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ABSTRACT
The use of cargo bikes for goods deliveries represents a promising concept of urban logistics. In this contribution, a new simulation-based assessment tool integrating this emission free vehicles in urban distribution systems is presented. First, typical schemes are identified and an analysis of the underlying planning problems is conducted. Second, the developed GIS-based discrete-event simulation model and the coupled tour-planning algorithm are described, implementing the pattern of control optimization. To the best of our knowledge, such a tool is not yet existing. Finally, the tool is applied, evaluating the potential use of cargo bikes for B2B-deliveries in the medium size city of Grenoble in France.

Keywords: urban logistics, cargo bikes, delivery network simulation, control optimization

1. INTRODUCTION
Mitigating and fighting climate change has become one of the major challenges of modern societies. To achieve the Paris Agreement (United Nations, 2015) global CO2 emissions shall not peak later than 2020. Urban transport is responsible for 23% of greenhouse gas emissions in the EU (European Commission, 2016). Thus, economies demand the implementation of disruptive actions and a sustainable urbanization everywhere (Rockström et al., 2017). The megatrend of urbanization goes along with serious issues of more congestion, material flows, air pollution and noise exposure. Growing e-commerce and freight volumes (Bogdanski, 2017) put more stress on cities, their inhabitants and infrastructure. Hence, municipalities and logistics operators are under pressure to bring up new solutions to maintain cities liveable.
Urban logistics as an attempt to cope with those challenges is undergoing a renaissance right now. As in reality also in science a growing corpus of work (Evrard Samuel and Cung, 2015; Lagorio, Pinto and Golini, 2016; Dolati Neghabadi, Evrard Samuel and Espinouse, 2016) is a sign mark for that. The cargo bike as new vehicle for urban freight (Gruber, Kihm and Lenz, 2014) is gaining ground. As a zero-emission vehicle it can be suitable for freight transport in dense urban areas like city centres (Conway et al., 2011; Schliwa et al., 2015). It has the potential to substitute 25% of motorized delivery trips (Reiter, Wrighton and Rzewnicki, 2013).
The cargo bike is used for direct transports within cities (Gruber, Kihm and Lenz, 2014) or it can be part of the last (respectively first) mile of a transport chain (Leonardi, Browne and Allen, 2012; Schliwa et al., 2015). Hence, it can become a vital part of urban distribution systems. Since cargo bikes can carry freight of the size of an euro pallet weighing maximally 300kg (Schenk, Assmann and Behrendt, 2017), the transport network needs to be adjusted. In order to replace vans and trucks used before in the last mile, a transhipment point in close proximity to the dense service area needs to be implemented. The setting-up of such a distribution system is imposing a magnitude of challenges concerning the planning of the transport network, locations and processes. Although work has been done on this issue of determining location and network architecture (Janjevic and Ndiaye, 2014, 2016; Agrebi, Abed and Omri, 2015; Rao et al., 2015), a simulation tool for assisting the planning process is missing.
Location selection problems for transhipment points in urban logistics can be classified as a special case of the facility location problem (Rao et al., 2015). The viability of the cargo bike integration is highly dependent on the right structure of network chosen. To deploy it, a profound planning process needs to be carried out. A magnitude of requirements (Agrebi, Abed and Omri, 2015), such as accessibility, connectivity, proximity to costumer etc. on the one hand and a very limited amount of available space in urban areas as costs constraints on the other hand do heavily limit the number of feasible locations. As experience with existing schemes shows, finding a feasible, accepted location for logistic operations in cities is one of the hardest planning tasks. This leads to the fact that the choice of location of transhipment points is rather a matter of availability (Van Duin, Quak and Muñuzuri, 2010) than of sophisticated optimization.

We are therefore aiming at assisting urban distribution planners in rapidly testing appropriate locations. Within the planning process, simulation of prospective configurations of a transport network is a viable method to identify beneficial solutions. The target is to develop a simulation tool, which allows a fast and convenient application. Meaning that a) it implements street maps via GIS-tools to achieve reality-proof route planning, b) it considers possible locations of transhipment points via an interface and c) it works with easy to gather location information and demand patterns of receivers. Demand patterns shall be easy to gather from a heterogonous group of receivers or senders. Therefore, the focus is on key indicators (e.g. avg. demand, maximum demand) which can be obtained by means of surveys.

The paper focuses on presenting an easy to use tool, providing a simulation to evaluate the network-setting of multimodal schemes integrating cargo bike. Therefore, such schemes will be classified and issues of location selection in urban areas will be introduced in section 2. Our GIS-based simulation tool will be presented in section 3. In section 4, it will be applied to and validated on a specific use case in the medium size city of Grenoble in France. Finally, we will draw our conclusion and give an outlook on future work.

2. APPLICATIONS OF MULTIMODAL SCHEMES & PLANNING PROBLEMS INTEGRATING CARGO BIKES

To define our framework of simulation, firstly a classification of cargo bike schemes in urban distribution systems is introduced. Although some authors already worked on the issue of developing a typology (Janjevic and Ndiaye, 2014; Staricco and Vitale Brovarone, 2016), none of them presented a satisfactory approach. Planners however will need to consider and evaluate different network configurations. A clear, unambiguous definition and classification will therefore be a vital assist for those. Those presented below are based on the works of (Benjelloun, Crainic and Bigras, 2010; Allen et al., 2012; Leonardi, Browne and Allen, 2012; Raimbault, Andriankaja and Paffoni, 2012; Janjevic and Ndiaye, 2014; Crainic and Montreuil, 2016; Staricco and Vitale Brovarone, 2016; Schenk, Assmann and Behrendt, 2017).

The basic concept of such schemes is to transfer freight from the outside of a city to the cargo bikes which are doing the tour in the urban area. The points outside the city are coined depots. Depots are distribution centres or warehouses (Anand et al., 2012) of single or multiple enterprises and can also be production sites.

The basic element of such a distribution system is the transhipment point (TP) which appears in different types. The most common utilization is an urban consolidation centre (UCC) (Allen et al., 2012; Holguín-Veras and Sánchez-Díaz, 2016). In UCCs, freight of different shippers, consignees, and carriers from different depots is consolidated into the same vehicle (Benjelloun, Crainic and Bigras, 2010). However, schemes without a consolidation function at the transhipment point do exist as well. Those will be named transit points. Having define these terms, a clear classification of multi modal schemes integrating cargo bikes in urban distribution systems is developed. The first class is direct transports (2.1). The second and third class are single-level (2.2.) and two-level (2.3.) systems (figure 1).

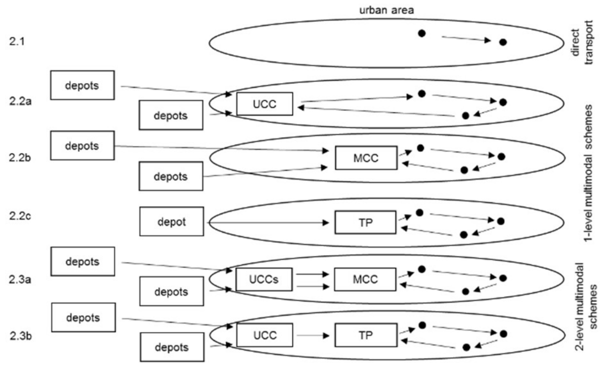

Figure 1: Classification of multimodal schemes integrating cargo bikes according to level and consolidation principle.

2.1. Direct urban distribution schemes

This class of cargo bike schemes contains all relations of transports where the freight is not transferred between vehicles when going from its origin to its destination. Cargo bikes can be used for point to point services and for delivery runs. Point to point service also entails trips where drivers combine several A to B relations in one cargo bike, as courier services do. Since no transhipment takes place, no consolidation in the defined sense does happen. Those transports are usually restricted to a city. As examples can be found: transports on own account or delivery rides by local businesses.

2.2. Single-level urban distribution schemes

A single-level multimodal scheme is characterized by one transhipment process between the origin and destination. Typically, freight is sent by a lorry from the origin, a depot outside the urban area, to a transhipment centre in close proximity of the delivery zone and changes to the cargo bike. The point of transfer needs to be distinguished in three classes having a significant impact on processes and goods handled, as introduced below. This can either happen at a UCC, a micro-consolidation centre (MCC) or transit point (TP).

a) Depot – UCC scheme

Scheme a in the single-level class is characterized by its UCC. Those facilities are well-known in terms of city logistics (Allen et al., 2012). The primary focus is on the consolidation of freight designated to the city (centre) on specific vehicles for the last mile. They are mostly located at the city edge. Vehicles do not need to be cargo bikes, it can also be electric vehicles or others since some UCCs have already existed for years and decades. At the UCC, freight of nearly all sizes is transferred and consolidated. The facility itself needs to have space and equipment for those, like pallet trucks or forklifts. Examples of depot - UCC schemes are *La Petite Reine* in

Paris and *Last Mile Leeds* in Leeds (Staricco and Vitale Brovarone, 2016).

b) Depot – MCC scheme

As for UCC, MCC is a widely used and well-known term within cycle-logistics. However, MCC is not clear and unambiguous. It is broadly defined as a very small UCC for transferring and consolidating parcels (Browne, Allen and Leonardi, 2011; Janjevic and Ndiaye, 2014). Since it has a variety of shapes and realization, these two functions which come together at a special point of space and the freight characteristic are taken as unique attribute. Its size can equal a container or smaller, a rooftop is not necessary and it can be either mobile or stationary. Due to its size, it can be in closer proximity to the delivery area and is connected to a depot. Examples are *Bento Box* in Berlin (Weber, Chiadò and Bruening, 2012) and *Gnewt Cargo* in London (Leonardi, Browne and Allen, 2012).

c) Depot – TP scheme

This scheme c is similar to b, but it differs in one core function. A transit point (TP) does not fulfil and allow the consolidation of goods. In contrast to UCC or MCC, just one shipper or carrier uses such a facility, where no flows of goods are consolidated or stored. This network is defined by a depot from where freight is shipped to a transit point at which the load changes to cargo bikes. Such a scheme allows crossdocking processes (Gudehus, 2012) where pre-packed load units are transferred. Examples for TP-schemes are *UPS* in Hamburg (Harris and Haycock, 2017) or *GLS* in Budapest (Zsolt, 2017)

2.3. Two-level urban distribution schemes

A two-level scheme is defined by two transfers of freight between the outside and the urban delivery area. A UCC is placed at the city-edge consolidating freight to and from depots outside the city. Within the city several MCC or TP are installed to allow another transfer on cargo bikes for the last mile. Those are in very close proximity to the city centre. Such a system can make sense if urban areas are large, inappropriate distances for cargo bikes between the already set up UCC and the delivery area exist or special modes of transport like barges can be used.

a) Depot – UCC – MCC scheme

In this scheme, a UCC consolidates incoming freight of several carriers. Although it is located between the city edge and the delivery area, it makes sense to install additional MCC in closer proximity to the actual delivery area. The MCC can be either stationary or mobile, allowing the transport vehicle of the latter to form the MCC itself.

b) Depot – UCC – TP scheme

In contrast to the scheme above, this one is just a consolidation process at the UCC. The second stage of transhipment just allows the transfer of freight or load carriers and no consolidation. An example is *Vert Chez Vous* in Paris (VNF, 2015; Staricco and Vitale Brovarone, 2016).

2.4. Special aspect of integrating cargo bikes

Cargo bikes do have other routing characteristics as conventional vehicles. Basically they can also drive on footpaths, pedestrian zones and cycle lanes (Hertel et al., 2014). This point should be represented in Vehicle Routing Problems (VRP) based on urban street networks. It becomes more important as cargo bikes are meant to perform best in urban areas that have high density, narrow streets, with limited access and higher percentages of pedestrian zones (Schliwa et al., 2015). Furthermore no general knowledge on maximal, viable distances between the transhipment point and the delivery area is existing, (Staricco and Vitale Brovarone, 2016). This aspect and a trade-off between the benefits of more complex cycle logistics schemes (2-level) and their increasing costs provide little determinants for planning processes.

Hence, a simulation tool as proposed in the following section is a vital assistance for city planner and logistic operator to integrate cargo bikes in urban distribution systems.

2.5. Location selection and vehicle routing in urban logistics

Transportation costs take a big share in the overall cost of a distribution system. Thus, it makes sense to treat them carefully and precisely no matter which overall planning and decision making methodology is applied.

One mean to get cost values for urban transhipment points can be the application of Operations Research methodologies. The body of methods and algorithms is rich (Rao et al., 2015). They predominantly focus on minimizing costs or improving the service level. (Lagorio, Pinto and Golini, 2016) found 45 vehicle routing problems (VRP) for urban areas, but none could be linked to cargo bikes. (Crainic, Ricciardi and Storchi, 2004) introduced a capacitated multi-commodity location problem formulation for a depot – TP scheme. They do consider two types of vehicle in the linear optimization, one conventional truck and one city freighter which is designed for dense areas.

(Mancini, 2013) is highlighting the importance of multi-echelon distribution systems in urban logistics. Corresponding optimization problems are the Two Echelon Location Routing Problem (2E-LRP) and the Two Echelon Vehicle Routing Problem (2C-VRP), also described by (Gonzalez-Feliu, 2008). Examples from the field of cargo bikes are the above presented cargo bike schemes 2.3a and 2.3b where the goods are consolidated and transhipped. Solving methods for these complex problems frequently include meta-heuristics and decomposition approaches (Prodhon & Prins, 2014).

Since dynamic and stochastic problem environments such as urban logistics can be difficult to model with the help of standard problem formulations, the integration of optimization methods with simulation techniques can provide substantial benefits by offering the possibility to evaluate solution candidates using simulation models, as shown by (Aurich, Nahhas, Reggelin, & Tolujew, 2016). Furthermore, optimization algorithms can be used to solve problems arising during a simulation run (Affenzeller, et al., 2015). Within the field of urban logistics, discrete-event simulation methods represent a promising approach, enabling the impact assessment of solutions and measures before implementation. A review on simulation techniques for evaluating urban distribution solutions is given by (Karakikes & Nathanail, 2017).

