving is reality, fully autonomous vehicles will become reality shortly.
- Electric vehicles: Mainly transit buses and short-range vehicles are electric at present, electric vehicles are becoming more economical and can travel longer without being charged.
- Connected vehicles: Traffic data are becoming available on vehicles, vehicles are equipped with internet connectivity.
- Collaborative consumption: On-demand mobility options are growing, collaborative options enable mobility without mostly unused individual cars.
- Efficient multi-modal networks: Crowdsourcing transit data will adapt schedules to travelers needs, multiple trip options will be offered to travelers.
- New materials: Lighter vehicles will be designed, also to increase the distance traveled by electric vehicles.

It may not take long to see a fleet of autonomous, shared vehicles, connected to the road infrastructure, to the internet, and to a broader network of public transit options. In the rest of this section some research directions will be discussed.

5.1. Electric vehicles

Hybrid electric vehicles, battery electric vehicles, plug-in hybrid electric vehicles from being exotic words have become part of the options of any potential car buyer nowadays. We will refer to all these classes of vehicles as electric vehicles. The duration of batteries has increased and thus the autonomy of vehicles. Charging stations, though still rare, are increasing in number. Costs are still high but are expected to decrease. Incentives to the use of electric vehicles come from political institutions that see the positive impact coming from the change to the environment. While the global impact of a massive substitution of traditional with electric vehicles remains to be assessed, especially in terms of production of electricity, the trend towards the use of electric vehicles seems to be irreversible. This will certainly lead to environmental benefits, especially in densely populated areas.

Several papers have already appeared that tackle optimization problems specifically arising for electric vehicles (see, for example, Adler & Mirchandani, 2014, Schneider, Stenger, & Goeke, 2014, Pelletier, Jabali, & Laporte, 2014, Yang & Sun, 2015). Depending on the technological characteristics of an electric vehicle, different problems become relevant. Such problems may concern the location of charging stations, the routing of vehicles constrained by the limited autonomy and the rarity of the charging stations, the reservation of a battery, the fleet management.

5.2. Reduction of traveling vehicles and parking space

Traffic congestion is a dramatic problem in every country. People have to queue in their cars daily to reach their working place, to take children to school, to perform any regular activity. Green areas are transformed in parking spaces. Queueing is not an exceptional event but rather, especially in urban areas, a regular event that causes delays and stress. Delays in turn have huge economic and social consequences. The substitution of traditional vehicles with electric vehicles will not reduce the number of traveling vehicles, the need of parking space or the congestion problems.

The number of traveling vehicles can be reduced only by reducing the number of people in need of travel and/or by increasing the number of people transported in the same vehicle. While we can hardly contribute to the former option, our contribution may be relevant in supporting the latter.

One of the main reasons that leads people to use their own private vehicles is the lack of flexibility of mass transit systems. Such mobility systems typically work on fixed itineraries and fixed schedules. In most cases the frequency is too low and the travel time is too high. Such characteristics make these systems inappropriate for a transportation demand that is extremely dispersed in space and time, and requests quick response and short traveling time.

Demand Responsive Transit (DRT) systems (also called dial-a-ride systems) are flexible services that provide ‘door-to-door’ transportation. DRT systems are nowadays mainly implemented as services for small groups of people but have attracted a lot of research (see Cordeau & Laporte, 2007 for a survey and, as examples of more recent contributions, Masson, Lehuédé, & Péton, 2014 and Marković, Nair, Schonfeld, Miller-Hooks, & Mohebbi, 2015).

Martínez, Viegas, and Eiró (2014) have suggested a classification of DRT systems:

- with fixed itineraries and stops, with pre-booking;
- with fixed itineraries and stops with possible detours;
- with unspecified itineraries and predefined stops;
- with unspecified itineraries and unspecified stops.

The last type of service, which is the most flexible one, can be considered as the closest to the concept of shared taxis.

DRT systems are attracting more and more interest and DRT service providers become interested in improving the efficiency of their operations. An implementation of a DRT system in Maryland is presented by Marković et al. (2015) and the benefits, with 450 trip requests daily, of a computerized routing and scheduling system are estimated with annual savings of $0.82 million, or about 18% of the total annual expense, with respect to manual operations.

In Archetti, Speranza, and Weyland (2015) a simulation study is performed where a conventional mass transit system, say a system of buses, is offered together with an on-demand service without fixed itineraries and schedules that allows users to communicate the desired departure time, origin and destination of the trip. The on-demand service is provided through minibuses. A minibus, if acceptable to the user in terms of arrival time to destination, will provide the service picking up the user at the origin of the trip and delivering him/her to the destination. In case neither the conventional bus nor the on-demand minibus provide an acceptable service to the user, he/she will use a private car. The analysis performed suggests that the on-demand service would dominate the conventional buses, in terms of number of trips attracted, travel time and cost, that it would attract most of the people using at present a private car, and it would be more environmentally friendly, as it would reduce traffic and congestion.

