‘Consolidation and Coordination in Urban Freight Transport’

Summary

Recent developments in the field of urban freight transport necessitate a move towards integrated logistics systems, which facilitate the efficient planning of fragmented freight flows. In this thesis, we study the role of consolidation and coordination to improve the efficiency of urban freight transport. We summarize the contributions of the thesis per chapter.

Part I of the thesis is comprised of Chapter 1 and provides an introduction to the problem setting. We present a summary of trends and developments in urban logistics. Among the key trends are increased urbanization, a revival of small-format stores, and an adoption of Just-in-Time ordering principles, resulting in fragmented freight flows and low utilization of transport capacity. This in turn has negative impacts on the economy, the environment, and social well-being. A variety of solution concepts has been proposed in the literature to tackle these problems, which can be divided into four categories: (i) infrastructural changes, (ii) transport system reorganization, (iii) company-driven initiatives, and (iv) administrative measures. Although many measures have the potential to improve the efficiency of urban transport and reduce hazardous impacts, many solutions fail in practice. An important reason for this is that urban logistics takes place in a complex field, in which multiple actors with divergent objectives operate. With this thesis, we therefore address the following research objective:

To develop mathematical models that support high-level actors in consolidated freight planning, and to obtain quantitative insights into the challenges and requirements to establish integrated logistics systems, in which independent actors coordinate their decisions to improve the efficiency of urban transport.

Part II is composed of two chapters. These chapters focus primarily on the methodological contributions to the field of consolidated freight planning.

Chapter 2 presents an algorithm to facilitate the dynamic planning of fractional truckloads in a network with transfer hubs. The algorithm is designed from the perspective of a 4th Party Logistics Service Provider (4PL) that plans the transport of orders in an intermodal network comprised of contracted carriers, but has the opportunity to replan later in response to arising consolidation opportunities. Transport prices in the network are volume-based, thus giving the 4PL an incentive to use the capacity of transport units as efficiently as possible. At the transfer hubs in the network, transport units may be transshipped between transport modes. Furthermore, the reload capabilities of the transfer hubs are used to transfer orders from one transportation unit to another. Orders are subject to time windows and the line-haul services may be subject to timetables. Therefore, the evaluation of consolidation opportunities must take into account the time feasibility of solutions. Our algorithm constructs and evaluates decision trees that take into account both the cost savings and the feasibility of solutions in which orders are transported by multiple transport means. We test the performance of the algorithm on a variety of virtual networks, as well as on a real data set provided by a leading Dutch 4PL. Our findings indicate that both the financial and environmental performance improve significantly by retaining flexibility in both the structure of routes and the dispatch times; compared to direct transport we are able to improve container fill rates by 57%, resulting in cost savings of 34% and reductions of CO_2 emissions of 30%. When we compare to the case in which we only consolidate on the best routes for each individual order, still average increases in fill rates of 28% are achieved.

In Chapter 3, we develop an algorithm that provides a consolidation policy for the operator of an Urban Consolidation Center (UCC). To estimate the future costs associated to current decisions, the operator makes use of its knowledge of the stochastic order arrival process. The goal of the operator is to minimize delivery costs over time. At each decision moment, the operator of the UCC faces the decision which subset of orders to dispatch. Holding orders for some time may result in better consolidation opportunities at a later point in time, but there is no guarantee that such opportunities will arise. We model this decision problem as a Markov Decision Model. In order to solve large instances of this problem, we propose a solution method based on Approximate Dynamic Programming (ADP) with a linear value function approximation. We study a variety of explanatory variables that may be used to estimate the future costs corresponding to dispatching decisions and identify a set of explanatory variables that can be used to accurately capture these costs. To solve the dispatching problem that is embedded into the larger optimization problem, we develop an Integer Linear Program; the applicability of this method is validated for action spaces that contain up to 2^120 decisions in the numerical experiments. We test the algorithm on a variety of network configurations; the results imply that the method works best when there is sufficient flexibility with respect to the times that orders are dispatched. Both myopic benchmark policies and lookahead benchmark policies are consistently outperformed. On average, our ADP algorithm outperforms the myopic benchmark policies by 10% to 15% and the lookahead benchmark policies by 2% to 8%.

Part III contains three chapters that focus on agent-based simulation of urban freight transport. Chapter 4 introduces an agent-based simulation framework to evaluate urban logistics schemes, with a scheme being composed of one or more company-driven initiatives and/or (local) government policies. We define five different types of agents: receivers, carriers, shippers, the UCC, and the local administrator. By defining these agent types and their corresponding actions, interactions, and objective functions, we are able to model and analyze a wide range of measures in urban logistics. The framework is explicitly designed to test combinations of company-driven initiatives and administrative policies; practice indicates that combinations of solution concepts from both classes typically yield the best results. Furthermore, we consider line-haul transport as an integral part of routes and decisions, rather than focusing only on the processes within the city boundaries. This design choice is better aligned with the profit model of carriers and the dispatching decisions made by shippers, thus allowing to more accurately evaluate the impact of urban measures on the upstream process and vice versa. We distinguish between three levels of decision making (strategic, tactical, and operational) and propose solution methods for each level. The working of the framework and the interpretation of results are illustrated with some small numerical experiments. In line with practice, the results of these experiments show that most measures are able to achieve environmental improvements, but that it is challenging to find schemes that are also financially sustainable for the involved stakeholders. Typically, multiple measures need to be combined to achieve both objectives; schemes that only contain company-driven initiatives or only administrative measures appear to be ineffective.

