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Simplified scenario based simulation of parcel deliveries in urban areas using electric cargo cycles and urban consolidation centers.

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Abstract

Densely populated cities in Europe are getting more and more under political and juridical pressure because they fail in meeting EU directive 2008/50/EC, which obliges cities to reduce harmful externalities (NOx, SOx, PM etc.) caused by the transport sector. City administrations in England, Germany and France are even considering banning Diesel engines from city centers. Logistics could contribute to emission reductions by switching to other vehicles on the last mile. This paper proposes a simplified but very effective approach (SEAM) to simulate different delivery concepts by fulfilling parcel deliveries with cargo cycles instead of conventional vans. The number of parcels, the volume, the driving time, the contact time with the recipient, and size of the catchment area are considered. Five different delivery concepts considering urban consolidation center and speed deliveries are simulated with SEAM and economically and ecologically assessed.

Keywords: city logistics; urban consolidation center; cargo cycles; urban freight; courier services; express services; parcel services; speed deliveries.

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SIMPLIFIED SCENARIO BASED SIMULATION OF PARCEL DELIVERIES IN URBAN AREAS USING ELECTRIC CARGO CYCLES AND URBAN CONSOLIDATION CENTRES.

Introduction

Commercial transport –mainly Diesel driven- contributes about one third to urban transport emissions. After a transition time the EU directive 2008/50/EC, which obliges cities to reduce harmful externalities (NO_x, SO_x, CO, PM2.5 etc.) caused by the transport sector, must be met by the EU member states from 2015. Densely populated cities in Europe are under pressure due to failing in meeting the directive. Recently, first legal actions against city administrations (such as Stuttgart, Munich, and Düsseldorf) by organizations or citizens have been initiated (Stuttgarter Zeitung, 2015). The first court decisions oblige cities to more regulatory interventions. City administrations in England, Germany and France are considering more than ever banning Diesel engines from city centers. As a consequence, the parcel sector which heavily relies on Diesel-driven vehicles is seeking for viable solutions: full electric vehicles and electrically-assisted cargo cycles are solutions which have been piloted in recent years. The latter has the potential to reduce tailpipe emissions and CO2 from the drive train, increase safety, decrease congestion due to double parking, lower noise and improve quality of life in cities. Research on electric cargo cycles for last-mile deliveries investigates technological feasibility and acceptance (Gruber & Rudolph, 2016; Lenz & Riehle, 2013) economic viability (Maes & Vanelslander, 2012) or regulative framework and new concepts (Jacques Leonardi, 2014; Schliwa, Armitage, Aziz, Evans, & Rhoades, 2015).

The installation of urban consolidation centers (UCCs) constitutes a prerequisite for last-mile delivery concepts with cargo cycles. Even micro UCCs can be considered since space requirements for the transshipping on a cargo cycle are small. The feasible distance between UCC and distribution area is limited when using cargo cycles (Browne, Allen, & Leonardi, 2011; Dablanc, 2012) as the loading capacity constrains this distance. Long distances between distribution area and UCC would consume too much time when reloading the vehicle is necessary. UCCs can be defined as logistics facilities situated in close proximity to the geographic area that it serves (e.g. city area or a specific site) where goods from outside the city center are received, consolidated or transshipped and subsequently delivered by smaller vehicles or by foot (Allen, Browne, Woodburn, & Leonardi, 2012; Janjevic & Ndiaye, 2017; Nordtømme, Bjerkan, & Sund, 2015). UCCs are mainly supplied from a larger distribution center (DC) outside the city. Inner urban transshipments at UCCs in combination with small electric vehicle (SEV) such as cargo bicycles or tricycle for last-mile deliveries may have positive effects in terms of costs (Roca-Riu & Estrada, 2012) and vehicle kilometers travelled (VKT) (Verlinde, 2015). The specific potential on savings and reduced VKT must be evaluated for each case separately. Choubassi et al. (2015) investigate investments for cargo bicycles and tricycles for US postal delivery: they show that in different spatial settings tricycles are the most cost-effective transport mode for urban goods delivery in congested and densely populated areas, such as central business districts. