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Learnings from the simulation of use cases in city logistics in the HARMONY project

Michiel de Bok[a,b*], Lori Tavasszy[a], Ali Nadi[a], Sebastiaan Thoen[b], Sofia Giasoumi[b], Jos Streng[c]

[a]Department of Transport & Planning, Delft University of Technology, Stevinweg1, Delft, 2628 CN, The Netherlands
[b]Significance, Grote Marktstraat 47, Den Haag, 2511 BH, The Netherlands
[c]City of Rotterdam, De Rotterdam, Wilhelminakade 179, Rotterdam, 3002 AN, The Netherlands

Abstract

City logistics simulation can help to provide empirical proof of potential benefits of new solutions in city logistics but decision support tools for such analyses are scarce because of a lack of empirical data and resources. The Tactical Freight Simulator (TFS) is a multi-agent simulator that represents the decision-making of freight agents and individual freight shipments. In this study it is applied to four distinct use cases in city logistics: micro hubs, introduction of zero-emission zones, crowd-shipping and the land use planning of logistic facilities.

The simulations show impacts of each development and provide learnings: the type of open or single carrier operation of micro hubs have big local impacts. The impact of freight traffic avoiding zero emission zones can have substantial local impacts. Depending on the configuration of the service, crowd-shipping can lead to more vehicle kilometres. A common finding is the impact of the chosen scenario parameters on the outputs: regulation is important to shape city logistics operations. This also illustrates that, although the technology seems to be ready for innovative solutions, the logistical organisation or business models and policies are not yet well developed.

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Keywords: micro simulation; city logistics; zero-emission; micro hubs; crowd-shipping; The Netherlands; HARMONY

1. Introduction

Metropolitan areas are facing fast-growing and innovative mobility services to address inefficiencies in the freight and passenger transport system. City managers and policymakers are now obliged to cope with associated pollution,

* Corresponding author. *E-mail address:* M.A.deBok@tudelft.nl

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increased travel times, poor regional connectivity, and accessibility. For city logistics the task is even more challenging because of the dynamic landscape of city logistics with the introduction of new technologies and logistic services, such as deliveries by drones or automated robots, crowd-shipping, or the growth of e-commerce demand. Metropolitan planning organizations can try to ensure or facilitate sustainable development with regulation and policies. Many technological solutions for more efficient city logistics appear technology ready: drones, light electric vehicles (LEV's) of all sorts, and even autonomous delivery robots. Business concepts and regulations however prove to be more complicated. Simulation of these concepts can help to provide empirical proof of potential benefits new developments and to identify an effective implementation path for new services. However decision support tools for such analyses are scarce because of a lack of empirical data and resources (Nuzzolo,, et al, 2018; Akgün et al., 2019; Sakai et al, 2020).

The main goal of the HARMONY project (https://harmony-h2020.eu/) is to develop spatial transport planning tools, which enable metropolitan planning organisations to develop and evaluate policies, prioritise policy measures, and analyse new mobility concepts that would ease the transition to a low-carbon new mobility era. The Tactical Freight Simulator (TFS) is the component of the HARMONY MS that simulates the demand of urban freight transport. The TFS is a multi-agent simulator that represents the decision-making of freight agents on the level of individual firms and individual freight shipments and can be applied to quantify the effect of future scenarios on the urban freight transport system. It aims to support local authorities such as the City of Rotterdam to ensure sustainable development of city logistics.

The major challenge in developing a simulator for city logistics is the wide scope of relevant city logistic developments and policies. In this paper, we provide a synthesis of four very diverse city logistics use cases that were analysed with the TFS. The use cases deal with micro hubs, introduction of zero-emission zones, crowd-shipping and the land use planning of logistic facilities.

In this paper we first describe the city logistics use cases. Next, the simulator that was used is outlined briefly. Next, the results from the simulations are discussed: in an overview and brief discussion of each use case. The paper concludes with general findings and a discussion of the research.

2. City logistic use cases

2.1. Use case 1: Micro-hubs

Increasing competition for urban space has driven logistics facilities outside of city centres to peripheral locations (Dablanc, et al., 2014), increasing the vehicle kilometres for logistics. To rationalise the B2C last-mile delivery streams, micro hubs are introduced as a possible solution as they can increase the consolidation of inner-city deliveries (Aljohani & Thompson, 2016). As per the definition of the Urban Freight Lab (2020), micro hubs are "logistics facilities inside the urban area boundaries where goods are bundled, which serve a limited number of destinations within a bounded spatial range and allow a mode shift to low (or zero) emission vehicles or soft transportation modes (e.g., walking) for last yard deliveries".

