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## TOWARDS SUSTAINABLE URBAN DISTRIBUTION USING CITY CANALS: THE CASE OF AMSTERDAM

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**KEYWORDS:** city logistics, simulation, waterborne transport, electric vessels, urban freight,  
multi stakeholders

### ABSTRACT

This study investigates whether a system of hub locations distributing goods across the water to the city of Amsterdam can be a potential future solution to guarantee same-day delivery to shopkeepers. A simulation model was developed to analyse the logistics performances and to optimise the number of hub locations and required fleet size. The simulation tests have shown that two hub locations are sufficient when they are equipped with two vessels. Conclusion of this study is that a waterborne city logistics concept with a small number of hub locations can compete with truck deliverance and seems to be a sustainable solution for other cities with large canals as well.

### INTRODUCTION

Urbanisation is an ongoing trend in the world. People are moving to the cities and leaving the rural areas. In fact, since 2008 the global urban population is higher than the rural population (Bozzo et al., 2014). Currently, more than half of the population worldwide lives in urban areas, and it is estimated to increase to over 60 % by 2030 (DHL, 2013). According to the Environment Action Programme to 2020 of the European Commission (2014) around 80% of the total population in Europe will live in urban areas. This means that cities are

facing a great challenge with respect to logistics. People consume more due to an increase in wealth and consume also an increasing variety of products (Anand et al., 2012).

The cities are the drivers of the European economy since 85% of the EU's gross domestic product (GDP) is created in urban areas (European Commission, 2007). Transport infrastructure and the accessibility have become decisive, albeit not sufficient success factors for regional development (Nijkamp & Abreu, 2009; Lakshmanan, 2011). Efficient urban transport contributes to the smooth functioning of transport networks, which makes it key for the economy and for the needs of the citizens. On the other hand city logistics is also becoming a more disturbing factor for quality of life (Lindholm & Behrends, 2012). Urban mobility accounts for 40% of all CO<sub>2</sub> emissions of road transport and up to 70% of other pollutants from transport (Lindholm 2013; European Commission, 2015). Bigger cities are dealing nowadays with congestions, low air quality, noise and hindrance for visitors, caused mainly by distribution vehicles.

Likewise an identical situation for the city of Amsterdam can be observed. The city of Amsterdam has been for many years an attractive area for both residents and tourists. This attraction has its origin by the historical canals and houses, but also the presence of many restaurants, entertainment and services that attracts people. As a result, Amsterdam has intensive daily delivery traffic (Municipality of Amsterdam, 2013a, 2015a). This huge delivery traffic but puts both the accessibility and the quality of life in the city under pressure, which is among other factors noticeable by the emission of harmful substances and environmental nuisance (noise) for residents of the inner city (Ploos van Amstel, 2015; Municipality of Amsterdam, 2015b). Also, the characteristic narrow streets in the inner-city form a disadvantage, since it leaves little room for passing traffic with related discomfort as a result.

To maintain the quality of life, while at the same time maintaining the flow of goods towards the downtown area, cleaner transport supplies are deployed (Municipality of Amsterdam, 2013a). This, however, addresses only part of the problem: the degree of accessibility and nuisance are not influenced by clean freight transport. The usage of clean vehicles for instance can still cause traffic congestion, which influences accessibility and nuisance negatively. Instead, the usage of clean haulage on the city canals, which for several years has been taken place on a small scale, does have serious potential to solve all disturbing factors. In the recently released draft plan of the Water in Amsterdam for 2040, the municipality offers the opportunities for clean water haulage (Municipality of Amsterdam, 2015b).

Previous research showed that this form of goods distribution is possible on a large scale while maintaining the quality of supply (van Duin et al., 2014). However, new plans of the city include more than the concept studied there. A new concept includes for the establishment of four new transshipment hubs, located on the outskirts of the city, from where electric vessels can sail goods to the inner-city. These locations are situated near large motorways, allowing for a good connection to the existing freight traffic road network (see Figure 1).



Figure 1. The inner-city of Amsterdam with the potential transshipment hubs (red circles) and their connecting roads (Municipality Amsterdam, 2015a).

To study this new concept the following research question is raised:

‘What fleet size is required for large-scale urban distribution through the canals of Amsterdam, making use of (up to four) new transshipment hubs, without compromising quality of delivery?’