3. DESIGN AND IMPLEMENTATION OF A SIMULATION-BASED DISTRIBUTION NETWORK ASSESSMENT TOOL

The scope of the tool as outlined in the introduction is to provide a fast, true to reality and easy to use simulation to test a certain distribution network scheme with some locations, considering the volatility of demands. For these purposes, two factors are of great importance. Firstly, current linear location selection methodologies work well under a certain environment. However, demand patterns of receivers, either in location of single entities or in volatility of good flows are dynamic. Secondly, non-linear multi-criteria decision making methodologies are gaining ground since they are able to represent the complexity of urban environments with their numerous stakeholders and influencing factors. However, these methodologies are typically based on the judgements of experts, which may not be unbiased or completely correct. As conclusion can be drawn that a methodology is of use, which enables decision makers to test different network configurations, improving their understanding and judgement of the system.
In order to provide support during the planning process, the following requirements have to be met:

- Definition of locations for receivers (also referred to as "customers"), depots and transfer points
- Consideration of stochastic demand patterns
- Modelling and simulation of a distribution network with multiple levels and different means of transport
- Integration of real street maps to provide realistic distance data and visualization
- Calculation of key indicators on distances, cost and environmental impact of the network for comparison of different alternatives

Figure 2 depicts the developed approach. The modelled logistics system represents a hierarchical distribution network with non-nested service varieties. The corresponding vehicle routing problem can be characterized as a 2-echolon VRP (2E-VRP) which is decomposed into Capacitated Vehicle Routing Problems with Multiple Depots (MDCVRP). The simulation model used for demand generation and delivery simulation is implemented using ANYLOGIC simulation software.
For reasons of simplicity and controllability, the implemented tour planning algorithm does not consider time windows for deliveries, vehicle range constraints, multi-dimensional capacity constraints and capacities of transfer points. Nevertheless, the behaviour of the system concerning these aspects is observed as well during the simulation, making it possible to detect infeasibilities occurring in a configured network.

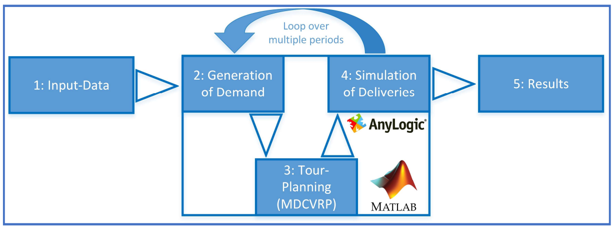

Figure 2: Approach for distribution network evaluation.

3.1. Input data

As a basis for any calculation, the below-listed information on nodes and vehicles of the distribution network must be provided (table 1). Additionally, the number of simulated periods (days) must be specified. The modelled network may consist of one or multiple levels, whereby higher-level nodes act as sources to supply nodes of the next-lower level. That way, typical multimodal schemes with consolidation and transhipment points can be modelled. Input data is imported automatically at the start of the simulation when provided in form of an Excel spreadsheet. Subsequently, nodes are created and animated on an Open-Street-Map (OSM), using the GIS-integration feature of the simulation software.

Entity	Category	Unit
Node	Location	Latitude, Longitude
	Network Level	0: Customer 1: Transhipment-Point 2: Consolidation Centre
	Order Frequency (Level 0 Nodes)	Min. & Max. Time between orders (days)
	Demand (Level 0 Nodes)	Min. & Max. Volume per order (m^3)
		Min. & Max. Weight per order (kg)
Vehicle	Routing-Type	Car / Cargo bike
	Capacity	Max. Weight (kg) & Volume (m^3)
	Velocity	Speed in (m/s)
	Network Level	Network level on which vehicles are in use
	Number	# of vehicle units in use
	Loading/Unloading Times	Time per stop
	Environmental Impact	CO2-emissions per km
	Economic Impact	EUR per km

Table 1: Input-Data on the simulated distribution network.

3.2. Generation of demand

First step in every period of the simulation is the generation of demand on the customer level where each node releases orders at a specified frequency. Weight and volume of an order are randomly generated according to a uniform distribution, specified by the corresponding input parameters. By multiplying the volume of an order with the vehicle-specific average load density (kg/m³), the dimensional weight is calculated (ups.com, 2017). Taking the maximum of dimensional and actual weight of an order reduces the dimension of the demand and simplifies the tour planning while considering capacity constraints of the vehicle in use.

3.3. **Tour planning**

Second step is the determination of tours to deliver ordered amounts from level-1 nodes to customer nodes. Therefore, information on location and demand of the customer nodes, capacity and routing type of the vehicle, and location of the level-1 nodes is submitted to an external tour planning application. Distance matrices for the different types of vehicles are obtained using the online routing functionality of OSM.

Figure 3 depicts all steps of the tour planning algorithm. Vehicle routing problems with multiple depots are known to be NP-hard (Ombuki-Berman & Hanshar, 2009). In order to quickly provide a feasible solution a heuristic approach is proposed. The MDCVRP is first decomposed into multiple single-depot CVRPs by assigning every customer to its nearest depot. In a second step, the vehicle capacity-exceeding share of demand of every customer is scheduled to be delivered by direct return trips, splitting the demand in slices of the capacity of the vehicle. This simplification seems legit, since delivered goods should be multiple units in most cases and therefore divisibility should be given to a certain degree.