The objective of this use case is to explore the impact of nine different scenarios of the large-scale implementation of micro hubs on the transportation system. Although it is a well-studied topic in city logistics, it is not completely clear how different configurations of a micro hub concept will affect the transportation system in terms of transport movements, number of travelled kilometres, etc. This case study explores three different design aspects: location, type of vehicles (delivery robots, cargo bike, LEV), and the business model (individual/full collaboration). Assumptions in the simulation scenarios are based on the Rosie demonstration in the HARMONY project, retrieved from the literature, as well as other recent Living Labs in Rotterdam (van Duin, et al., 2022).

2.2. Use case 2: Zero-emission zone for City Logistics

Rotterdam has announced the introduction of a Zero-Emission Zone (ZEZ) as part of the Green Deal Zero Emission City Logistics that aims at reducing CO_2 emissions and improving both air quality and accessibility in the city. The zero-emission zone implies restricted access to the city centre (only with zero-emission vehicles allowed) and consolidation of shipments in urban consolidation hubs (UCCs) on the outskirts of the city. The ZEZ spans a 40 km^2 area of the city within the orbital ring road. The simulations are based on the transition scenario presented in the Road Map zero-emissions City Logistics (Rotterdam, 2019). Two types of behavioural responses are considered: a shift from conventional vehicles to vehicles with a zero-emission driveline, or a shift of distribution structure where shipments are first consolidated via an UCC and distribution within the ZEZ takes place using LEV, cargo bikes or small electric vans or trucks.

2.3. Use case 3: Crowd-shipping

Crowd-shipping is one of the new opportunities and business models for last-mile logistics, that links parcel carriers to individual travelers on digital platforms. Crowd-shipping is considered a solution to make use of the capacity of passenger transport in delivering parcels to customers. It could work in parallel with traditional delivery methods (conventional carriers) to make last-mile deliveries more sustainable and efficient (Punel et al.,2018 & Rai et al., 2017). Although crowd-shipping seems to be beneficial in terms of capacity utilization in the transport system, its pros and cons have not yet been explored thoroughly due to its complexity. In this use case, the TFS module is used to simulate the impacts of different implementation scenarios of crowd-shipping services in the study area. With this simulation experiment, the viability of crowd-shipping is explored by assessing its positive and negative impacts on both freight and passenger transport systems.

2.4. Use case 4: Land use planning of logistic and industrial sites

Increasing competition in urban space has driven many logistic activities outside of the city centres into peripheral locations, also referred to as logistic sprawl (Dablanc et al., 2014). In addition, the size of logistic facilities is scaling up: almost half of the total logistic surface area is hosted by large distribution centres of >20,000 m^2 (Onstein et al, 2021). The locations of these facilities have a direct impact on accessibility, liveability, and sustainability, including visual intrusion of the landscape. Regional coordination of the location planning of logistic facilities can be an effective tool to mitigate the external impacts of new logistic facilities but policies are lacking. In this use case, the TFS was used to simulate the impacts of two different land use planning scenarios for logistics facilities on local traffic flows and emissions: one scenario assumed a land development with limited regulation, and with little economic growth. The second scenario assumed a regulated land market scenario with land development restricted to existing industrial terrains.

3. METHODOLOGY

The use cases are explored with the TFS, a multi-agent urban freight transport demand model developed in the H2020 project HARMONY. A manifold number of actors influence the decisions made in freight transportation markets (Marcucci et al, 2017) and their preferences and behaviors are diverse. Therefore, the TFS simulates the decision-making of freight agents on the level of individual firms and individual freight shipments. An incremental development path is followed and earlier prototypes were presented in de Bok et al, (2021).

The model is developed to quantify the effects of future scenarios on the freight transport system. The TFS distinguishes three main segments of urban commercial vehicle movements: Freight Shipments, Parcels, and Services. The model also distinguishes two phases. The first phase is the long-term tactical level that simulates shipment- and parcel demand in the shipment synthesis or demand modules. The second phase is the daily scheduling of the final transport movements in the scheduling modules. Separate scheduling modules are developed for freight shipments and parcel delivery because the size and consolidation of individual products (shipments or parcels) are inherently distinct.