The delivery quality is of great importance for the local shopkeepers, because the types of goods which are under consideration in this study are HoReCa (Hotels, Restaurants, Cafes) goods for the catering industry. For these types of goods the transport time is a critical factor to realise on-time delivery and freshness of the products. For waterborne city distribution companies such as Mokum Mariteam (our case study) it is crucial to develop a competitive alternative for the traditional way of delivering goods (i.e., road transport). The fleet size and usage are important cost factors for city distribution (Crainic et al., 2009). Therefore, in order to reduce the operational costs it is important to know how many vessels are needed and what their occupation rates are. Also, in order to reduce costs, we need to minimise the number of transshipment hubs.

To answer the research question a discrete simulation model is developed using the Simio simulation platform (Kelton et al., 2013). In this way, a waterborne distribution system can be simulated in a valid way and possible bottlenecks can be discovered. Also, we can determine the influence of different input variables on system performance. Examples of such input variables include the number and time pattern of arriving goods or the number of vessels that is used. Discrete simulation is an adequate instrument to study the impacts of goods and cargo characteristics - such as size, origin, quantity, capacity, and speed - while considering the spatial characteristics of the canals. Also it may provide useful insight into the relevant outcomes such as delivery speed and the occupancy of ships. The modelling paradigm of Sargent (2010, p. 170) is followed which prescribes the development of a conceptual model and a simulation model and applies verification and validation to both models before using the simulation in experiments. Therefore the structure of this paper

follows this modelling paradigm. Section 2 explores the literature on (simulation of) city logistics (waterborne transport). Section 3 addresses the demarcation and definition of the conceptual model. Section 4 presents the second step of the paradigm, the specification of a simulation model. Section 5 describes the verification and validation of the models. Section 6 describes the last step of the paradigm showing the results of the experiments with different fleet sizes and locations of the transshipment hubs. Section 7 draws conclusions and provides recommendations.

## LITERATURE REVIEW ON WATERBORNE URBAN FREIGHT TRANSPORT

Although Cranic et al. (2015) mention that city logistics systems belong to the important class of consolidation-based transportation systems that include rail and less-than-truckload carriers, high-sea navigation lines, intermodal systems, express courier and postal services, and so on, it can be observed that the last mile is mainly dominated by the application of vehicles and roads instead of vessels and canals. In city logistics just a few articles can be found which are related to waterborne urban freight transport. Janjevic & Ndiaye (2014) mention a couple of waterborne urban freight transport initiatives in European cities like:

- (1) the Beer Boat (Utrecht) for deliveries to local shops, hotels and restaurants;
- (2) Mokum Maritiem (Amsterdam) for deliveries to local shops and waste transport;
- (3) Vert Chez Vous (Paris) for parcel deliveries;
- (4) DHL floating distribution centre (Amsterdam) parcel deliveries;
- (5) Franprix (Paris) Supermarket deliveries;
- (6) Sainsbury's (London) transport of food to supermarkets;
- (7) POINT-P (Paris) transportation of palletized construction material;
- (8) Paper recycling (Paris) by barge, Paris.

Their analysis of several initiatives in European cities demonstrated that there is a significant potential for using city waterway networks for the distribution of goods in several urban freight transport segments, ranging from parcel deliveries to waste transportation, and that a usage of road vehicles for the last leg of transport allows implementing these solutions in cities with a lower waterway network density, such as Paris.

Lindholm et al. (2015) showed in their paper the feasibility and sustainability of using urban waterways for excavated materials transport in urban areas. The feasibility study was conducted through theoretical studies, studies of the context specific conditions in Gothenburg, and a benchmark of six similar cases. However, only four cases have been using waterways for transport of excavated materials (Potsdamer Platz in Berlin, Olympic Park in London, BanaVäg i Väst between Gothenburg and Trollhättan, and Förbifart Stockholm). Their research findings show that the large vessel investigated outclasses all other transport solutions both regarding feasibility and sustainability. Trojanowski and Iwan (2014) discuss in their paper the analysis of Szczecin waterways in terms of their use to handle freight transport in urban areas. Although the title of their paper indicates the scope on urban areas, this paper is not focussed on last-mile delivery by vessels and has broader scope on barge terminals receiving goods for the urban areas of Szczecin.

