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Urban freight transport using passenger rail network: Scientific issues and quantitative analysis

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ABSTRACT

This paper addresses a real-life problem arising in the ongoing “Grand Paris” project. We investigate an environment-friendly urban freight transportation alternative using passenger rail network, by providing a decision support tool for decision makers to assess the technical feasibility, the impact on services to passengers, the needs in infrastructure and hence in investment. We identify relevant scientific issues that need to be addressed in this topic at strategical, tactical and operational levels. Then we focus on the Freight-Rail-Transport-Scheduling Problem which provides valuable information to and constitutes a basis for other related problems. This problem is first formulated into a MIP. We prove its NP-hardness and hence propose a heuristic based on dispatching rules and a single-train-based decomposition heuristic. The performances of these heuristics are evaluated via employing a discrete-event simulation approach, which also provides a general framework which supports decision-makers in modelling and evaluating the dynamics of such a system for various alternative solutions under various scenarios.

1. Introduction

The European Union targets a carbon-dioxide-and-greenhouse-emissions reduction by 20% in 2020 from their 1990 level, in order to cope with climate change (OECD, 2014). This target has to be met in a context of population concentration in cities, e-commerce development and increase of the world population (Comi and Nuzzolo, 2016). Indeed, 73% of the European population now lives in urban areas with an expected even higher rate in the future (United Nations, 2015). As a direct consequence, according to Van Audenhove et al. (2015), it is expected that the generated urban traffic measured in travel distance would triple by 2050, including urban goods distribution. Nevertheless, urban freight transport is necessary to support efficient economic and social development in urban areas (Taniguchi et al., 2001). For urban freight transport, road has been predominant despite its significant weaknesses such as worsening congestion, low safety and negative environmental impacts (Limbourg and Jourquin, 2009). A quarter of the carbon-dioxide emissions are caused by transportation activities (Nanaki et al., 2016). For several decades, although freight transport by trucks has been representing only 10% of the total traffic, it has accounted for 40% of pollutant emissions in big cities (European Cooperation in the Field of Scientific and Technical Research, 1998; Tang et al., 2017). In many European cities, the authorities regulate urban transport through restrictive policies such as progressive ban on the most polluting vehicles, or even by introducing a toll proportional to the pollution degree of vehicles (in Milan for instance). Moreover, the European Union coordinates its actions

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through the Transport Committee of the EU by setting ambitious targets for member states such as zero-pollutant emissions related to goods transport in urban areas until 2030 (European Commission, 2011). In December 2015, the United Nations conference on climate change “COP21” fixed a more ambitious environmental target, which will surely have an impact on urban freight transport.

The above-mentioned context requires changes toward more environment-friendly transportation systems to cope with increasing demand for mobility in urban areas. Introducing freight transport into passenger rail network is one of the ways to absorb a significant part of the current road traffic. Goods deliveries can be ensured by combining other sustainable modes such as Electro-Mobility “E-Mobility” (MacHaris et al., 2007; Köhler et al., 2009; Offer et al., 2010; Van Wee et al., 2012; Van Duin et al., 2013). The main idea here is to mitigate ground traffic by shifting as much road traffic as possible toward rail and get a better use of the currently under-exploited passenger trains' capacity.

This work aims to provide a decision-support tool to investigate the feasibility and to evaluate the potential benefits and other impacts of such practices in Parisian metropolitan area. The challenge comes from coordinating freight and passenger flows using existing and forthcoming urban passenger rail infrastructure, which is actually in extension through the ambitious “Grand Paris” project. This challenging project aims to shift toward a resilient and smart city by innovating in terms of offers in services and infrastructure. The existing Parisian rail network is one of the largest in Europe and aims to add 200 km rail lines and 68 stations. This project promotes sustainable development and improvement of life quality in Paris and its periphery. One of the most relevant ideas is integration of urban freight flow with the passenger one. For example, a passenger that wants to send a parcel by post should be able to deposit it at the metro/tram station before traveling. This pick-up system has been experimented in several countries and is expected to be deployed in the near future in France. The objective of this work is to take this opportunity to explore the possibility of expanding the urban rail infrastructure to freight transport, by evaluating the technical feasibility, the impact on services to passengers and financial viability, while considering technical and organizational constraints. This evaluation will enable the project managers to envision different options. For this purpose, they need a decision support tool capable of proposing optimized solutions and evaluating various alternatives under different scenarios. This paper aims to provide such a tool.

The first step is to identify the scientific issues in decision-making for such a configuration, from short-term operational decisions to long-term strategical decisions. From this analysis, we investigate the Freight-Rail-Transport Scheduling Problem (“FRTSP” for short), since its solution provides valuable information to other decision-making problems and thus constitutes the basis to address such a system. For this problem, we propose a MIP formulation and several heuristics to solve the problem. A simulation model is used in order to evaluate the performance of these heuristics and the dynamics of such transportation systems which is essential for practitioners and decision makers and for academics to better understand and address the system.

The remainder of this paper is organized as follows. Section 2 reviews the related literature. Section 3 is devoted to the identification of relevant scientific issues at different levels of decision making. Section 4 describes in detail the FRTSP. In Section 5, the FRTSP is mathematically formulated into a MIP and its computational complexity is analyzed. Section 6 presents the solution methods: a dispatching-rule-based heuristic and a single-train-based decomposition heuristic. Section 7 describes the simulation framework we develop to model and evaluate urban freight transport using passenger rail network. In Section 8, the simulation results are reported and analyzed. These results include the performance of different solution methods and the impact of freight transport on various core components of rail networks: trains, stations and rail lines. Finally, Section 9 concludes the study and discusses future research directions.

2. Literature review

2.1. Urban freight transport: Road mode predominance

Freight transport in European cities is mainly related to goods flows from producers, wholesalers and distribution centers toward retailers such as stores, outlets and markets (Nuzzolo and Comi, 2014). The freight transport is still road predominant (Lindholm and Behrends, 2012). In France, for instance, it is estimated between 85% and 90% by the National Institute of Statistics and Economic Studies (2015). However, cities' ground transport has limited capacity and trucks cause very high level of nuisance (e.g.: noise, gas emissions, increased traffic…). Dablanc (2007) notes that transport-related operations in cities generate between 20% and 30% of the road traffic but, depending on the pollutant considered, it produces between 16% and 50% of air pollutants. For example, Paris statistics show that 90% of freight is carried out by trucks, representing 20% of urban traffic and 1/3 of pollutant emissions in the city (Mairie de Paris, 2009).

The idea of mixing freight with passenger flows using urban road transportation is studied in Trentini and Malhene (2012) where the possibility of sharing passenger buses is suggested. In particular, they analyze urban passenger and freight flows and demonstrate that there is enough room in passenger service to transport a part of the urban freight. They propose to use the spare capacity of passenger buses to transport goods from bus depots to different bus stops inside cities. This study is completed by Masson et al. (2015), where the authors optimize, with a mathematical model, goods deliveries from bus stops to final customers, using near-zero-emissions vehicles.

A research team working on physical internet proposes to redesign the logistics system to consider sustainability and traceability issues and goes toward an open global logistics system where supply networks are interconnected (Sallez et al., 2016). They propose to use a set of collaborative protocols, modular containers and intelligent interface standards to increase efficiency and sustainability. The principle of this approach is to pool all transport resources for commodities from different carriers between countries, cities and inside cities. The European Technology Platform ALICE plans the deployment of physical internet approach by 2050 (ALICE and ERTRAC Urban mobility, 2015). In spite of the potentially interesting benefit of such concepts, the physical internet requires changing current practices and infrastructures of the whole supply chain and developing new ones, which must take a very long time.