Figure 1 shows the functional modules within the TFS. Three main segments of urban freight transportation demand are distinguished: Freight Shipments, Parcels, and Services, and it has two phases. The first phase is the long-term tactical level that simulates shipment and parcel demand in the shipment synthesis or demand modules. The second phase is the daily scheduling of the final transportation movements in the scheduling modules. Separate scheduling modules are developed for freight shipments and parcel delivery because the size and consolidation of individual products (shipments or parcels) are inherently distinct. Different goods types are grouped into logistics segments which are expected to have similar transportation profiles. The model distinguished 8 types of logistic segments: nonrefrigerated Food Miscellaneous/ general cargo, Temperature Controlled, Construction Logistics, Facility Logistics, Waste Logistics, Parcel and Express, and Dangerous goods logistics.

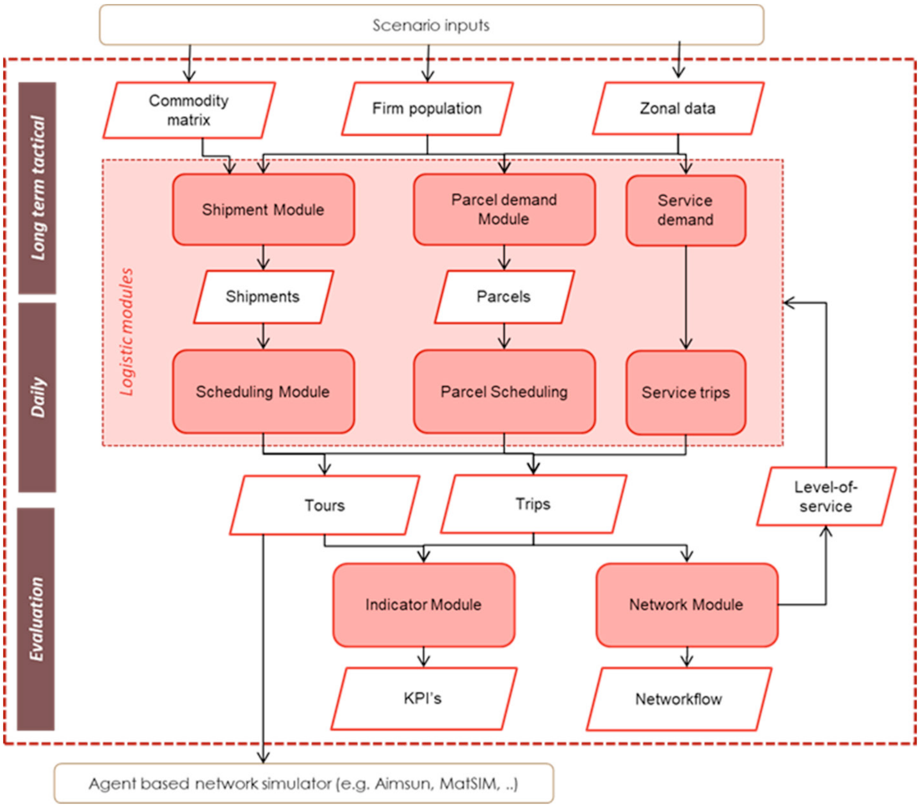

Fig 1: The Tactical Freight Simulator

Specifically, the shipment synthesizer builds a set of shipments that are transported in the study area. To create this set of shipments, an event-based simulation is used for the following logistic processes: producer selection; distribution channel choices; shipment size & vehicle type choice; and desired delivery time. On the other hand, the scheduling module simulates the formation of tours, chooses the time for each tour based on the desired delivery times and optimizes the vehicle type choice.

Time-of-day decisions are simulated both in the Shipment Synthesizer module, and the Scheduling module. In the shipment module first, a choice for the desired shipment delivery time is simulated. The scheduling module uses the desired delivery time in the selection of shipments to be considered for consolidation in round tours.

Parcel deliveries follow different transportation patterns compared to other types of good's flows. They are delivered by Light Commercial Vehicles (LCVs) with distribution patterns that usually originate from a parcel depot. Parcel delivery is hardly ever represented in conventional freight models. However, parcel delivery is an important component in city logistics since it creates a large number of vehicle movements in the urban environment. The parcel demand module simulates the B2C and B2B demand for parcels and creates a synthetic set of parcel demand for households and businesses (receivers) that are allocated to a parcel carrier and its depot (origin). The parcel scheduling module simulates the allocation of parcels to vehicles and creates delivery tours. These can be used as input for network modules for vehicle kilometres and emission calculations.

The TFS is also equipped with two auxiliary modules to analyse the outcomes of the logistic modules: an indicator module that calculates the Key Performance Indicators (KPIs) that measure the impacts of different policies and future development scenarios on the system. The second module is a network module that simulates route choice for each vehicle tour and calculates emissions.

