Application of the HARMONY tactical freight simulator to a case study for zero emission zones in Rotterdam

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ABSTRACT

As part of a broader vision for emission-free city logistics, the city of Rotterdam plans to introduce a zero-emission zone in combination with urban consolidation centers (UCCs) at the outskirt of the city to generate a shift to zero-emission vehicles. For the design of this zero-emission zone many research questions arise that require a systematic analysis of the impacts of the transition scenarios on the freight demand patterns, the use and market shares of new (zero-emission) vehicles, and the impacts of truck flow and emissions. As a case study we implemented heterogenous transition scenarios for each logistic segment into the Tactical Freight Simulator from the project HARMONY and analysed the system wide impacts. This model is multi-agent, empirical and shipment based and simulates long-term tactical choices (distribution channel choice, shipment size and vehicle type choice, sourcing) and short-term tactical choices (tour formation, delivery times).

Results shows that the impact of UCCs is not trivial: we can see a small increase in vehicle kilometers travelled (VKT) overall: +0.25% which can be attributed to the rerouting of shipments through the UCCs. Calculations confirm that emissions are reduced dramatically, by 90%, inside the Zero-Emission Zone. At the city scale this corresponds to a reduction of almost 10%, as most freight related traffic is generated by the port and involves long haul HGV transport that do not enter the city center. At a regional level the reduction of impacts is very small. More measures are needed if more ambitious reductions in emissions are to be achieved.

Keywords: Urban freight transport demand, Multi-agent models, Big data applications, Zero-emission zones, The Netherlands.

INTRODUCTION

An important tool for local administrators is the introduction of low (or ultra-low) emission zones, with imposed access restrictions for commercial vehicles or emission-based access fees. Systems have been put in place in many European cities [1],[2]. However, recent evaluations show that the effectiveness of low emission zones is marginal [1].

With the current municipal coalition agreement, in line with the national coalition agreement, the Mayor and Executive Board of Rotterdam have committed to achieving the goal of reducing CO2 emissions by 49% by 2030 [3]. For city logistics Rotterdam is working to achieve a transition to a system that is as efficient as possible (reducing vehicle kilometers) and deploys zero emission (ZE) vehicles. For this purpose, Rotterdam plans to introduce a zero-emission zone [3]. This zero-emission zone is part of a broader vision for emission-free city logistics that involves supporting measures such as consolidation hubs at the outskirt of the city and generating a shift to zero-emission vehicles. Part of this solution is the deployment of electric light goods vehicles (LEVVs) such as cargo bikes or small vehicles with an electric engine, or vehicles with no emissions, such as electric, hydrogen, hybrid or biofuel drivelines.

To support the decision-making process, it is relevant to be able to make an analysis of different scenarios for the boundaries of the zone, supporting measures on the impacts and demand for new last mile solutions. But in spite of the importance of urban freight transportation, and the growing importance in the use of urban infrastructures, tools for strategic decision making, with a comprehensive scope and sufficient behavioral detail to be used for urban freight transportation policies are missing because of a lack empirical data and resources [4-6].

The project HARMONY (http://harmony-h2020.eu/) has the objective to develop a new generation of harmonized spatial and multimodal transport planning tools which comprehensively model the dynamics of the changing transport and mobility sectors and impacts of new technologies and services. Urban freight transport is one of the domains that is covered in HARMONY project and for this domain a Tactical Freight Simulator is being developed. The simulator is based on an existing multi-agent simulation system MASS-GT [7],[8]. In HARMONY this approach is further extended by improving the logistic decision models and implementing the use-cases addressed in the HARMONY project.

One of the use-cases in HARMONY is the introduction of zero-emission zones. In this paper we describe the application of the Tactical Freight Simulator to this use case. In a previous analysis, an earlier version of the MASS-GT model was used to explore the impacts of a zero-emission case [8]. However, this study had some shortcomings: the analyzed zero-emission scenario lacked stakeholder specific transitions, and the modelling system did not provide emission calculations. In this paper we present a more advanced version of the model and we implement heterogenous transition scenarios for each logistic segment.

We first discuss the background of zero-emission zones and strategic simulation tools. Next, we present the tactical freight simulator developed in the HARMONY project. Next, the zero-emission transition scenario is described. Finally, the simulation results are presented and discussed in in the perspective of multi-agent simulation and urban freight transportation policies.

