

An Agent-Based Simulation Study on the Effectiveness of Urban Consolidation Initiatives

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1 Introduction

With this study, we assess the effectiveness of urban consolidation centers (UCCs) under a variety of governmental policies and company-driven initiatives. The inefficiency of urban freight transportation contributes to external costs such as congestion, emissions, and noise hindrance. Furthermore, inefficient transport reduces the profitability of the parties in the supply chain. To address these problems, there is a strong interest in city logistics initiatives. For a recent literature review on urban logistics, we refer to Bektas et al. (2015). They report that most studies describe and evaluate existing initiatives. A number of papers adopts an operations research perspective, mainly contributing to (i) the positioning of UCCs and (ii) solution methods to one-echelon or two-echelon routing problems. The use of a UCC characterizes most urban logistics initiatives. The key concept is that inbound trucks no longer enter the city center, but instead unload at a UCC, typically located at the edge of an urban area. Subsequently, goods can be bundled at the UCC, such that efficient tours can be made for the last-mile distribution. Furthermore, environment-friendly vehicles can be dispatched. Particularly for independent low-volume, high-frequency deliveries, UCCs could substantially improve performance.

Browne et al. (2005) provide an elaborate overview of UCC projects, and report that only few UCC initiatives remain in operation for multiple years. A key success factor is the involvement of commercial parties that share a common objective. UCCs yield the best results when involving a sufficiently large number of small, independent shippers and retailers, where low-volume, high-frequency orders are the norm. Government administrators are typically required to cover the capital expenses of the UCC. Gains from policies could (partially) cover operational expenses. However, UCCs depending primarily on subsidies are unlikely to succeed in the long run, as profit margins in logistics are small.

To achieve norms on external costs, administrators encourage or enforce the desired behavior of actors in the supply chain by implementing policies. Common policies are

vehicle access restrictions, time access restrictions, enforcing a minimum load factor, and road pricing (Russo and Comi, 2010). Companies aim to increase transport efficiency mainly for economic reasons, but also because external costs become increasingly important for them. Forms of company-driven changes are, e.g., joint consolidation (coalition of carriers), joint ordering (coalition of receivers), deliveries outside normal delivery hours, or using the UCC as delivery address (Taylor, 2005). We refer to a setting with one or more policies and company-driven changes as an urban logistics scheme.

Collaboration is notoriously difficult to realize in urban logistics. As the objectives of the actors in urban logistics are often divergent (Bektas et al., 2015), system-wide optimization yields little practical insights. Taniguchi et al. (2013) state that agent-based simulation is the most applicable method to study the behavior of and interaction between the various actors for urban logistics schemes. Tamagawa et al. (2010), Van Duin et al. (2012), and Wangapisit et al. (2014) perform agent-based simulations, in which they study the effects of several schemes. They heuristically solve a VRP for the carriers, and iteratively update the actions of the actors. A gap in urban logistics literature is that research tends to evaluate isolated schemes, often applied to a specific case (Browne et al., 2005). This makes it difficult to deduce generic insights on the effectiveness of existing measures. We contribute to literature with an agent-based simulation study in which we test many different schemes rather than evaluating schemes in isolation, thereby providing a direct comparison of the effectiveness of policies and cooperation forms.

2 Experimental Design

In our experimental design, we distinguish five actors: carriers, the UCC operator, shippers, receivers, and the administrator. The first four actors aim to minimize their own costs, while the latter seeks to achieve thresholds for external costs. In the following, we describe their roles and how their operational costs are composed.

Long-haul carriers periodically plan the transport of their received orders, subject to soft delivery windows. We consider a line-haul service with a fixed schedule; the carrier decides to which time slot they allocate the orders to ship. Their operational costs consist of fixed costs per vehicle dispatched and volume-independent costs per distance unit. They will use the UCC if this yields a financial gain or is enforced by regulation. The UCC operator periodically dispatches a subset of orders in inventory. We assume a given cost structure, which may follow from using their own fleet or hiring independent carriers. Operational costs follow from the last-mile distribution; handling costs and -times are fixed. Shippers dispatch orders – characterized by order size, destination, and delivery window – based on requests posed by the receivers. Shippers decide when to dispatch orders. As higher volumes yield an advantage, they have an incentive to internally consolidate the