The share of demand inferior to vehicle capacity is considered not to be divisible. This way, a minimal number of stops for each customer can be ensured. Tours to deliver the remaining part of the demand are obtained using a sequential version of the well-known savings algorithm (Clarke & Wright, 1964), extended to handle the case of asymmetric distance matrices, even though there may be major reductions in effectiveness in this case as shown by (Vigo, 1996).

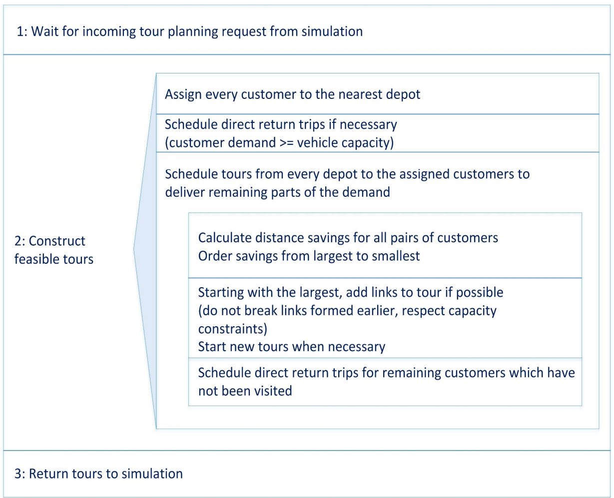

Figure 3: Solution procedure of the tour planning algorithm.

This heuristic constructing feasible tours is implemented using MATLAB, set up as a TCP/IP server to which the simulation (ANYLOGIC) connects as a client, following the idea of control optimization, also referred to as online optimization, described by (Affenzeller, et al., 2015). In order to get a realistic behaviour of the simulation, optimization algorithms are used to solve problems arising during the simulation run. The simulation and tour planning application coupling simplifies improvements of the algorithm and allows parallelism. Due to the TCP/IP interface, optimization algorithms may be implemented on different platforms and executed on different machines.

Constructed tours are returned to the simulation. The sum of all amounts of goods which have to be delivered from a level-1 node to customer nodes determines the level-1 nodes' demand, which has to be supplied from level-2 nodes. The set of demanding level-1 nodes and the set of supplier nodes is again submitted to the tour planning application, as well as characteristics of the vehicle in use on this second level. In this manner, the tour planning application is used to subsequently determine the tours on every level of the network.

Figure 4 shows a simple example of an arbitrary 2-level network with scheduled tours. Demands of level-1 nodes are determined by the 1st level tours to the customers. In the second iteration of the tour planning, 2nd level tours are calculated, starting from level-2 nodes.

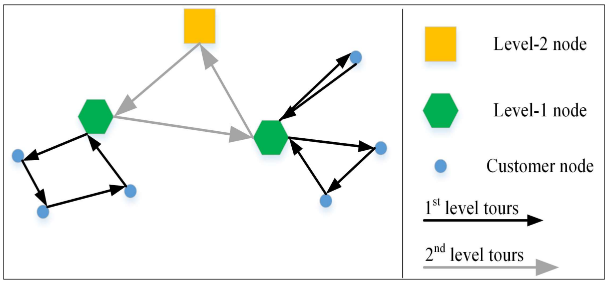

Figure 4: Example of a 2-level network with delivery tours.

3.4. **Simulation of deliveries**

The execution of the tours on the different network levels is simulated and animated, respecting the given number of available vehicles as well as their velocity and stop times. The logic is programmed using discrete-event and agent-based concepts from the ANYLOGIC simulation environment. In case the number of vehicles is not sufficient to execute all the tours of a day, this deficiency is reported to the user. The execution of the tours is simulated on the underlying street-map, taking into account characteristics of the road network and specific means of transport. The use of different IRouteProvider objects from the simulation library for bikes and cars enables the consideration of the different routing characteristics. Figure 5 shows a screenshot of the interface of the simulation tool in use for the case study.

The animation of the tours eases not only the presentation of new delivery concepts and communication with stakeholders, but also verification and validation of the tool. To ensure flawless functioning, various tests of the