BACKGROUND

Zero-emission zones in city logistics

The last decade has shown the emergence of measures to reduce emissions in city logistics. An important tool for local administrators is the introduction of low (or ultra-low) emission zones [1],[2]. These low emission zone impose access restrictions for commercial vehicles or emission-based access fees. Systems have been put in place in Prague, Gothenburg, London, Rome, Ljubljana, and different cities in The Netherlands and Germany. The dimensions of the measures vary: the stringency of measures, size of the area and enforcement [1]. Sometimes high emission vehicles are completely banned or pay a fee to enter. In Ljubljana vehicles exceeding 7.5 tons are not allowed within the inner ring road at peak times. Prague has two zones with weight restrictions for HGVs (since 1999). To improve air quality Gothenburg introduced a LEZ in 1997, which was then extended to cover a larger area in 2007. In London access restrictions are in place for vehicles from different weight or emission classes in the London Lorry Control Scheme. Findings from monitoring suggest that trucks use less direct routes, which can lead to an increase in heavy goods vehicle (HGV) kilometers and environmental emissions. As of 2019, the Ultra-Low Emissions Zone is introduced and only diesel trucks with minimum Euro standard VI are allowed. The reported impacts of low emission zones vary, according with the type of implementation [1]. The environmental vehicle ban in around 60 German Cities is reported to reduce emissions by 0-15% [1]. However, it is not possible to attribute this to the LEZ introduction or autonomous trend of HGVs moving towards cleaner Euro standards. Over-all it can be concluded that in most cases the impacts f LEZ were found to be insignificant, maybe except for the LEZs in Germany.

Modelling studies that make an ex-ante evaluation of the impacts of the introduction of such measures are scarce. [9] presented an early example of a modelling study analyzing the impacts of a total ban on heavy trucks in Rome, using a system of satellite transshipment centers. This approach was developed on scarce available data and still very aggregate in zoning, and representation of the freight transportation system (vehicle types, shipments and agents).

In a selection of Dutch cities**,** a reduction of emissions of 5 % was expected from banning diesel trucks below Euro IV standards to enter the zone (since 2007/2008). But measurements of emissions before (2008) and two years after (in 2010) implementation of LEZ policies in The Netherlands show that the decreases in traffic-related air pollution concentrations was insignificant [10]. In most zones, heavy goods vehicles with Euro IV standard are still allowed; this limits the total reduction of emissions that can be accomplished.

To make city logistics greener, the major Dutch municipalities have signed an agreement to introduce zero-emission zones. In order to reach climate goals and create a sustainable livability of the city, stringer measures must be imposed. Rotterdam has signed the agreement and will introduce a zero-emission zone by 2025. In their roadmap zero-emission city logistics [3] a transition scenario is sketched for each city logistic segment. Accessibility also needs to be ensured, and zero-emission zones can only be introduced in combination with supporting city logistic services in order in order to provide accessibility for all entrepreneurs in the zero-emission zone.

Since fully restricted zero-emission zones have not been implemented yet, and modelling studies are scarce, there are several research questions open that need to be answered to predict and better understand the impacts of the introduction of the zero emission zones. Here we study the impact of the transition scenarios on the freight demand patterns, the use and market shares of new (zero-emission) vehicles, and the impacts on truck flow and emissions. These research questions are analyzed using a descriptive multi-agent simulation model for urban goods transport. An advantage of simulation models is the possibility to analyze a combination of potentially supportive policies [11].

Disaggregate model for urban freight simulation

Disaggregate multi-agent models have the potential to be able to make a better prediction of impacts of urban freight measures than aggregate models, considering the heterogeneity of agents and services in city logistics.

However, disaggregate simulation models that adequately address stakeholder specific implications of urban freight policies at system level are still scarce. The earliest published study [9] into network level impacts of area restrictions for heavy goods vehicles calculated the impacts of ban for city of Rome but using aggregate data and no detail in the freight transport demand (vehicles, shipments, agents).

A new generation of multi-agent tools for evaluation of network impacts, simulates behavior of individual firms [12-14]. Some models are shipment based [6,15-20]. In a different line of literature specific segments, or concepts are simulated with dynamic agent-based models [18],[21],[22]. These models study dynamics behavior between and with agents (negotiation, learning) and are conceptually more complex but often have a poor empirical implementation or have a limited scope to provide valid predictions for impacts at network level or the whole city logistics domain.

To contribute to this new generation, we are developing a multi-agent tool for freight transport demand, following an incremental path. The approach simulates individual logistic agent behavior and is shipment based. The design principles are described in [7],[8]. One of the most important challenges in developing multi-agent simulation models for urban freight transportation demand is the collection of disaggregate data [17]. Data collection is time and cost intensive, but innovations and new ways of data collection are providing efficient ways to get access to disaggregate freight transportation data.

ANALYTICAL FRAMEWORK

The Tactical freight Simulator

The Tactical Freight Simulator is a multi-agent simulation model of urban freight transport demand. It is based on an existing multi-agent simulation system MASS-GT [7],[8], which is multi-agent, empirical and shipment based. We develop a multi-agent approach to explicitly address all stakeholders and the heterogeneity of all agents. Second, we use an extensive dense dataset on freight transport, to simulate representative freight transport patterns and calibrate logistical choice models. Demand is simulated at the unit of shipments as this is a more realistic for how most logistic decisions are taken.