The TFS and MASS-GT simulators are developed in Python and available as open source on GitHub (https://github.com/mass-gt).

4. RESULTS

This section summarizes the lessons learned from the evaluated use cases in simulation experiments. The TFS was applied for the four city logistics use cases in the HARMONY project: micro hubs, introduction of zero-emission zones, crowd-shipping and the land use planning of logistic facilities. The simulation results include a variety of indicators, such as number of tours per vehicle type, total vehicle kilometres, local traffic intensities by vehicle types, average tour distance per vehicle, kilometres travelled by empty vehicles, and emissions. The use of different key performance indicators (KPIs) depend on the evaluation and can differ between the scenarios. Figure 2 shows a snapshot of the simulation results of the four different use cases implemented in the simulator.

This section provides an executive summary of findings for each use case; detailed simulation results are available in the projects Technical Deliverable 6.4 (HARMONY, 2022).

4.1. Micro hubs

The micro hub use case explored the impacts of a wide implementation of micro hubs where the last yard of parcel delivery is operated through a system of micro hubs with different configurations of delivery vehicles. The case study included nine scenarios in which the hub location, type of vehicles, and the business model were explored.

In the base scenario without hubs, a total 44 delivery tours are made by delivery vans from the different carriers. In the hub scenarios all deliveries are delivered to the hubs by 8 or 9 consolidated truck tours: a reduction in vehicle movements to and from the area. Within the area, we see many tours in the scenarios that use vehicles with limited capacity (cargo bikes and autonomous robots). The scenarios with light electric vans, on average have fewer tours from the micro hubs; this is considered an operational advantage. Also compared to the conventional delivery van in the base scenario, the vehicle kilometres inside the area are reduced: in particular when the hubs have a shared business model, and the deliveries from multiple carriers are consolidated in the hubs. In general, the collaboration models show better vehicle utilisation than the individual carrier models. The full collaboration model with light electric vehicles leads to the least vehicle kilometres in and outside the study area.

4.2. Zero emission zone

The evaluation of the impacts of the zero emission zone is based on transition scenarios formulated for each city logistics segment in the Roadmap Zero Emission City Logistics (Rotterdam, 2019). Two types of behavioural responses are considered: a shift from the conventional vehicle to vehicles with a zero-emission driveline, or a shift of distribution structure where shipments are first consolidated via an UCC and distributed within the ZE zone using zero emission vehicles (LEVV, cargo bikes or small electric vans or trucks). The outputs confirm that emissions are reduced dramatically, by 90%, inside the ZEZ. At the city scale, this corresponds to a reduction of almost 10% of whole emissions produced by freight transport. At a regional level, the reduction of impacts is marginal. Using UCCs reduces emissions within the ZEZ areas but slightly increases the vehicle kilometres travelled (VKT) outside the ZEZ. The rerouting of freight vehicles around the ZEZ or to and from the UCCs can lead to substantial increases in local freight traffic: this is an important side effect that needs to be mitigated.