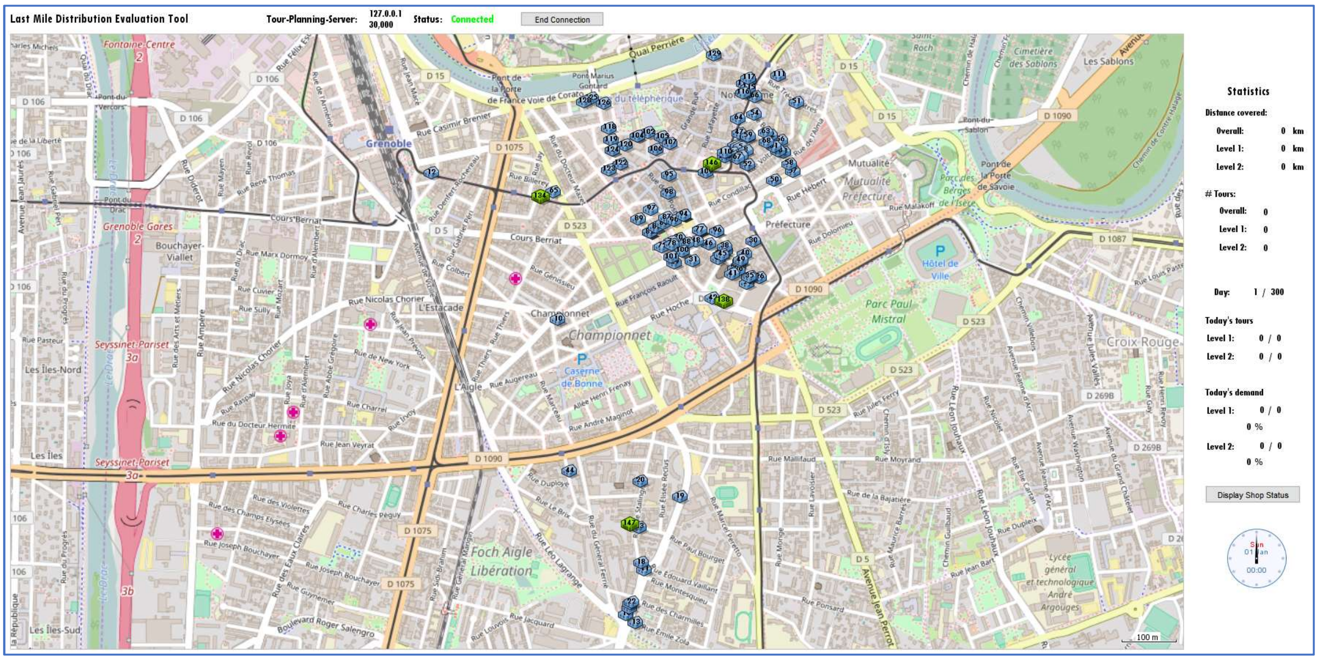

Figure 5: Interface of the GIS-based simulation model, showing a map with 127 shops (blue) and 4 transhipment points (green) from the case study.

optimization algorithm and the simulation model have been carried out and results have been checked. Furthermore, the results of the case study described in section 4 were compared to the ones obtained during the actual implementation of a similar type of network.

3.5. Output Data

In order to gather data on the performance of the distribution (or collection) network with respect to fluctuating demands, the pattern of demand generation, tour planning, and simulated execution is iterated over the specified number of periods. Based on the mileage of each type of vehicle on the different levels the CO2-emissions and transportation costs of the evaluated network are calculated. Furthermore, the time periodically needed to complete all tours gives a clue about the number of vehicles needed on each network level to be able to guarantee certain service levels. The amount of goods transhipped by different nodes indicates their importance and the requirements on their performance and capacity.
By simulating the execution of tours in the modelled distribution network, the general feasibility of the use of cargo bikes can be validated with help of the simulation, even though some real-life constraints such as vehicle range and time windows for deliveries have been excluded from the optimization.

4. CASE STUDY: DEVELOPING A B2B CYCLE-LOGISTICS NETWORK IN GRENOBLE CITY

The following subsections present the application of the developed tool to support currently conducted research on the potential use of cargo bikes for goods delivery to shops (B2B) in the centre of Grenoble city in France.

4.1. Initial situation & survey

There are several characteristics of the city making the implementation of modern city logistics concepts such as cargo bike deliveries in this particular place extremely interesting. First, there is the bowl shape of the city, resulting in a poor, some days alarming air quality (lametro.fr, 2017). Consequently, political efforts are made which target the reduction of traffic and its emissions. Another reason is the narrow city centre with a high number of one-way streets and pedestrian zones which are leading to challenging conditions for traditional forms of deliveries.
In 2016, a survey conducted by the laboratories CERAG and G-SCOP has been carried out within the framework of their research project ULIS (Urban Logistics: Integrated Solutions). This survey investigated the logistics requirements and the demand patterns of 183 shops from various sectors in the centre of Grenoble city. It was determined that a majority of over 80% of the shops is delivered using small boxes or parcels which makes a delivery using cargo bikes generally possible.
For the calculation 127 of the initially 183 shops have been selected, excluding shops with load units other than parcels. Furthermore, pharmacies have been excluded since they are assumed to be supplied by a dedicated distribution network.
Delivery frequencies of the selected shops vary from daily to monthly, the number of units per delivery is between one and more than ten. More than 80% of the shops prefer to be delivered in the morning from 6-10am, leaving a time window of approximately 4h for the deliveries.
Weight and volume of the orders of a shop are assumed to be evenly distributed. The corresponding minimal and maximal parameter values were estimated for every shop based on the type of business and the nature of the

ordered goods. Orders of the shops are generated according to the given frequency and to the parameter values of the probability distributions. Figure 6 shows a sample of 300 days and the demand of the shops calculated in the scenarios. Values are aggregated on a daily basis and sorted in ascending order. Simulation runs were carried out with a fixed random seed and the dimensional weight is calculated the same way for all vehicles. Thus, the demand values are the basis for all simulated scenarios.