A manifold number of actors influence the decisions made on freight transport markets [18,21]. The stakeholders in the model are policy makers, firms as producers and consumers of goods, and logistic nodes (distribution centers and multimodal terminals from which carriers operate). The flows of shipments start from the production firms and are delivered to the consumers. These flows can either be direct or via one or more logistics nodes (distribution centers or transsshipment terminals). Along these, different logistic choices are made, such as vehicle type choice, distribution channel choice, shipment size choice, tour formation and time of day choices. Producers, and in case of outsourced transport, Logistics Service Providers (LSPs), define the size of shipments and the choice of distribution channels. Carriers and LSPs with own account transport form the tours and choose the type of vehicle. Finally, consumers set the time-of-day delivery requirements. On the other hand, the supply of transport is covered by carriers, LSPs and shippers with own account transport. Although local authorities provide the transport infrastructure, they are not represented directly in the TFS, but their policies and behaviors are part of the what if scenarios tested by the TFS.

The core of the tactical freight simulator consists of two levels of logistic decision making: long term tactical choices, simulated in the shipment synthesizer, and short-term tactical choices, simulated in the scheduling module. These two core modules simulate the demand of freight transport at shipment level. In parallel, two modules simulate the demand of parcels. See Figure 1 for an overview of the structure of the TFS. It is designed to operate as a single simulator for urban freight demand, but it can work together with other simulators in the HARMONY model suite. The TFS provides input to the operational simulation of vehicle movements and receives inputs from the strategic simulator on regional freight demand and a synthetic firm population.

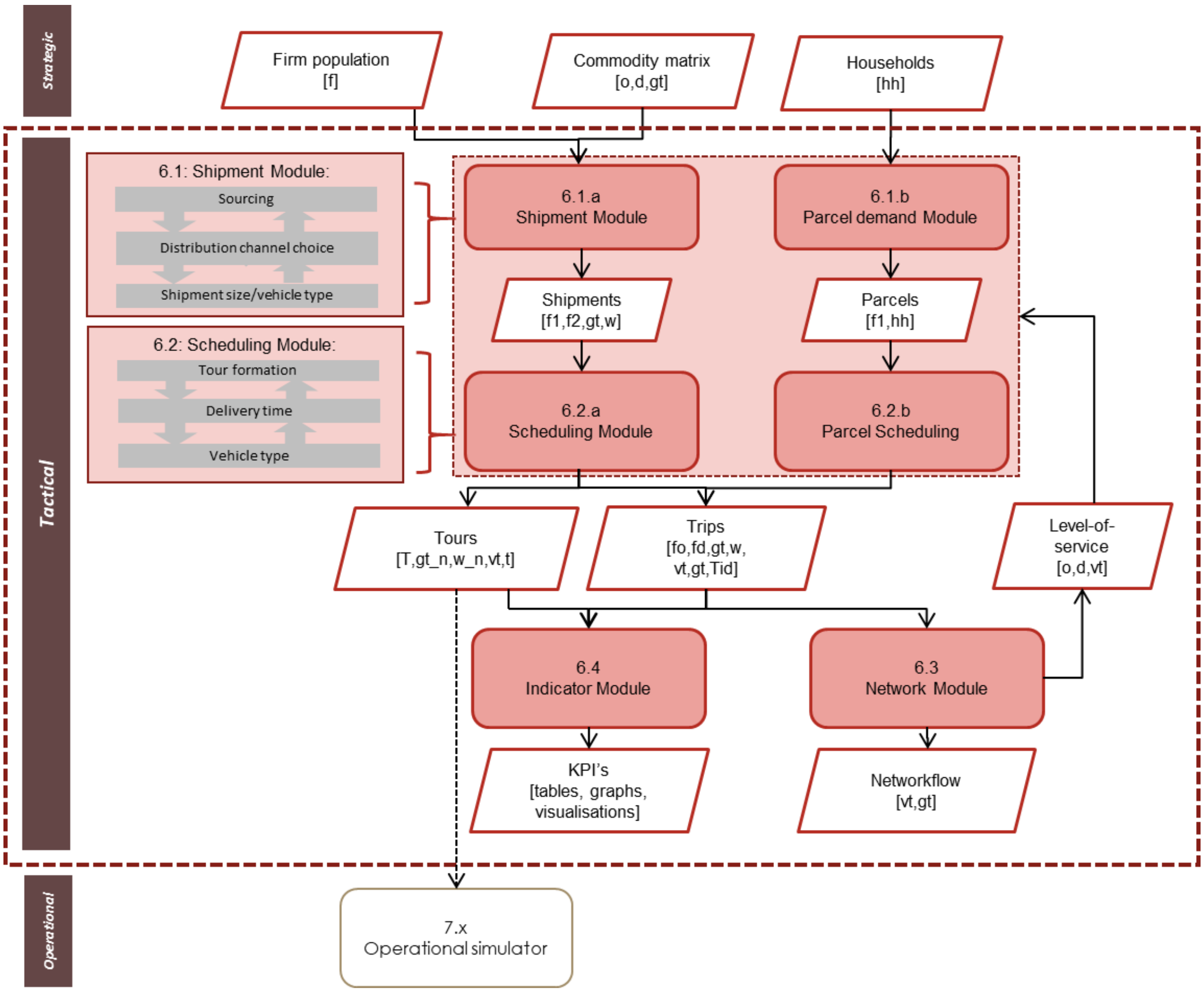

Figure 1: Technical structure of the Tactical Freight Simulator in HARMONY

The shipment synthesizer simulates long-term tactical decisions. The module employs choice models to build in a stepwise procedure a set of shipments that are transported to, from and within the study area. Many approaches follow a bottom-up approach calculating disaggregate freight demand at firm level [15],[23],[24], but in our approach we follow a top-down approach from aggregate to disaggregate flows, such as used in the ADA-model [12], SimMobility Freight [6],[25] or freight demand model FOCA [26]. The TFS simulates the following logistic processes: sourcing, distribution channel choice, and shipment size & vehicle type choice. Vehicle type and shipment size choice is simulated with a calibrated simultaneous choice model [27], based on EOQ theory. The distribution channel choice is simulated using observed market shares and monte carlo simulation.