Besides a contribution on noise performance at terminals (van Duin & van der Heijden, 2012) and our paper on the water traffic influence of city logistics distribution by vessels for horeca-goods from one terminal (van Duin et al., 2014) our literature search found no other contributions with respect to simulating a city logistics concept based on canals and vessels. However, many literature contributions of discrete event simulation can be found with respect to the modelling inland navigation and barge operations for freight transport at national and terminal level (Caris et al., 2011; Liu et al., 2002; Saanen, 2004; Rijsenbrij and

Saanan, 2007; Verbraeck et al., 2016).

In general it can be concluded that in case of urban freight transport the on-time deliveries of the orders have the highest priority meanwhile the cost should be reduced as good as it can. These perspectives, unique for city logistics, are not found in the other discrete event models. Therefore the focus in our model is 1) to guarantee the on time-deliveries to the shopkeepers and restaurants, and 2) to maximize the usage of the fleet size of the vessels (and therefore reducing the cost of delivery) is more important than the terminal utilisation, i.e. the fleet size of the vessels needs to be determined based on an on-time delivery to the shops. The developed model of the vessel concept is based on discrete event modelling, since the transport and loading operations can be represented as a chronological sequence of (sometimes parallel) events. The vessels are using common shared infrastructure such as canals and loading zones. The operations at the canals and loading zones can be interpreted as a discrete queuing systems. There are several reasons for selecting simulation modelling. The most important ones are (Verbraeck, 2010):

- The mathematical part of the problem can be treated as a stochastic queuing system;
- The problem is complex in such a way that the outcomes are not simple and one-sided;
- The new concept we want to study does not exist yet and it is too expensive, and too time-consuming to experiment with a 'real world' model;
- Not all information required to describe the problem situations is available;
- There is no simple, analytical solution to the mathematical models of the system.

To model the discrete event system, in particular the dynamic interactions between the ordering, delivering and (un)loading operations, stochastic simulation is chosen as the modelling technique. Stochastic simulation can improve the confidence of the modelling outcomes by replicative experiments.

## CONCEPTUAL MODEL OF DISTRIBUTION CANAL SYSTEM

To model the freight flows in the canals, it is important to identify which company locations are accessible by vessels. In our study the city center of Amsterdam is chosen as the scope of study due to the fact that a big part of the canals are located here and 40% of the HoReCa branch is located in this area (OIS Amsterdam, 2015a). The area is much broader compared to the former study (van Duin et al., 2014). Figure 2 shows the city center with its canals. The light orange parts show the HoReCa establishments, not only in the city center but also outside the city center.

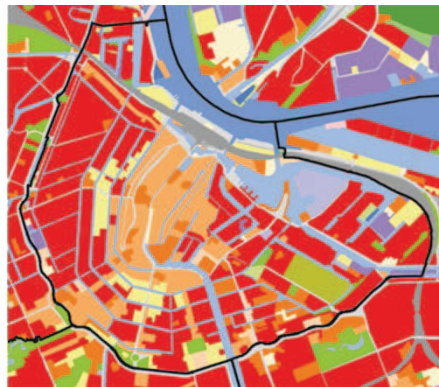


Figure 2. City Center with HoReCa establishments in Amsterdam (Municipality Amsterdam, 2015a)

As a start of the conceptualisation the main objects and processes are identified (following Sargent, 2013):

## Freight

In our study the focus is the delivery of HoReCa goods. Most of these goods are transported by trolleys with a surface of 70 cm x 80 cm (Van den Boogaard, 2013). On average each HoReCa shop receives one trolley per shipment. To allow for a benchmark on the outcomes we used identical assumptions as in the study by van Duin et al. (2014). Freight is delivered by trucks from several directions to one of the (up to) four hub locations. At the hub location some freight is temporary stocked, because not all freight is bound for the Amsterdam inner-city. The freight with destination inner-city is sorted and planned to realise optimal routes of the vessels. The trolleys are transhipped on board by a crane. All hub locations (see Figure 1) have close connections to the highways and are accessible for waterborne transport. The locations were proposed in the draft program WaterVision by the municipality Amsterdam: Marktkanalen, the Riekerhaven, the Duivendrechtsevaart and the Nieuwe Vaart (Municipality of Amsterdam, 2015b).