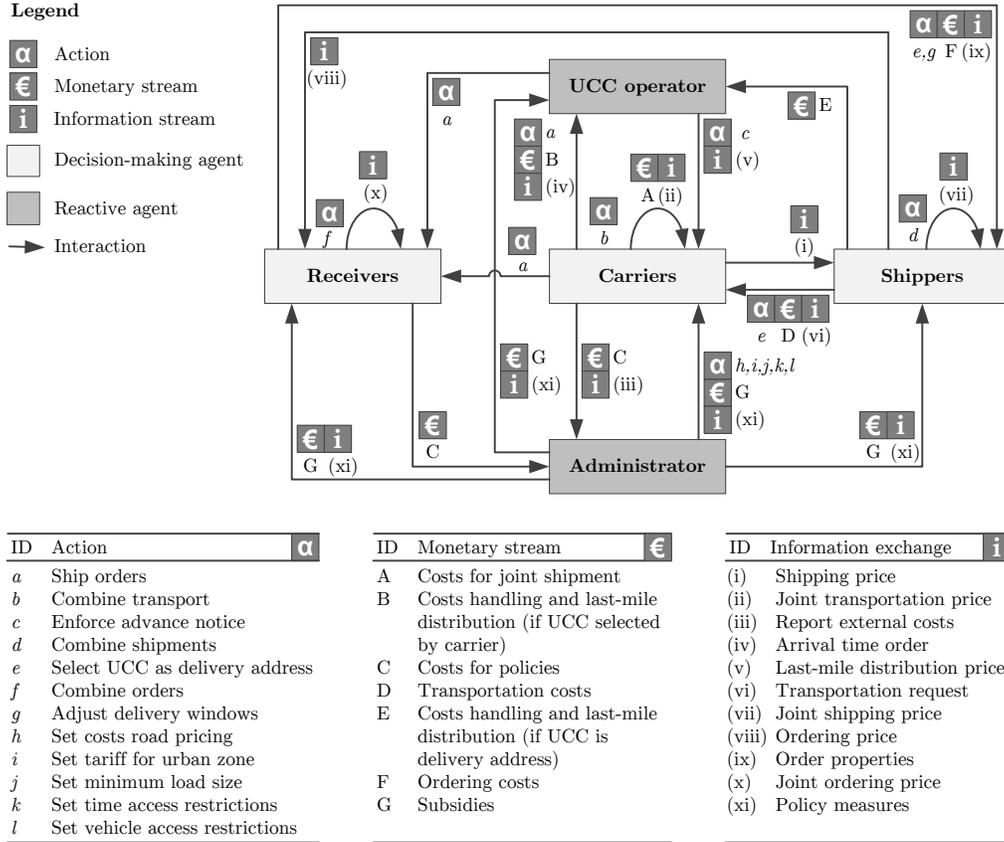


Figure 1: Actions and interactions for all agents

orders to dispatch. They may also ship their orders via a coalition. Receivers place orders depending on their demand. Their operational costs depend on order volume and the total time spent unloading. They can enter a coalition of receivers to jointly place orders. Furthermore, they can decide to select the UCC as their delivery address, e.g., to reduce unloading time or to reduce external costs. Finally, the administrator is responsible for implementing policies. Given norms for the external costs, the administrator can tailor these policies to achieve the norms. The financial gains of these policies may be used to subsidize actors. A prerequisite is that the resulting system remains feasible.

It is difficult to predict how actors will behave in a given scheme. Therefore, we model the interactions between the logistics actors in an agent-based simulation environment. Figure 1 depicts the actions and interactions of each actor. Our performance indicator is the change in costs compared to the base case without any policies or changes. These costs are given per agent as well as on a system-wide level. To quantify external costs, we consider (i) the number of vehicles per type within the urban area, (ii) CO₂ and NO_x emissions, and (iii) total distance covered within the area.

3 Results and Discussion

In this study, we propose an agent-based simulation environment to evaluate the effect of various urban logistics schemes. We consider interactions between five actors, distinguishing between actions, monetary streams, and information streams. Outcomes of the simulation indicate that not many schemes significantly reduce external costs, while at the same time maintaining acceptable profit levels. We find that – consistent with the results of other studies – a combination of company-driven initiatives and government policies is likely required for feasible and sustainable schemes. However, consolidation in ordering or shipping already significantly reduces external costs, in some cases against lower costs than when using the UCC. Decision makers should therefore carefully define their goals when considering UCCs.

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