The scheduling module simulates the daily schedules for the delivery of all shipments that are transported to/from within the study area. The module simulates tour formation and delivery times in a stepwise simulation. Tour formation is simulated with a shipment-based algorithm that consists of discrete choice models calibrated on disaggregate data [28]. Delivery times are simulated using observed delivery time distributions, and Monte Carlo simulation, similar as in [16].

The TFS is also equipped with two auxiliary modules. The indicator module: used to calculate the Key Performance Indicators for transport and logistic efficiency. The network module assigns freight traffic to the network and calculates emissions. The route choice information is first used to calculate generalized transport costs in the logistic choice models in TFS. In addition, the truck assignment is used to perform a novel emission calculation, considering the vehicle characteristics, the load of the vehicle and the type of links along its path [29].

Study area

The TFS has been first developed for the city of Rotterdam. It is, however, an open-source model created with the philosophy that it can easily be transferred to other metropolitan areas. The model version that is used in this study is upgraded to the study area of the province of South Holland, see Figure 2. This area is the most urbanized region in The Netherlands and has a population of 3.3 million, and 1.8 million jobs. One of the largest seaports in the world, the Port of Rotterdam is situated in the area.

It should be mentioned here that this is an initial version of the TFS. The models described in this deliverable will be improved as the project evolves and enriched with the planned data collection in the HARMONY project in the coming year.

Data used

A multi-agent simulation model such as the Tactical Freight Simulator simulates freight trip patterns at the level of individual shipments and freight agents, which requires a large amount of disaggregate data for model development. This type of data is usually collected via truck trip dairies and carrier and shipper surveys; but are scarce due to the difficulties and high costs inherent with data collection [17]. Additional data sources include annual national statistics on commodity flows, transport statistics and national account data.

For the development and calibration of the HARMONY shipment synthesizer we combine aggregate and disaggregate data from various sources. The primary data source applied in the shipment synthesizer is a large dataset of truck travel diaries collected by the Netherlands Statistics Bureau (CBS). CBS applies an innovative XML-interface to automatically extract microdata from the Transport Management Systems (TMS) of transport companies. The trip diaries include information on the vehicle type, the route, the commodity type, the weight the loading and unloading locations but do not have data on the location of shippers and receivers of goods.

The location of shippers and producers is synthesized using aggregate statistics from the Netherlands firm registration data (ABR). The data on distribution centers (DC) and transshipment terminals (TT) are provided from two sources. The DC database comes from Rijkswaterstaat (Directorate-General for Public Works and Water Management of the Netherlands) and contains over 1600 registered distribution centers along with their 6-digit address, size, and sectors. The TT database contains 54 transshipment terminals in the Netherlands. The above datasets were used to enrich the CBS trip diaries with additional location information [30].

The regional commodity flow data are derived from the freight transport demand forecast of the Dutch strategic freight model "BasGoed" [31].

The different goods types are grouped into logistics segments which are expected to have similar transport profiles. Each segment is defined "based on the characteristics of the firms that by players in the supply chain and how the market is structure" [32]. The rationale behind this classification is that firms belonging in the same logistics segment *(ls)* have similar supply chains and that transport between two segments cannot be combined. Eight logistics segments are defined:

1) Food (general cargo): All agricultural and animal products that do not need to be refrigerated.
2) Miscellaneous (general cargo): Rest of general cargo products.
3) Temperature Controlled: Goods that need to be transported in a temperature-controlled environment.
4) Construction Logistics: Materials transported from/to both large and small constructions projects.
5) Facility Logistics: Transports related to maintenance of buildings.

6) Waste Logistics: Waste products of both business and residents.
7) Parcel and Express.
8) Dangerous Logistics: Dangerous goods that require specialized handling.

In the Annex (Table A-1) we assign commodities (by NST/R code) to logistics segments. Below, a descriptive statistic is provided of the share of each segment in the vehicle kilometers in the study area.