## Freight vessels

In our study the electric vessel from Mokum Mariteam was selected as a representative vessel with a maximum speed of 7.5 (km/h), a headroom of 1.80 (m), a vessel length of 20 (m), a vessel width of 4.25 (m), a loading capacity of 85 (m<sup>3</sup>) which equals to 65 trolleys (Mokum Mariteam, 2010a). An on-board a crane is available which places the trolleys at the quay at a maximum distance of 15 (m) and a maximum weight load of 760 (kg). Sometimes even a 'Mover' (Figure 3) is placed on board for the final deliverance to the shops. The energy use forms no restriction on the operations. During night the batteries are recharged.

## Canals

When the vessel are loaded, they sail among the old canals to the inner-city (see Figure 2). Not all the canals are suitable for these freight vessels. In our model dedicated canals are specified considering the width and headroom of the vessels (an de Kamp, 2016).



Figure 3. The Mover (Mokum Mariteam, 2012)

## Destinations (shops) and their final delivery

After having arrived at their destination in the inner-city, the trolleys are put on the quay. Within a vicinity of a couple of 100 metres the trolleys are delivered by the Mover to their shops. The Mover can drive to the cargo destination or it can be carried on board.

Based on the objects and process descriptions the following black-box representation of the model can be made (see Figure 4).

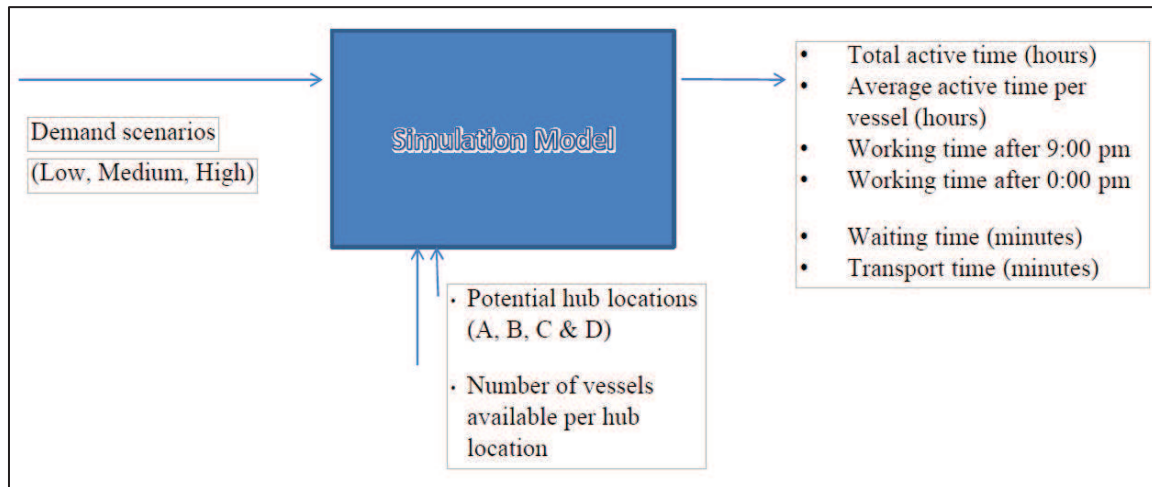


Figure 4. Conceptual model of the simulation model

## SPECIFICATION OF THE MODEL

Our conceptual model was used to specify a simulation model of the proposed distribution system. For this we gathered data (and where necessary made some assumptions) and developed scenarios for demand patterns as discussed below.

### Data collection and general modelling assumptions

The trucks are not explicitly modelled in the model. The inter-arrival time of the freight trucks at the hub locations follows a negative exponential distribution function from 6:00 am until 1:00 pm. The resulting arrival pattern matches the supply patterns in Amsterdam made by DHV (2007).

The system model has no limitations with respect to the storage capacity at the hub locations. Transshipment and storage are located at the same location. The inner-city is divided in three zones. Each zone can be delivered by two hub locations. At the wide canals a speed of 7.5 (km/h) is allowed, while at the smaller canals a speed of 6.0 (km/h) is considered (van Duin et al., 2014). The delivery by vessels starts after 8.00 am if the vessels are sufficient loaded. In general this deliverance process lasts until 6.00 pm, but delivery until 0.00 pm is also possible. This is again in line with the supply patterns provided by DHV (2007).

