Mixing quantitative and qualitative methods for sustainable transportation in Smart Cities

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Abstract

The transportation system has been subject to significant paradigm shifts over the past decades, as regards both the freight transportation and people mobility. On the one hand, the urbanization and economic development in the mid-'90s have led the rise of faster-growing medium-large-sized companies that have specialized in the delivery of small parcels, giving birth to the Global Courier, Express, and Parcel (CEP) market [2]. Since the 2000s, the advent of e-commerce changed the logistics and freight transportation dramatically, with an increase of the deliveries to the Business-to-Consumer segments in the urban areas and the competition of e-commerce giant platform to cope with the increasing requests for fast and cheap deliveries.

On the other hand, the urbanization and demographic growth increase the need for people mobility with a huge impact on the saturation of transportation infrastructure. Freight vehicles compete with private and public vehicles transporting people for the capacity of the streets and arteries of the city, and contribute significantly to congestion and environmental nuisances, such as emissions and noise [1]. Thus, the urban space needs to be rethought in order to optimize the flow of traffic, but also encourage the use of non-motorized transport to move people and goods (e.g., bikes and cargo bikes), and collaborative business models. Therefore, a different way of improving the performance of the transportation system has to be found to make people and freight transportation more efficient, cost-effective and

sustainable, becoming key factors for the economic development of a country and its competition at the international level. A number of new organization and business models have recognized this challenge, leading researchers and practitioners to propose initiatives that jointly optimize the economic, operative, social, and environmental goals of transportation and logistics, mitigating their externalities and inefficiencies.

City Logistics provides a first mean toward this end. Originally, the authors in [7] defined as City Logistics as "the process for totally optimizing the logistics and transport activities by private companies in urban areas while considering the traffic environment, the traffic congestion and energy consumption within the framework of a market economy". However, recent phenomena as the on-demand economy, e-commerce, and urbanization, as well as pervasive technologies, lead to enlarge this framework and give the birth to new domains as the Physical Internet, and their convergence into the Hyperconnected City Logistics.

City Logistics has a multi-facet nature, characterized by concepts as multimodality and intermodality, synchronization of information and physical flows, consolidation and coordination, and finally, sustainability of the urban freight transportation and logistics systems (operational, economic, social, and environmental) [5]. Despite the high interest in City Logistics and its influence on urban development, not all initiatives and proposals are successfully implemented. The main reasons of failure lie the lack of support and commitment from the different actors (with different expertise) in the urban areas [4, 6], also as a consequence of the lack of a managerial perspective in designing sustainable policies appropriate for freight transportation and logistics. Indeed, usually implementation and proposal are too focused on the technological aspects as platforms, or optimization tools, missing a global vision and the lack between the business and operational models.

Moreover, another reason comes from the coverage of the urban area. City Logistics solutions can deal with the entire urban area, but very often they are focused on a limited area or subareas of the city characterized by specific socio-economic and demographic patterns, and the need to protect the cultural and historical property.

Much research and state-of-the-art in recent years have focused on technological solutions and interesting developments are still ahead. In fact, City Logistics challenges researchers to develop models, methods and decision support tools [3]. However, the complex system above described involves several critical issues (e.g., large-scale problems with a huge number

of deliveries points, uncertainty) and actors that must not be considered individually, and a holistic approach is necessary. This brings new challenges and complexity for urban transportation system that must work as a system integrator, incorporating current structures and, new and future business models (e.g., new delivery options and low-emission transportation modes) in a modular manner. Moreover, due to the on-demand economy, we are witnessing to a contraction in the timing for decision making. In fact, it appears that medium-term "tactical" decisions may involve very short-time horizons, highlighting the need of a flexible system able to represent different behaviors into an overall model.

This integration of new business models and the common practice of outsourcing in the parcel delivery and transportation might become sustainable if a negotiation process is done between actors (e.g., between shippers and carriers), and attention is paid to the design of the infrastructure, the capacity planning and the design of the different services. In doing so, negotiations and the decision-making process must be aided by *ad-hoc* methodologies. These methodologies must aim a comprehensive concept of sustainability from economic, operational, environmental and social standpoints, and thus they must be based on a mixture of qualitative and quantitative techniques. In fact, methods and models by the communities of researchers in Operation Research, Management and Business, Transportation Science, Statistics and Computer Science, within new frameworks as the City Logistics must be integrated. However, such an approach is still missing in the literature.