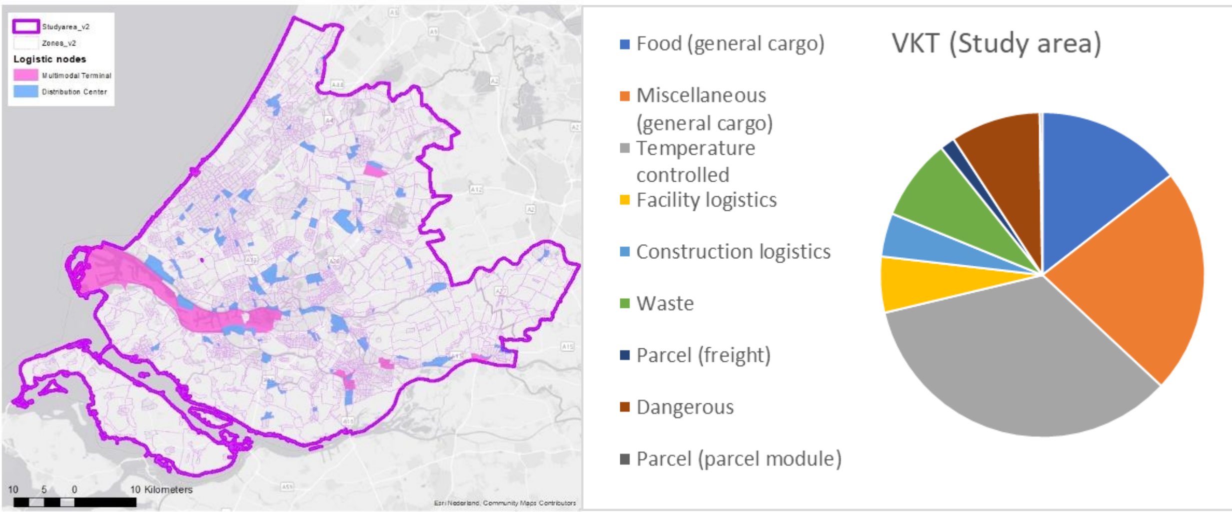

Figure 2: Study area (left) and share of vehicle kilometers by each logistic segment (right).

ZERO EMISSION SCENARIO

The introduction of a zero-emission zone is part of the Green Deal Zero Emission City Logistics (GDZECL) that aims at reducing CO2 emissions and improving both air quality and accessibility in the city. The zero-emission zone implies restricted access to the city center only with zero-emission vehicles and consolidation of shipments in urban consolidation hubs (UCCs) at the outskirt of the city. The use of UCCs effectively means adding a stage to existing supply chains [33]. Each logistic segment has its own specific characteristics and will use different solutions. Parcel delivery services are more likely to shift from vans to emission free electric light goods vehicles (LEVVs), while construction logistics will change the driveline of tractors used from diesel to biofuel of hybrid drivelines. [33] found evidence that some sectors are more likely to use the consolidation potential of UCCs: retail stores are more receptive because they have lower delivery frequencies and are less time critical. Food shops and restaurants have higher delivery frequencies and are more time critical and, therefore, less likely to accept an additional transportation leg in their supply chain.

The Road Map zero-emissions City Logistics presents an expert-based description of likely shifts to zero-emission city logistics for each logistic segment [3]. These transition scenarios consist of two types of shifts. The first is a shift from the conventional vehicle to vehicles with a zero-emission driveline, the second is a shift to a new zero-emission last-mile solution via UCCs. Distribution from these UCCs takes pace using LEVVs, such as cargo bikes or small vehicles with an electric engine, or electric vans.

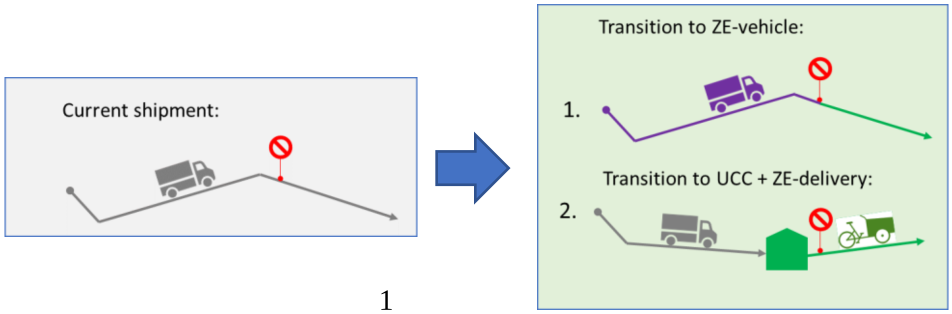

Figure 3: Implementation of transition scenarios

In this case study we will use the presented simulation model and make a scenario-based case study of the impacts of the transition scenarios presented in the roadmap. This means that the expected transitions for each logistic stakeholder/segment are interpreted from the expert-based scenarios from the road map. Strategic research questions for the implementation of the policy concern the dimensions of the zero-emission zone, the location of consolidation hubs, and the impacts on freight demand patterns, vehicle use and network impacts (emissions).

The most likely boundaries of the zero-emission zone are just the inside of the highway ring around the city of Rotterdam. UCCs are planned at the edge of the zero-emission zone: seven possible locations for consolidation centers for last mile deliveries were identified. We reformulate the general definition of a UCC [34] to our specific case study as: a logistics facility that is situated in relatively close proximity to the zero-emission zone, from which consolidated deliveries are carried out within that area. The UCC receives the deliveries from a larger number of suppliers. We also assume that horizontal collaboration exists, and shipments are assigned to the UCC based on their proximity. The propensity to use the UCC as an alternative depends on the logistic segment [33]. Table 1 presents the UCC propensity that is assumed in the transition scenario.