The duration of a transshipment of the trolley takes about 2 minutes (Interview with the manager van Mokum Mariteam, August 2016). Per stop, irrespective of the number of trolleys to be delivered, an extra time of 1 minute is added for mooring the vessel. Each vessel has a fixed route, which is optimal if all the destinations have to be delivered. Google Maps (2016) and Datacharter.com (2016) are used to calculate the shortest path. Once the vessel starts unloading, the Mover will be available at the quay side. In the morning at the first vessel trip the Mover is on board, later the Mover is driving around following the route of the vessel.

### Demand patterns

We determined demand patterns for different areas in the inner-city. Based on a



complete list of potential unloading points (LA Group, 2010) and using Google Maps (2016) a number of 108 unloading locations in the inner-city of Amsterdam was determined. The unload locations were divided over three zones for which the demand was estimated. The division of zones is needed because it is necessary to know the assignment to the hub locations. Zone 2 is delivered by hub locations A & B (see Figure 1) and the other two zones are delivered by hub location C and D respectively. It should be mentioned here that the trucks sometimes have to visit more than 1 hub location and enter the city from different origins. These extra kilometres are not considered in the model, however the total distance is added in the final comparison of the alternatives.

To determine how much freight per destination is demanded several sources are linked together. The exact input data can be found in Van de Kamp (2016). Based on the information provided by the municipality of Amsterdam an estimation is given for the number of HoReCa shops in a specific destination. This information is combined with other information sources in order to obtain a reliable picture of the dispersion of HoReCa shops per destination (OIS Amsterdam, 2015a; Municipality of Amsterdam, 2015c; 2015d; 2015e). The resulting demand scenarios, starting from 6.00 am until 1.00 pm, as shown in Table 1 were used as input to the simulation model. We first estimated the demand with four hub locations and later two additional variants were considered where only 2 hub locations are available (B&D). The demand scenarios of the hub locations B and D are summed by the additional demand of A and C respectively.

Table 1: Demand scenarios (*High, Medium, Low*) for the number of trolleys & inter- arrival times (Negative exponential distribution functions are used to generate these numbers,(van de Kamp, 2016))

Hub locations		Number of rolling containers (per day)			Average inter-arrival time of goods at the hubs (minutes) Exponential distribution		
		<i>High</i>	<i>Medium</i>	<i>Low</i>	<i>High</i>	<i>Medium</i>	<i>Low</i>
4 hubs	<i>A</i>	196.2	65.4	19.6	2.140	6.421	21.402
	<i>B</i>	204.3	68.1	20.4	2.056	6.169	20.563
	<i>C</i>	333.9	111.3	33.4	1.258	3.773	12.578
	<i>D</i>	320.8	106.9	32.1	1.309	3.927	13.091
2 hubs	<i>B</i>	400.5	133.5	40.0	1.049	3.146	10.487
	<i>D</i>	654.7	218.2	65.5	0.641	1.924	6.415

## VERIFICATION & VALIDATION

According to Banks et al. (2009) verification of a model is the process of confirming that it is correctly implemented with respect to the conceptual model (it matches specifications and assumptions deemed acceptable for the given purpose of application). Validation checks the accuracy of the model's representation of the real system. A model should be built for a specific purpose or set of objectives and its validity determined for that purpose (Sargent, 2010). In this section the verification and validation of our model are discussed.

### Verification

To verify the model various verification tests were performed to determine the correctness of the model: an input test, a structure test and a test to verify if all of the entities in the model leave the model before the end of the simulation run. Our model passed all of these tests.

The network of canals with crossings is represented as directed graph based on detailed waterborne maps (Waternet, 2016). Every canal is represented as a double connection which reduces the chance of input errors. Connectivity is also explicitly checked for headroom (datacharter.com, 2016). Also all loading/unloading locations in the inner-city are checked to have enough loading space to position the trolleys.

To check the model logic on consistency several functions of Simio are applied such as watch, trace, notify and breakpoint functions. Finally the output variables are checked to see how the model responds to high deviated inputs, one entity and many entities. No logical errors were found.