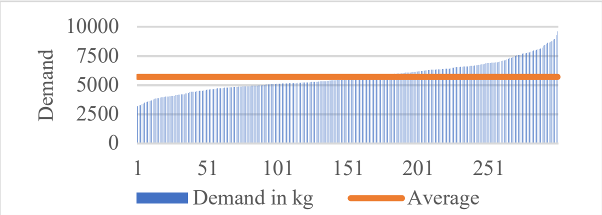

Figure 6: Daily demand of the shops over 300 days.

4.2. Calculated scenarios

In order to assess the feasibility of the use of cargo bikes for delivery, two scenarios have been developed:

1. Reference scenario (1-level), using conventional vans
2. Multimodal scenario (2-level), using trucks and cargo bikes

It is assumed that all incoming goods have been consolidated at a UCC which was established in 2016, located at about 12km northwest of Grenoble city. Table 2 lists the different means of transport and their characteristics.

	(Scenario 1)	(Scenario 2)	
	Van	**Truck**	**Cargo bike**
Max. load	1800kg	4500kg	180kg
Max. vol.	10m³	25m³	1m³
Avg. speed	14m/s	14m/s	3m/s
Number	3x	1x	6x
Routing	Car	Car	Pedestrian

Table 2: Means of transport used in the case study.

The data on cargo bikes represent realistic values, easily reached by modern, electrically supported models (Schenk, Assmann and Behrendt, 2017). Values of stop times are estimated. In this case study, unloading stop times are assumed to be composed of a fixed share of 3 minutes and a variable share of 0.5 seconds per kg demand unit transferred during the stop of every vehicle. For loading the fixed share is estimated at 5 minutes. This is leading to an overall time of 20 minutes for a van and 6.5 minutes for a cargo bike to get fully loaded.

In scenario 1, vans are used to deliver goods directly from the UCC to the shops. As shown in Figure 7, the daily number of scheduled tours varies between 2 and 6, depending on the amount of requested goods. Days are ordered as presented in Figure 6. On average, 12.2 shops are visited per tour and the 3 vans need 149 minutes to finish all tours. The time window of 4h is never violated. The average tour length is 27.9km which is mainly determined by the distance from the UCC to the city centre.

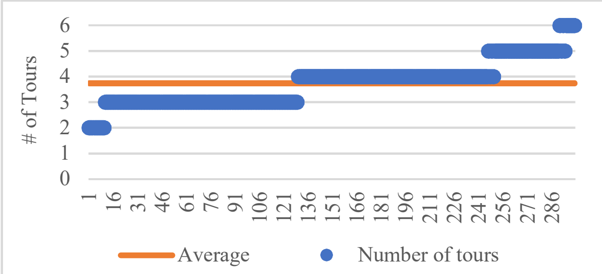

Figure 7: Number of daily tours in the reference scenario.

In scenario 2, 4 spots which are used as transfer points are proposed. They are strategically well located close to a high number of shops in the city centre. The points have been selected by hand from existing stations of a postal company, assuming that they are able to provide space and infrastructure for transhipment. A bigger truck is used to supply these transfer points where goods are transhipped and then delivered to the shops using cargo bikes. This type of distribution network can be classified as a two-level multimodal logistics scheme type 2.3b. Due to the higher capacity of the truck compared to the van, the number of tours on the first level decreases as depicted in Figure 8.

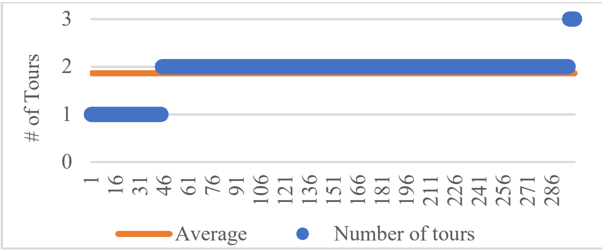

Figure 8: Number of daily tours of the truck in the multimodal scenario 2.

The number of daily tours of cargo bikes on the 2nd level is depicted in Figure 9. As it can be expected from the capacity which is 1/10 of the vans' capacity, the number of necessary tours increases accordingly. The limited capacity leads to a share of 70% of direct return trips visiting only one shop. During the remaining 30% of the tours, 3.4 shops are visited on average; maximum is 11. Due to the proximity of shops and transfer points and because of the limited capacity of the cargo bikes the maximum tour length reaches only 2.5km.

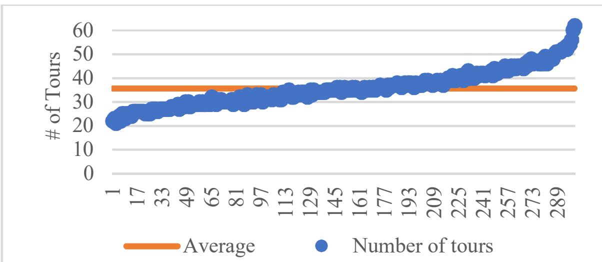

Figure 9: Number of daily tours of the cargo bikes in the multimodal scenario 2.