Table 1: UCC propensities by logistic segment

Logistic segments	UCC propensity
1. Temperature controlled	15%
2. Fresh Food(General Cargo)	20%
3. Mischellaneous (General Cargo)	20%
4. Waste	0%
5. Express and parcels	50%
6. Facility	20%
7. Construction	30%
8. Dangerous	0%

The second shift in the scenario involves the transition from the conventional vehicle to a ZE-vehicle. One of the solutions is the usage of LEVVs (cargo bikes or small vehicles with an electric engines) or electric van. These are effective solutions for many smaller volumes. But since the carrying capacity is insufficient for larger shipments, many shipments will be carried with conventional vehicle types but with alternative drivelines (electric, hybrid or hydrogen). In this scenario we assume that all transports that are not rerouted via a UCC but do (un)load in the Zero-Emission Zone (ZEZ) will make the switch to a hybrid driveline. Hybrid vehicles use an electric engine inside the zero-emission area, and switch to diesel power train outside the area: this way the vehicles still have a large operational range. Geofencing can be used to force the vehicles to use their electric engine inside the ZEZ. The most likely shift to alternative vehicle or driveline depends on the logistic segment. Table 2 shows the assumed vehicle type shares for the transports between the UCCs and ZEZ (and within the ZEZ) in the ZE-scenario.

Table 2: ZE vehicle type shares per logistics segment

Vehicle type + combustion	Logistics Segment						
	Fresh food (General Cargo)	Misc. (General Cargo)	Temp. Control-led	Facility	Construc-tion	Waste	Express and parcels
Electric cargo bike	6%	6%	27%	20%	0%	22%	50%
Electric scooter	0%	0%	14%	0%	0%	0%	0%
Van-Electric	35%	35%	27%	60%	17%	0%	50%
Van-Hybrid	0%	0%	0%	0%	4%	0%	0%
Truck-Electric	25%	25%	16%	12%	24%	13%	0%
Truck-Hydrogen	0%	0%	0%	0%	2%	0%	0%
Truck-Hybrid	16%	16%	11%	8%	15%	9%	0%
Tractor Trailer-Electric	4%	4%	1%	0%	6%	0%	0%
Tractor Trailer-Hydrogen	4%	4%	1%	0%	6%	0%	0%
Tractor Trailer-Hybrid	11%	11%	3%	0%	17%	0%	0%
Waste Collection-Electric	0%	0%	0%	0%	0%	11%	0%
Waste Collection-Hydrogen	0%	0%	0%	0%	0%	11%	0%
Waste Collection-Hybrid	0%	0%	0%	0%	0%	33%	0%
Special Construction-Hydrogen	0%	0%	0%	0%	2%	0%	0%
Special Construction-Biofuel	0%	0%	0%	0%	8%	0%	0%

RESULTS

The scenario is applied on the simulated shipments from the Shipment Synthesizer, the first module in the TFS. Next, the Scheduling module is run. Results are compared to the reference run. Figure 4 shows the shows simulated patterns of the vehicle trips. In red and blue the shipments are visualized that are rerouted through the seven UCCs. This leads to a small increase of 0.25% in the total Vehicle Kilometers (VKT) in the study area compared to the reference scenario. This is an unexpected, but realistic finding and can be explained by the extra leg that was added to the deliveries that are routed through the UCCs.