In Chapter 5, we apply our agent-based simulation framework. To be able to generalize our conclusions, we create a data set that is representative for a large number of Western European cities. To this end, we collect data from a multitude of overview studies, case studies, and publicly available data sources. We use the collected data to assign realistic properties to the agents in urban supply chains. To reflect the large differences that exist between such supply chains in practice, we create a number of receiver profiles that represent the ordering systems of receivers. These profiles differ in the number of distinct shippers that deliver to one receiver, delivery frequencies, and delivery volumes. By randomly assigning profiles to receivers, we reflect the real-life variety of urban supply chains. Furthermore, we test several geographically distinct instances. On these instances, we test 15 distinct measures that are either company-driven or imposed by the local administrator. First, we test the measures individually to obtain insights into their impact in isolation for various parameter settings. Then, we apply a fractional factorial design to quantify the main effects and two-way interaction effects. This way, we evaluate the symbiosis between measures, in particular between administrative policies and company-driven initiatives. Third, we perform scenario analysis to evaluate the effects of various schemes on both environmental KPIs and the financial performance of the agents. We conclude that bundling of orders is essential to achieve significant environmental benefits; this bundling may either take place upstream at the carrier level or downstream at the UCC level. When carriers cooperate with each other and centrally plan their order transport, emission reductions of 56% are attainable; by consolidating at the UCC, emission reductions up to 44% are achieved. Collaboration between carriers appears to be sustainable from a financial point of view, although for such a collaboration to materialize in practice, significant hurdles should be overcome. The concept of the UCC is also challenging to successfully implement, particularly from a financial point of view. Stringent regulations or substantial subsidies allocated to carriers are effective in altering the behavior of decision makers, but require a long-term commitment from the administrator.

Another application of the agent-based simulation framework is described in Chapter 6. This chapter focuses explicitly on the feasibility of UCCs. The test instance is based on the city of Copenhagen. Using an OpenStreetMap implementation, we generate a realistic network based on the street network of Copenhagen. By making use of geo-tags, retailer locations are also obtained from OpenStreetMap. Furthermore, we use the location of an existing UCC in Copenhagen. To accurately describe the supply chains and measures, we use the data collected in Chapter 5, specific data for the city of Copenhagen, and data obtained in expert interviews. The initial state of each simulation run is a UCC without a user base. To support the UCC, subsidies may be allocated to receivers, carriers and the UCC, but only for a limited period of time. After that period, the UCC must have attracted sufficient users to operate without external funding. Furthermore, regulations may be implemented to support the UCC. We numerically test 1,458 distinct urban logistics schemes. In line with both literature and practice, we find that a UCC without any support has very slim chances for long-term survival; both external funding and supporting regulation appear to be necessary. For less than 5% of the scenarios we find a profitable long-term situation for the UCC (when ignoring potential environmental benefits, which are not translated in financial terms); these scenarios mainly assume favorable cost settings for the UCC. We find that the sequence in which users commit to the UCC is essential for its long-term viability. The bulk of the revenues can be generated from carriers, yet when receivers have already set the UCC as their delivery address, the carrier can essentially outsource its last-mile distribution for free. We therefore propose measures that focus on attracting carriers; zone-access fees and in particular (temporary) subsidies are effective for this purpose. Despite the financial challenges, the numerical results show that the environmental benefits of a UCC may be substantial; we achieve emission reductions of about 70% and are able to reduce the number of trucks in the city by up to 60%.

Part IV concludes the thesis. Chapter 7 reflects on both our main research objective and the individual research questions. We summarize the key managerial insights that were obtained with our research:

- By preserving flexibility in both the dispatch times of orders and the construction of routes composed of multiple segments, the efficiency of fractional truckload line-haul operations in networks with transfer hubs may be improved significantly;
- Using a linear value function approximation based on (i) the available vehicle capacity, (ii) the volumes per latest dispatch time, and (iii) the number of locations that might be visited, lookahead policies may significantly improve the efficiency of order dispatching decisions for urban consolidation centers;

- An analysis of urban logistics schemes should address urban supply chains and all its stakeholder as a coherent entity, rather than treating a city as an isolated system unaffected by upstream logistics decisions;
- When evaluating urban logistics measures, all involved stakeholders must be taken into account in order to find solutions that both yield considerable environmental improvements and provide a financial incentive to the stakeholders that are required to alter their behavior.

Finally, we provide a number of directions for further research. First, we suggest extensions of the work presented in this thesis. Our solution method for line-haul planning might be enriched by incorporating stochastic properties such as time-dependent travel times and uncertain handling times, attaining a closer fit to reality. For our DDP-TW solution method, we propose the design of algorithms to intelligently reduce the action space. Furthermore, analytical expressions for richer VRPs might be incorporated to better reflect the practice of urban logistics. A new use can be found for our agent-based simulation framework by incorporating more intelligent planning methods, so that it becomes suitable for optimization rather than evaluating within the current context. The last model extension that we discuss is the integration of our line-haul and last-mile planning methods, signifying another step towards an integrated logistics system in the spirit of the Physical Internet. The second category of further research topics is comprised of a number of possible research directions that are related to the implementation challenges. A major challenge relates to the allocation of gains and costs; we believe that game theory offers a suitable approach to solve this problem. Other implementation challenges are overcoming gaps in resources and knowledge, addressing competitive concerns of stakeholders, and improving the facilitating roles of both the government and transport sector agencies.