Figure 10 shows the time needed by the 3 vans or the 6 cargo bikes to deliver all goods to the shops (and to the transfer points in case of the truck). As expected, the time starts to correlate with the number of tours and the demand if the number of tours exceeds the number of available means of transport.
Even though the overall capacity of the 6 cargo bikes is way less than the capacity of the 3 vans, the proximity of the transfer points and the shops as well as the possibility to use shorter routes lead to a decreased time to deliver the goods to the shops. The higher amount of time needed to deliver the goods by truck to the transfer point is caused by the lowered overall capacity of one truck compared to the 3 vans. This does not necessarily need to cause problems, provided that the truck tours start early enough and assumed that there is sufficient storage space at the transfer points.

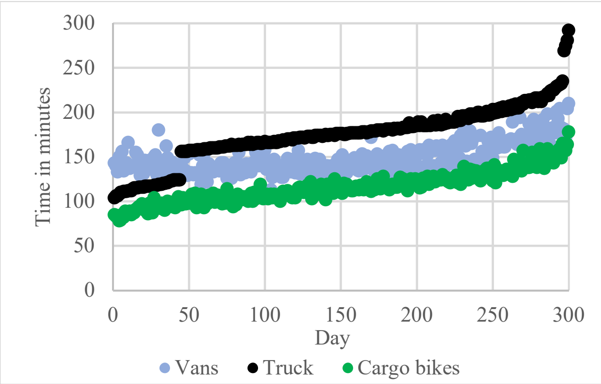

Figure 10: Daily time in minutes to deliver all goods.

In order to evaluate the influence of the number and location of the transfer points, a variation of scenario 2 has been created (scenario 2b). This scenario assumes that transfer point 146 (north east in the city centre, see figure 5) is not available anymore, reducing the number of transfer points to 3. As a result, the average tour length of cargo bike tours increases by 50%. Nevertheless, the general feasibility of the cargo bike delivery concept is still given, since the maximum tour length does not exceed 3.3km.

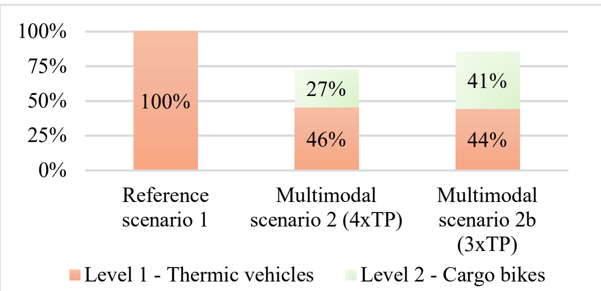

Figure 11: Normalized overall distance driven on different levels.

Figure 11 shows the overall distance driven on the different levels compared to the reference scenario. With the help of the simulation tool, the potential impact of a consequent use of cargo bikes for B2B last-mile deliveries has been calculated, quantifying a possible reduction of the kilometres driven by thermic vehicles of about 55%. This reduction in mileage can be explained by the significantly decreased number of tours from the UCC to the city centre caused by the increased capacity of the truck in use on this relation
The reduction would not only result in decreased local CO2-emissions and an improved air quality, but also in lowered traffic congestion.
The decreasing overall mileage indicates an economic viability of a 2-level multimodal logistics scheme, since driver wages can be assumed to slightly decrease as well because of the lower qualification level needed (Assmann & Behrendt, 2017). Nevertheless, further research on the cost of deployment and operation of transhipment points needs to be carried out for corroboration. The calculated reduction rate in mileage is similar to the one obtained while actually implementing a similar type of network during a pilot study in London, GB in 2010 (Leonardi et al. 2012).

5. CONCLUSION & FUTURE WORK

The use of cargo bikes for goods deliveries represents an interesting concept of urban logistics. Within this contribution, a simulation-based assessment tool for multimodal distribution schemes has been presented and applied to evaluate the use of cargo bikes in the case study of Grenoble city in France.
The presented simulation tool is able to simulate deliveries in multi-level networks in order to estimate network performance as well as environmental and economic impacts. Applied to the case study, the tool revealed the potentials inherent in a two-level multimodal logistics scheme for B2B goods deliveries in Grenoble city using cargo bikes for the last mile deliveries. Even though it is obvious that aiming at a fully consolidated and cargo bike-based last-mile delivery may not be realistic, the above presented case study shows the existing potentials to be exploited by a consequently oriented policy.
The results of the simulation are subject to several biases caused by simplifications, estimations and the simple heuristics used, leaving room for further improvements. Despite the imposed inaccuracies, the developed tool shows that simulation can provide substantial benefits for the assessment of complex multimodal distribution systems arising in urban logistics.

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