### Validation

To validate the model an experimental treatment is applied (Sargent, 2010). A simulation run lasted 24 hours and represented a regular weekday. The system that was modelled was considered finite and, therefore, a warm-up time was not needed. To calculate the required number of replications of the experiment to yield a sufficiently narrow 90% confidence interval the method by Pegden et al. (1995) was applied. 25 simulations runs were needed to obtain the 90% confidence. A comparison with the model (van Duin et al, 2014) showed identical outcomes with respect to the number of goods delivered. The other variables like the number of vessels, occupation rates and waiting time can of course not be compared. As a final test of the validation the input variables (10% increase/decrease in the freight scenarios. are changed. After some more detailed analyses it could be concluded that the model shows valid outcomes. More detailed information on the verification and validation is available in (Van de Kamp, 2016).

## EXPERIMENTS

48 simulation experiments were conducted as outlined in Table 2. In each experiment we used different values for three input variables:

1. Number of hubs: 4 (A, B, C, and D) or 2 (B and D only);
2. Number of vessels assigned to each hub: 1 to 6 vessels per hub;
3. Transportation demand: 3 scenarios (low, middle, high).

Table 2. Survey of simulation experiments with different fleet size configurations. The terms ‘High’, ‘Medium’, and ‘Low’ refer to the three demand scenarios. (The numbers in Table 2 indicate the number of vessels assigned to a hub).

	Hub A			Hub B			Hub C			Hub D		
	High	Medium	Low	High	Medium	Low	High	Medium	Low	High	Medium	Low
4 Hubs (A, B, C, and D)	2-4	1-3	1-2	2	1	1	2	1	1	2	1	1
				3	2	2	3	2	2	3	2	2
				4	3		4	3		4	3	
2 Hubs (B and D)				4	2	1				4	2	1
				5	3	2				5	3	2
				6	4					6	4	

## Overview and discussion of simulation experiments

The influence of the different fleet sizes and the number of hubs can be determined by measuring the performance indicators. The waiting (T1)- and transport times (T2) are crucial for the final receivers, the HoReCa shopkeepers. For the barge operator it is important to evaluate the occupancy rates of the vessel, the total working hours for all vessels and the average working hours for a vessel. Additionally, we measured how often the work is not finished after 9.00 pm (denoted below as '>21:00') and after 0.00 pm ('>24:00'). The confidence intervals (CI) show the representative value of the means. The simulation experiments are discussed for each hub location A, B, and B without A individually. The other simulation outcomes of C, D and D without C can be found in Van de Kamp (2016).

Table 3. Simulation outcomes hub location A (experiments using 4 hubs)

Scenario	Demand	Vessels	Total active hours	Active hours per vessel	> 21.00	> 24.00	Occupation per tour	CI (95%)	T1: Waiting-time (hour)	CI (95%)	T2: Transport-time (hour)	CI-0,95
1	Medium	1	9,64	9,64	0	0	0,73	68,8% - 77,4%	2,89	2,7 - 3,1	2,04	2,0 - 2,1
2	Medium	2	10,60	5,30	0	0	0,73	68,8% - 77,4%	2,51	2,3 - 2,7	2,05	2,0 - 2,1
3	Medium	3	10,60	3,53	0	0	0,73	68,8% - 77,4%	2,51	2,3 - 2,8	2,05	2,0 - 2,1
4	High	2	19,32	9,66	1	0	0,88	85,8% - 89,5%	2,34	2,3 - 2,4	2,10	2,1 - 2,1
5	High	3	19,26	6,42	0	0	0,88	85,8% - 89,5%	1,49	1,5 - 1,5	2,12	2,1 - 2,1
6	High	4	19,06	4,76	0	0	0,88	85,8% - 89,5%	1,37	1,3 - 1,4	2,12	2,1 - 2,1
7	Low	1	8,15	8,15	0	0	0,34	32,2% - 35,7%	3,67	3,5 - 3,8	1,55	1,5 - 1,6
8	Low	2	8,15	4,07	0	0	0,34	32,2% - 35,7%	3,67	3,5 - 3,8	1,55	1,5 - 1,6

Freight distributed from hub location A was often confronted with higher waiting times compared to transport times (see Table 3). It can be observed that the waiting time is decreasing as the demand is growing. In the Medium-demand experiments (1 – 3) the average waiting time is between 2 and 3 hours. Adding another vessel reduces the waiting time significantly by half an hour ( $z = -3.111 > 1.96$ ). Adding a third vessel has no influence on the waiting time. The occupation rate per tour remains the same, because this depends on the freight demand. The number of tours remains the same for experiments 2 and 3.