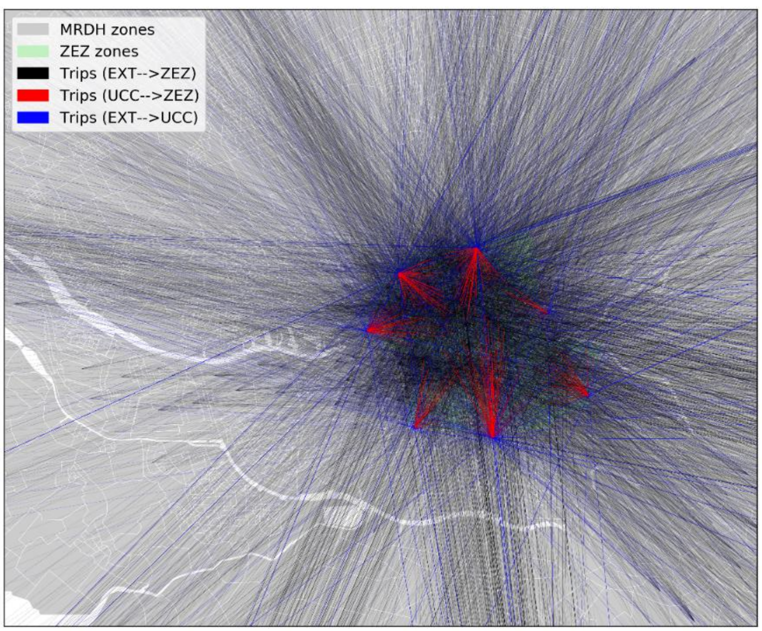

Figure 4: Impact zero-emission scenario on shipment patterns

The transitions change the composition of vehicle movements in the ZEZ. Figure 5 shows the evolution of the fleet kilometers by vehicle type before and after the scenario application. New smaller vehicles such as e-scooters and electric cargo bikes travel around 10% more vehicle kilometers. These types of vehicles are introduced more frequently because they are the predominant vehicle used for last mile deliveries from the UCCs. The results also show that the composition of vehicles driving in the city center do not change dramatically. Of course, this is the result of the scenario assumptions: the Roadmap outlines how many shipments will be delivered using heavy goods vehicles (HGVs) but with alternative driveline type. This assumption is conditional to the availability of ZE- or hybrid vehicles. The outputs of these case studies can also be used as a prediction for the number of vehicles required to see if these numbers can be met by the truck manufacturers. We assume that carriers will use the available ZE- and hybrid HGVs in city logistics.

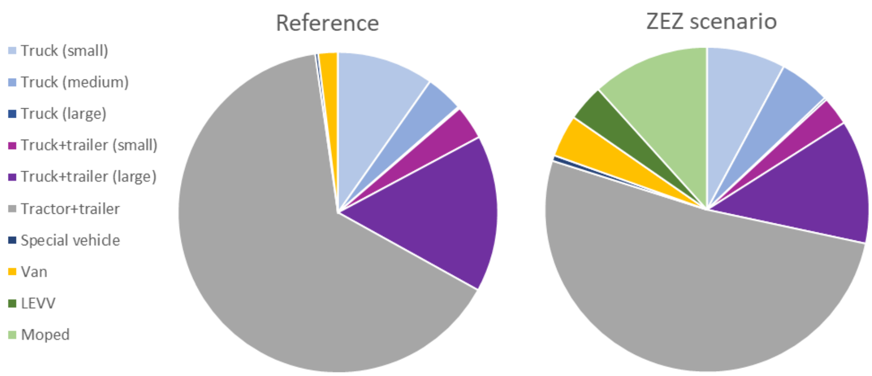

Figure 5: Vehicle kilometers by vehicle type before and after introduction of the zero-emission zone

Emissions are calculated from the route of each freight trip: this means that the calculation can take into account the vehicle type and load, but the route as well (location, link type, congestion) [29]. This is necessary for an accurate calculation of emission of hybrid trucks that have zero-emissions driveline based on their location. As expected, the implementation of the ZEZ led to a significant decrease in emissions in the ZEZ as it can be seen in Figure 6 and the totals presented in Table 3. All Greenhouse Gases (GHG) had a 90% decrease inside the ZEZ and were reduced by almost 10% in the rest of Rotterdam area. Results also show that the reduction of impacts is very small at regional (or national) level. Most of the freight traffic in this study area is unaffected by the zero-emission zone. In the area of Rotterdam most freight related traffic is generated by the port and involves long haul HGV transports that do not enter the city center: these transports remain unaffected. This case study shows that zero-emission zones are not the silver bullet in reducing greenhouse gasses. Additional measures are required to reach more ambitious climate goals. Future case studies with the presented simulation model will address the effectiveness of a combination of measures, both at local and national scale.

Table 3: Reduction in emissions at different scale levels

Type	In the ZEZ	Rotterdam	Study area (prov. South Holland)
CO2	-91%	-8%	-1%
SO2	-91%	-8%	-1%
PM	-89%	-8%	-1%
NOX	-91%	-9%	-1%