More recently, DRT systems have been referred to as Flexible Transportation Services (FTS) (see Mulley & Nelson, 2009) when used as feeder systems for more traditional public transportation services such as buses or trains. A recent paper (Atasoy, Ikeda, Song, & Ben-Akiva, 2015) introduced a Flexible Mobility On Demand (FMOD) system that offers different services, taxis, shared taxis and minibuses, where the minibus service works as a regular bus service with fixed schedules.

Many research issues arise in DRT systems, from fleet management to dynamic routing of vehicles. Also, when used as feeder systems, synchronization problems should be addressed.

The so called dynamic ride-share systems share with the DRT systems the goal of increasing the number of people sharing the same vehicles. Such systems aim to bring together travelers with similar itineraries and time schedules on short-notice. Effective and efficient optimization methods that match drivers and riders in real-time are necessary for a successful implementation of such systems (see Agatz, Erera, Savelsbergh, & Wang, 2012 for a review of dynamic ride-sharing systems).

Whereas DRT systems aim at reducing the number of traveling vehicles, the need of parking space can also be reduced through car sharing systems. In a car sharing service a car is pre-booked, used and returned to a parking station. One-way, with respect to two-way, systems provide more flexibility to users since cars can be dropped-off at any station. As recent papers on optimization models for car sharing problems we refer to Boyacı, Zografos, and Geroliminis (2015) and de Almeida Correia and Antunes (2012). Research opportunities include the location of stations and cars, car relocation problems, coordination of reservations.

5.3. Reduction of congestion

We tend to think that congestion is uniquely determined by the number of vehicles on roads. In fact, this is only partially true, because congestion is determined also by the paths followed by traveling vehicles and by the time at which vehicles travel. Congestion happens when many vehicles travel along the same road at the same time. With the technology available nowadays it becomes possible, for a given number of traveling vehicles with given origins and destinations, to coordinate traveling paths and times.

The most common in-vehicle device aimed at supporting drivers in path selection is based on a digitalized road network map and a GPS aerial. Given a destination, the navigation system provides an optimal route usually in terms of distance or travel time. Recently, navigation systems possess some real-time traffic data and may reroute the drivers to non-congested paths. However, these systems do not consider the systemic impact of the provided directions. The navigation devices offer drivers with close origins and destinations the same information and, as a consequence, route guidance may simply shifts congestion to other roads. The potential for coordination and congestion reduction is enormous.

Optimization models have been presented in Jahn, Möhring, Schulz, and Stier-Moses (2005) and Angelelli, Arsik, Morandi, Savelsbergh, and Speranza (2015) with the goal of finding a system-optimal traffic distribution that ensures fairness, that is does not increase the shortest paths of drivers by more than a given percentage. In both papers a road network is given together with an origin-destination (OD) matrix that, for each OD pair, gives the flow, that is the number of cars traveling from that origin to that destination in a given time period. In Jahn et al. (2005) the arc travel time is modeled as a function of the number of vehicles on that arc. The resulting model is non-linear and a column generation solution method is proposed. In Angelelli et al. (2015) the arc travel time is given and the resulting models are linear. The proposed approach assigns paths to drivers with the objective of minimizing congestion while not increasing their travelled distance by more than the given acceptable percentage.

Research directions include the dynamic generation of acceptable paths, time-dependent optimization models (because the OD matrix changes over time), evaluation of drivers behavior, impact of incentives to drivers to follow the directions of the system. Previously mentioned technological advances, in particular the autonomous or driverless vehicles, may change the situation and would have several benefits in terms of congestion. Drivers will get used to trusting their vehicle and will more likely accept a route that is longer than the shortest one.

6. Conclusions

Recent technological and automotive advances are rapidly changing the way supply chains are managed and goods and people are transported. Economic pressure pushes companies to become more efficient and effective by also taking advantage of the technological advances. At the same time, institutions are driven by the sustainability goal, intended as the ability to meet the needs of the present without compromising the ability of future generations to meet their needs. It is expected that the huge economic impact of logistic costs on companies and of transportation on the environment, together with new arising business opportunities, will rapidly change transportation and logistics.

Operational research has given fundamental contributions to supply chain management and transportation problems and more essential contributions are expected in response to the new research challenges. This paper has summarized some of the major trends but several others are behind the corner. Opportunities for the consolidation of goods and people on the same vehicle are already arising. For example, customers may deliver goods of other customers, for a small economic incentive. Revenue management is another research area that was only marginally mentioned in this paper. Operational research is more vital than ever and can add relevant value to new available technology.

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