The high-demand experiments (4, 5 & 6) show a significant ( $z = -4.372$ ,  $z = -4.372$ ,  $z = -3.12$ ) difference in waiting time reduction. Adding a third vessel saves 45 minutes and also makes all the vessels ready for 9:00 pm (which is a desire of the vessel operators). Adding a fourth vessel reduces the waiting time again with 7.2 minutes. However, the vessel occupation remains too low to become a serious scenario. The experiments with low demand (7 & 8) show that one vessel is sufficient to deliver the trolleys.

Table 4. Simulation outcomes hub location B (experiments using 4 hubs)

Scenario	Demand	Vessels	Total active hours	Active hours per vessel	> 21.00	> 24.00	Occupation per tour	CI (95%)	T1: Waiting-time (hour)	CI (95%)	T2: Transport-time (hour)	CI-0,95
9	Medium	1	9,16	9,16	0	0	0,62	58,7% - 64	2,39	2,3 - 2,5	1,73	1,7 - 1,8
10	Medium	2	10,80	5,40	0	0	0,62	58,7% - 64	1,97	1,8 - 2,1	1,70	1,7 - 1,7
11	Medium	3	10,80	3,60	0	0	0,62	58,7% - 64	1,97	1,8 - 2,1	1,70	1,7 - 1,7
12	High	2	19,11	9,56	0	0	0,86	84,3% - 87	2,30	2,3 - 2,3	1,91	1,9 - 1,9
13	High	3	19,33	6,44	0	0	0,86	84,3% - 87	1,49	1,5 - 1,5	1,94	1,9 - 2,0
14	High	4	19,09	4,77	0	0	0,86	84,3% - 87	1,35	1,3 - 1,4	1,94	1,9 - 2,0
15	Low	1	8,01	8,01	0	0	0,35	33,2% - 36	3,67	3,5 - 3,8	1,41	1,4 - 1,4
16	Low	2	8,01	4,00	0	0	0,35	33,2% - 36	3,67	3,5 - 3,8	1,41	1,4 - 1,4

The simulation outcomes of hub location B (see Table 4) show identical patterns as the simulation outcomes of hub location A. Again, with medium demand the average waiting time varies between 2 and 2.5 hours (experiments 9 - 11). Adding a second vessel reduces the

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waiting time with half an hour. Adding a third vessel doesn't show any added value. The high demand experiments (12, 13 & 14) show larger reductions in the waiting times, i.e. adding a third vessel leads to 45 minutes reduction, and, adding a fourth vessel leads to additional reduction of 8.4 minutes.

The low demand experiments (15 & 16) show no significant reductions when adding vessels. One vessel performs as the best solution.

Table 5. Simulation outcomes hub location B (experiments using 2 hubs)

Scenario	Demand	Vessels	Total active hours	Active hours per vessel	> 21.00	> 24.00	Occupation per tour	CI (95%)	T1: Waiting-time (hour)	CI (95%)	T2: Transport time (hour)	CI-0,95
17	Medium	2	14,07	7,04	0	0	0,82	79,4% - 84,9%	1,72	1,7 - 1,8	1,92	1,9 - 2,0
18	Medium	3	14,33	4,78	0	0	0,82	79,4% - 84,9%	1,53	1,5 - 1,6	1,92	1,9 - 2,0
19	Medium	4	14,33	3,58	0	0	0,82	79,4% - 84,9%	1,53	1,5 - 1,6	1,92	1,9 - 2,0
20	High	4	34,02	8,51	0	0	0,92	90,4% - 93,0%	2,31	2,3 - 2,3	1,89	1,9 - 1,9
21	High	5	33,64	6,73	0	0	0,93	92,2% - 93,8%	1,85	1,8 - 1,9	1,89	1,9 - 1,9
22	High	6	33,63	5,60	0	0	0,91	89,7% - 92,7%	1,66	1,6 - 1,7	1,89	1,9 - 1,9
23	Low	1	8,60	8,60	0	0	0,64	62,1% - 66,4%	3,57	3,5 - 3,7	1,81	1,8 - 1,8
24	Low	2	8,60	4,30	0	0	0,64	62,1% - 66,4%	3,57	3,5 - 3,7	1,81	1,8 - 1,8

The medium demand experiments (17, 18 & 19) show relatively low reductions in the waiting times if another vessel is added. Comparing the results of 1 vessel with 3 vessels yields a reduction of only 15 minutes. Also, the transport times and total active hours do not change significantly by adding extra vessels. It is clear that one hub location leads to transport time savings (0.7 hours) and total active hours savings (around 6 hours). The bundling of volumes lead to improved usage of the vessels.