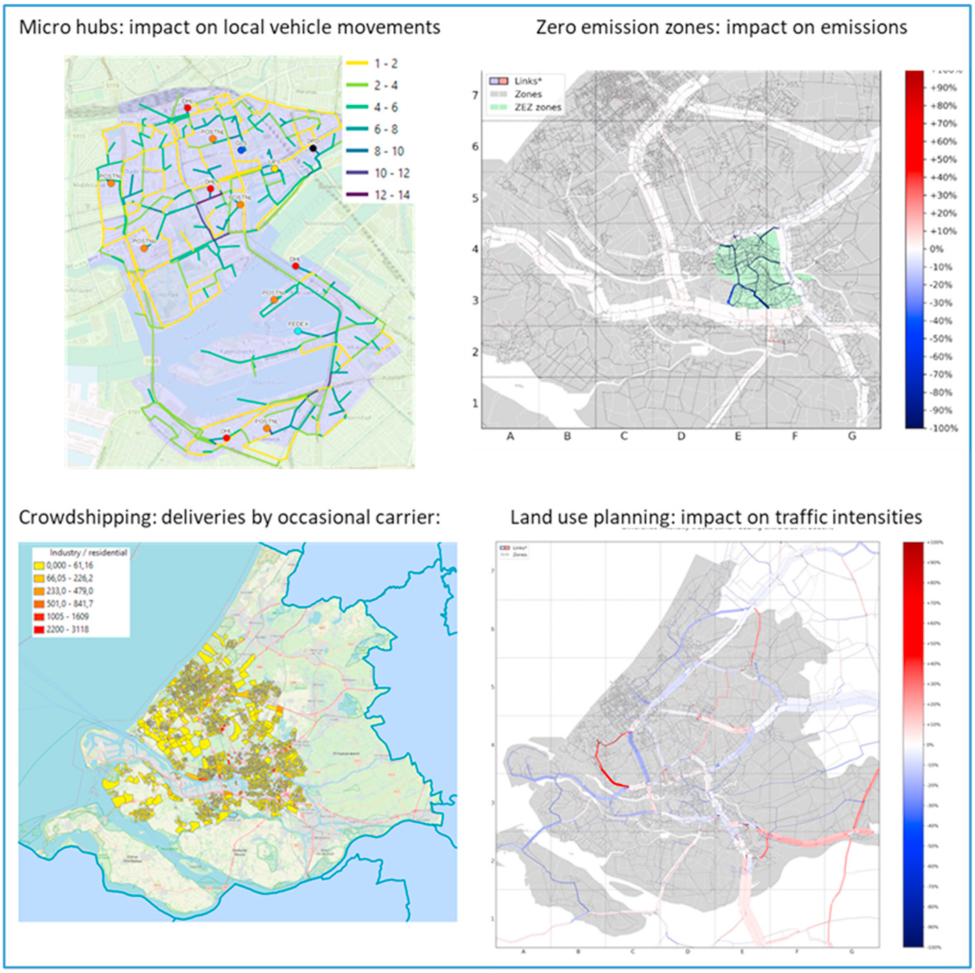

Fig 2: Illustrations from the use cases' simulation

4.3. Crowd-shipping

Crowd-shipping could improve the efficiency of the freight transport system in delivering parcels. In the simulated scenario, 9,569 parcels were eligible for crowd-shipping and of which 8,311 parcels (86.85%) were delivered by occasional carriers (by car or bike). This leads to a reduction of delivery van kilometres of 1553 km. The average provided compensation for the occasional carriers was 2.32 euro. The simulations showed that the detour length is on average 3.95 km per parcel for cars (12,450 vehicle kilometres in total) and 1.59 km per parcel for bikes (8,230 vehicle kilometres in total). In effect this means the net impact of crowd-shipping is an increase in total vehicle kilometres. Network plots also showed that this increase is mainly manifest in residential areas, where the delivery is done. The side effects could be mitigated by applying control policies on crowd-shipping platforms and services.

4.4. Spatial planning

In the spatial scenario's the localization of new facilities have a redistributive impact on the pattern of freight shipments. In the two scenarios it was explored what would be the impact of unrestricted allocation (peripheral and near highways) and restricted to brownfields (existing industrial terrains). The results show that policies for the allocation of new logistic facilities have an impact on freight transport patterns. The unrestricted policy leads to a marginal increase in vehicle kilometres, even though the distribution centres are allocated near highways, the peripheral locations contribute to longer transport distances. The restricted policy in scenario 2 contribute to a modest reduction in vehicle kilometres. This is a positive outcome as it shows that the redistribution of logistic activities can help in reducing freight transport. Findings also show that it is important to look into the local impacts: the network intensity plots show stronger local differences in freight traffic as a result of the spatial planning scenarios. Therefore, this policy dominates local impacts.

5. Conclusion

The application of a new city logistics simulator shows the possibilities of using simulation to study the impacts of new technologies and services in city logistics at a system level. The explorations have taught us that although the technology seems to be ready for innovative solutions, the logistical organisations or business models and policies are not yet well developed. The simulations show that to improve the effectiveness of urban consolidation centres, it is crucial to stimulate or support collaboration between logistics service providers. We also learned that the secondary impacts of location policies, such as access restrictions or spatial planning of new logistics facilities have significant impact on local traffic conditions. Simulation tools such as TFS can contribute to a better formulation of initiatives and policies by showing potential system-wide impacts providing a systematic and objective quantification of the pros and cons, and barriers, challenges and opportunities of new solutions. This can stimulate the relevant stakeholders in urban logistics to collaborate which becomes ever more relevant and necessary in the age of growing urbanization.

To create more value from the simulations with the TFS, future work can focus on the integration of the different use cases into broader logistic scenarios. These use cases are complementary as micro hubs can be considered in combination with a spatial planning scenario and extended in a scenario with a crowd-shipping service where the micro hubs also serve as a location for the picking-up or dropping-off of parcels. By combining the use cases, a holistic logistic scenario can be created with consistent assumptions across the use cases. The development of broad logistic scenarios requires regional coordination and the involvement of logistic stakeholders. The results from the individual use cases can be used to feed the discussion between these stakeholders.

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