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City Logistics and Traffic Management: Modelling the Inner and Outer Urban Transport Flows in a Two-Tiered System

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Abstract

City logistics deals with the logistical aspects involved in urban freight transport and related operations. These include, in addition to transport, handling and storage of goods, the management of inventory, and all related pickup and delivery operations. Traffic management and control deals with all operational aspects related to the traffic flow and (re)design of infrastructure. These aspects include the possibility to turn normal traffic lanes into reserved bus lanes or to define special routes to be operated only by freight transport. In this paper we discuss and model one of the effective management strategies for city logistics and traffic management in a metropolitan area. This strategy is based on a two-tiered system for which we propose an optimization model, in natural variables, and discuss some of its related challenges and solution approaches. We then propose an instance generator for this optimization model and show the solutions of one of these instances.

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Keywords: city logistics; optimization of traffic networks; logistics and traffic flow modelling

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1. Introduction

City logistics aims at optimally planning, managing and controlling, in an integrated and coordinated manner, the freight movement within a logistical network in a metropolitan area. The logistical activities and aspects involved in this process include, in addition to transport, handling and storage of goods, the management of inventory and related *pickup and delivery* operations. An in-depth discussion of the challenges and perspectives in city logistics can be found in Crainic *et al*. (2009), Benjelloun and Crainic (2008), Benjelloun et al. (2008), Dablanc (2007), Russo and Comi (2004), and Taniguchi *et al.* (2001). The typical basic optimization problem underlying the city logistics system can be formulated as an enriched inventory routing problem including facility location-allocation features. Variants of this problem attempting to integrate traffic information were formulated as dynamic routing problems with time windows and time dependent travel times (Taniguchi and Shimamoto, 2004). Impact on the environment is also considered, and models have been proposed to measure and minimize CO2 emissions (Taniguchi and Van Der Heijden, 2000, Taniguchi and Thompson, 2002).

Traffic management and control in a metropolitan traffic network is typically formulated as a bi-level optimization problem (Patriksson and Rockafeller, 2002). In the upper level of this non-cooperative Stackelberg game, the traffic manager sets controls (e.g. allowed driving directions, traffic signals and restrictions, speed limits) in order to optimize a given objective such as minimizing the total time spent by all travellers. In the lower level, each traveller is assumed to selfishly optimize his travel choices (mainly route of travel), leading to the well-known Wardrop user equilibrium conditions (Wardrop, 1958). Total traffic demand is usually assumed as given and fixed (i.e. travellers set out for their trip regardless of the traffic conditions or control). Special user classes (e.g. emergency vehicles, public transportation vehicles) can be given higher weights in the objective of the controller, or in practice are usually given full priority. This is however known to substantially increase the delays incurred by other user classes (Furth and Muller, 2002).

Many strategies or systems were proposed for city logistics and traffic management, to efficiently and effectively manage urban freight transport and other traffic flows, with a main objective of achieving an optimal trade-off between ensuring optimum supply network productivity, reliable customer service and reducing environmental impacts, air pollution emissions, energy consumption and traffic congestion. A first strategy involves a single-tier system, in which inbound freight is consolidated at one or several city distribution centres (CDC), located at the city limits, and is then distributed to the customers inside the city (Benjelloun *et al*., 2009). Single-tier systems, suitable for small to medium-sized cities, implement direct-distribution strategies, serving customers in the city centre by vehicles operating tours starting and finishing at some CDC facility. A second strategy, involving two-tiered systems (Crainic *et al*., 2004, 2009), typically appropriate for large cities, are based on a so-called consolidation-distribution strategy, which uses a second level of facilities and different vehicle fleets in order to avoid the presence of large vehicles in the city centre, and improve the ratio of load to travelled distance.

This paper considers a two-tiered system and proposes a two-layered optimization model for the urban freight transport, taking delivery time-widows and traffic conditions into account, as well as the replenishment of satellite warehouses and coordination of both flows. We then discuss some properties of the model and possible solution approaches for it.

2. Modelling the urban traffic in the two-tier strategy

The model described in this paper is formulated as a *Time Dependent Vehicle Routing Problem with Time Windows* (TDVRPTW) composed of two layers and enriched with constraints which reflect the city environment. The outer layer deals with the urban freight transport from the CDCs, situated on the outskirts of the city and therefore referred as *external zones*, to *depots* or *satellites*, which are intermediate facilities strategically located in the interior of the city. The transportation in this layer is performed by *urban vehicles*, which have relatively high capacities but are not allowed in all areas of the city and cannot directly serve the *customers*.

The inner layer deals with the transport of the goods from the intermediate facilities to the customers. This is performed by smaller vehicles called *city freighters*. Urban vehicles and city freighters meet at appointed times at