The high-demand experiments show more significant differences. The average waiting time reduces with 30 minutes if the number of vessels is changed from 4 to 5. However, adding a 6th vessel shows no significant changes. The transport times and occupation rates do not vary much between the different scenarios. Total active hours are reduced by almost 30 minutes if the number of vessels is increased from 4 to 5. Again we can observe that bundling of the demand leads to better performances. Total active hours can be reduced with 2 or 3 hours ( $19(A)+19(B) - 33(B-A)$ ). Also the occupation rates increase from 0.88 (A) and 0.86 to 0.92 (B-A). The waiting times are not significantly affected. The effect of more efficient unloading can be best observed in the reduction the transport time going from 2.12 hours (A) and 1.94 hours (B) to 1.89 hours (B-A). The low-demand experiments (23 & 24) show again no differences if a vessel is added.

Comparing this to the simulation outcomes where four hubs are used, a doubling of the occupation rates can be observed which is in line with the expectations.

## Discussion of the main findings

In the low-demand experiments (where the waterborne transport still has little market share) the use of two hub location is sufficient to maintain the delivery quality. If more distribution hubs are in operation, the costs will increase strongly due to a higher number of ships and the related costs of the hubs.

In the experiments with middle and high demand scenarios, when more bars and restaurants receive their goods by water, it is still advantageous to maintain two hub locations (B&D) instead of four (A - D). Still the delivery quality can hereby be guaranteed, i.e. the waiting times remain the same and transport times reduce by smarter routing. It should be mentioned here that occupation rates of 0.92 are extremely high. This implies tight scheduling and no incidents should occur. Backup facilities should be foreseen for these occasions.

However, the simulation results for C & D and D-C showed different insights (van de

Kamp, 2016). The waiting times are growing when one hub location is closed. Also working times after 9:00 pm and even after 0:00 pm occur more often. This implies the hub locations, the routes and the local demand ask for a dedicated approach for individual circumstances.

In any case with sufficient certainty it is shown that the supply quality position remains when freight delivery on water increases. Additional calculations (outside the simulation) have been made how many polluting trips to the inner city can be saved per day if this system is applied. (based on the assumption that a truck contains on average 19.2 trolleys, 80% loading rates (DHV, 2007)):

- Low demand scenario 5 trucks;
- Medium demand scenario 18 trucks;
- High demand scenario 55 trucks.

## CONCLUSIONS

Like other recent studies in literature on waterborne transport for the last mile (Janjevic & Ndiaye 2014; Lindholm et al. 2015); Trojanowski and Iwan (2014)) we conclude that studying the local conditions for cities with canal infrastructure can contribute to a serious, potential, sustainable solution to deliver the last mile by electric vessels, which is beneficial to many stakeholders.

For the most important stakeholders the customers of this system, the HoReCa entrepreneurs, same-day-deliver is important to guarantee the freshness of their products and the availability. Therefore the transport time to the shops and the average waiting time at the hub location are import indicators to represent their interest. For the logistics service provider it is important that the occupancy rates of the vessels are sufficient, the total working hours is not too much and his captains on the vessels work not longer than the legal times.

This paper shows the value of simulation in studying these new innovative concept as electric waterborne transport. The simulation study provided some initial answers to these issues of concern. With different scenarios it was possible to optimise such a system. In general it was found that 2 hub locations combined with 2 vessels are sufficient in the low demand scenario. The other scenarios showed some contradictory findings, which give reason to study the local situations individually. This rectifies our dedicated simulation approach. Next research step is to investigate the financial viability of this concept. Although the occupation rates are quite high, the necessity to pick up and deliver other product flows such as construction, laundry and return flows (garbage) are suggestions for research to make the service profitable.

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