Scheduled Service Network Design with Resource Management for Multimodal City Logistics with Inbound and Outbound Flows

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The transportation of goods in urban areas is a complex activity, essential to the economic and social life of the city. It is also a major contributor to significant nuisances, e.g., congestion, emissions, noise, excessive consumption of fossil fuels, etc. The complexity, as well as the positive and negative impact of freight transportation on the city, its citizens and activities are amplified by two heavy trends observed world-wide. Increasing urbanization is the first. While 54% of the world's population was living in urban areas in 2014, the United Nations are expecting an increase of up to 66% until 2050 (the OECD prediction is 85% by 2100). This already results in increased numbers and amplitudes in the demand for transportation, freight and people, as well as in the flows of goods and vehicles of all modes moving into and out of the city. The strong continuous growth of e-commerce activities (e.g., some 13% yearly in the last years in Europe) compounds the problem, further straining the distribution systems.

New *City Logistics* (*CL*) organization and business models are proposed and, in some cases, deployed, to address these issues [5, 3, 4, 1]. Consolidation of shipments into the same vehicles, irrespective of the commercial transaction that generated them, and some form of stakeholder coordination/collaboration are at the core of most such proposals. Two-tier systems are generally considered for medium and large urban zones, where shipments inbound for distribution within the city are first consolidated at main facilities on the outskirts of the city, moved to smaller satellite facilities close to the city-logistics controlled zone, where they are transferred to "green" (usually) vehicles of appropriate dimensions for the zone providing the final last-km distribution.

Consolidation-based transportation systems require advanced planning methods and CL is no exception. Yet, while a number of models were proposed, e.g., [2], the literature is still scarce in both solution methods and the CL characteristics considered. We aim to contribute to fill these gaps by addressing the tactical planning problem of a two-tier CL system integrating several features, rarely considered previously: 1) multiple transportation modes, including non-truck ones such as rail- (e.g., tramways or subways) or water-based; 2) several vehicle fleets within the same mode, with potentially several compartments per vehicle; 3) two types of transportation demand, i.e., inbound for distribution within the city and outbound to be picked up within the city and delivered at a main facility for long-haul movements; 4) the integration of resource-management concerns into the tactical planning model.

We present a scheduled service network design model for the tactical planning of this CL system. The model selects 1) the first-tier services - main facility origin (and end), mode, sequence of satellites visited, departure and arrival times at origin, destination and visited satellites - to operate during a given schedule length, which will be repeated for the duration of the planning horizon, and 2) the itinerary of each inbound and outbound demand: the main facility where the inbound/outbound demand enters/exists the city, the satellite from where the distribution is performed or to which the picked up demand is brought, and the modal service, and compartment when appropriate, performing the inter-facility first-tier movement.

The model takes the form of a mixed integer formulation, defined on a cyclic time-space network, involving two main sets of integer-valued decision variables representing the service and demand-itinerary selection, the latter being defined on the (service) arcs of the network thanks to the structure of the problem. The model minimizes the total system cost of selecting and operating the services and resources while moving the demand. Following [2], the delivery/pick-up cost to/from a customer from/to any satellite is an approximation of the routing cost, the idea being that, while the main service and resource-allocation plan will not (significantly) change during the planning horizon, the actual routing will have to be decided each time the plan is applied. The constrains ensure that demand is loaded in one compartment only, outbound demand is picked up only after the inbound one has been delivered emptying the vehicle/compartment, and the respect of capacities: compartments and vehicles, fleet size, satellite in terms of vehicles and demand volumes.

We propose a Benders decomposition algorithm, embedded in a Branch-and-Cut framework, to address this model. We enhanced the method with pareto-optimal cuts, partial decomposition, and valid inequalities derived, in particular, from the knapsack structures characterizing the formulation.

The results of an extensive experimentation campaign show significant computational benefits compared to a top-of-the-class MIP commercial solver. They also show that considering different transportation modes and addressing inbound and outbound demand is beneficial, and provide insights on the management of resources, vehicle fleets in particular.

The full details of the model, method and numerical experiments will be presented at the conference.

References

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