This work contributes to filling this lack in the literature in terms of multi-disciplinary approach and modeling framework for new planning problems. In particular, this thesis starts with the analysis of the recent relevant literature on intermodal freight transportation that is acknowledged as the backbone of international trade, supporting the efficiency of the above discussed emerging operational and business models, such as City Logistics, in achieving sustainable transportation and logistics. For this reason and due to the similarities at the logical level with the urban context, it can provide important insights from which draw inspiration to optimize the urban freight transportation and design a sustainable system. The review conducted on the intermodal freight transportation literature confirms the multi-disciplinary and multi-facet nature of applications in freight transportation. The results highlight the need for incorporating into simulation and optimization tools a managerial perspective and a representation of the business models of the various stakeholders. Thus, the challenge for simulation development is to

model the business models of the different actors and their interactions in terms of contracts, pricing and costing schemes, and operational issues.

In this direction, the thesis has two goals:

- investigate if the integration between business and operational models is possible and which could be the value of this type of integration;
- discuss the benefits of the integration of business and operational models in the urban context. In particular, this thesis is focused on the last mile segment of the supply chain that as mentioned, is the most critical segment due to the large scale problems in a small-sized area and the different sources of uncertainties.

Then, two main problems in the transportation context are proposed to highlight how qualitative and quantitative methods and models are used to support the decision-making processes and to extrapolate industrial and public policies. These applications concern the integration of traditional freight transportation modes with low-emissions vehicles and new delivery options (e.g., cargo bikes and lockers), and the tactical capacity planning problem, respectively.

In particular, the first part of the thesis provides an overview of urban freight transportation and logistics, introducing the emerging challenges, and deriving by the intermodal approach interesting insights as the need for linking new business and operational models and incorporate them into decision support systems for new planning problems. Thus, we propose a multi-disciplinary approach to deal with the issues that affect the freight transportation and logistics in urban areas and design a sustainable urban system.

In the second part of the thesis, we present the first application of the proposed multi-disciplinary approach that concerns the integration of traditional transportation modes (i.e., vans) and new vehicles with a low-environmental impact (i.e., cargo bikes). This study integrates a managerial analysis of the current business models in urban freight transportation and parcel delivery, describing the stakeholders' profiles in terms of their needs and, cost and revenues structures. Then, the integration of business and operational models, is supported by a performance analysis of the traditional and green delivery options, based on the main variables that affect the last-mile logistics in urban areas (e.g., distance, delivery time). Finally, a quantitative analysis of the system is guaranteed by a Monte Carlo simulation, to extrapolate mixed-fleet policies.

Then, we extend the prior analysis investigating to what extent the integration of traditional transportation with new delivery options can be sustainable, considering not only vans and cargo bikes, but also the automated pick-up and delivery point "lockers", reflecting the current practice in the market. After introducing the context, we identify a lack in the City Logistics initiatives regarding a standard framework for simulating and studying the impact of optimization to achieve reasonable levels of efficiency in urban freight transportation, limiting the possibility to validate solutions and policies in real settings, and compromising the technology transfer to industry. Thus, we propose a new standard simulation-optimization framework for building instances and assess operational settings. To illustrate the usefulness of the framework, the authors conduct a case study, in order to evaluate the impact of integrating delivery options to face the demand from e-commerce, in an urban context as the city of Turin (Italy).

The integration of different transportation modes and outsourcing practices necessitate complex negotiation, and monitoring of contracts between shipper and carrier. In particular, in the last part of the thesis, we present a tactical capacity planning problem in freight transportation. This problem considers a shipper who seeks to secure transportation and warehousing capacity of multiple types from a carrier, to meet its demand for deliveries. The medium-term nature of contracts, requires to deal with the uncertainty, that in this study is expressed in terms of the demand of loads to be transported, the availability of contracted capacity, the cost and the availability of additional capacity if required. After introducing the problem, which is relevant in both the first and last mile segments of the supply chain, we formulate a stochastic two-stage model and propose a meta-heuristic based on the Progressive-Hedging (PH) algorithm. We present new instance sets for tackling the problem partially derived by real parcel delivery applications. Then, we discuss the extensive computational campaign conducted to evaluate the impact of considering uncertainty in the first and last extremities of the supply chain (i.e., long-haul shipment and last-mile delivery) and provide managerial insights.

Finally, the thesis concludes with a summary of the findings as well as suggestions for future research activity.

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