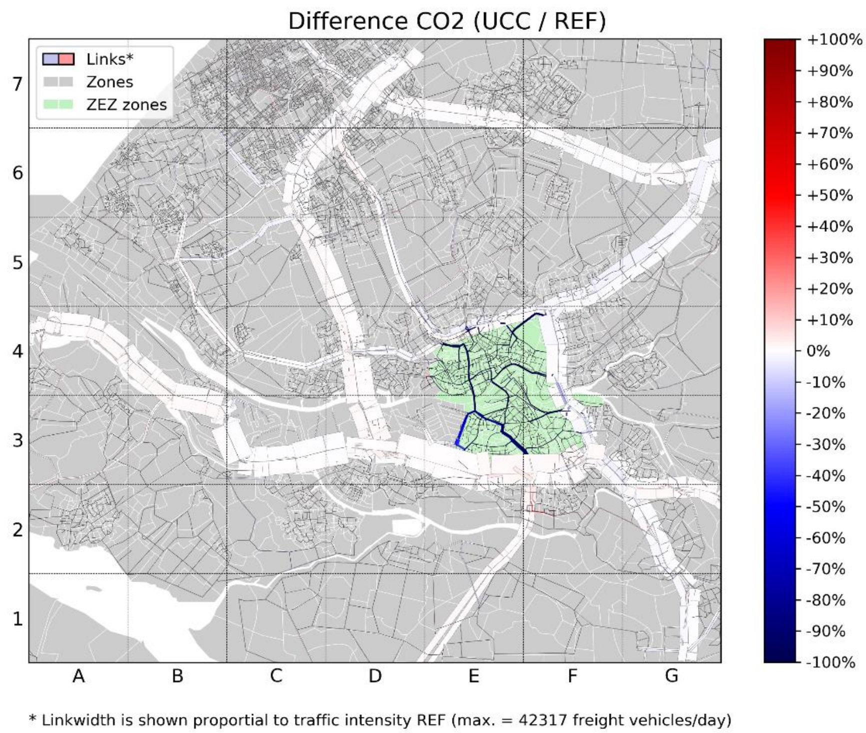

Figure 6: Change in emissions as a result of the zero-emission zone in Rotterdam

At this stage, the results of the application are largely affected by the scenario assumptions, however, the implementation still provides an insight into the magnitude of the impact of the ZEZ in the study area.

CONCLUSIONS

This case study shows that the impact of UCCs is not trivial: emissions within the ZEZ are reduced (because all transport takes place with ZE-vehicles) but we can see a small increase in vehicle kilometers travelled (VKT) outside the ZEZ: +0.25% which can be attributed to the rerouting of shipments through the UCCs. Calculations confirm that emissions are reduced dramatically, by 90%, inside the ZEZ. At the city scale this corresponds to a reduction of almost 10%, as most freight related traffic is generated by the port and involves long haul HGV transport that do not enter the city center. At a regional level the reduction of impacts is very small. The impacts on city level are significant and a good step towards the ambition from the current municipal coalition agreement to reduce CO2 emissions by 49% by 2030. However, to achieved this policy objective more measures are needed for instance measures to decarbonize long-haul freight transportation, that make up for a large part of the emissions in the study area.

We also present the effectiveness and possibilities of the HARMONY Tactical Freight Simulator to address a complex zero emission city logistics scenario, with UCCs and vehicle type transitions. The level of detail in the multi-agent model also permits the assessment of different transition paths to ZE – vehicles for each logistics segment, to better account for heterogeneity in preferences of different actors. This provides a better empirical basis for informed decision making, e.g. on the planned size of the zero-emission zone, and to plan to support UCCs to provide accessibility for all stakeholders.

The case study presented here shows an application of a scenario driven approach. We underline that the results are to a great extent dependent on scenario assumptions. Even though it is an expert-based scenario, the implementation in a microscopic freight simulator provides relevant insight into the magnitude of the impact of the ZEZ. These scenarios can and will be further developed by collecting data and preferences of the stakeholders in the study area. Surveys will be held to further analyze the transition paths to Zero Emissions vehicles per logistics segment, and the preferences of stakeholders regarding the propensity to use consolidation centers and new last-mile solutions.

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AUTHOR CONTRIBUTIONS

The authors confirm contribution to the paper as follows: study conception and design: M de Bok, L Tavasszy, I Kourounioti, S Thoen, J Streng; data collection: M de Bok, I Kourounioti, S Thoen, L Eggers; analysis and interpretation of results: M de Bok, S Thoen, L Eggers, V Nielsen; draft manuscript preparation: M de Bok, I Kourounioti; All authors reviewed the results and approved the final version of the manuscript.

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Annex A-1: Categorisation of commodities into logistics segments

Logistics Segment	Commodity Category- NST/R code
Fresh foods (General Cargo)	1110,1120, 1130, 1210, 1360, 1390, 1480, 1610, 1620, 1630, 1641, 1642, 1650, 1660, 1710, 1720, 1790, 1812, 1813, 1819, 1821, 1822, 1829, 1220, 1250, 1280 1110,1120, 1130, 1210, 1332, 1331, 1340, 1350, 1472
Miscellaneous (General Cargo)	4510, 4530, 4550, 4559, 4620, 5120, 5150, 5610, 5630, 5650, 5680, 6110, 612181,89, 2110, 3100, 3210, 3231, 3232, 3250, 3270, 3300, 3410, 3430, 3490, 6230, 6390, 8190, 8200, 8310, 8390, 8410, 8931, 8940, 8950, 8960, 9490, 8910, 9101, 9102, 9103, 9104, 9105, 9106,9200, 9310, 9390, 9510, 9520, 9610, 9621, 9622, 9630, 9710, 9990, 9750, 9761, 9762, 9790
Temperature controlled	331,1935,1392, 1410, 1420, 1430, 1440, 1450, 1460,
Construction logistics	5220, 61,65, 5450, 5510, 5520,6122, 6140, 6150, 6230, 6310, 6320, 6330, 6340, 6410, 6420, 6910, 6920, 9410, 9920
Facility logistics	8920, 8932, 9720, 9730, 9740, 9930
Waste logistics	8420, 9910, 14.1[1], 14.2[2*]
Parcel and Express	9720, 9730, 15.1[3*], 15.2[4*]
Dangerous	81,89, 2110, 3100, 3210, 3231, 3232, 3250, 3270, 3300, 3410, 3430, 3490, 7130, 7190, 7220, 7240, 7290

[1] Here we use the NST code
[*] Here we use the NST code
[*] Here we use the NST code
[*] Here we use the NST code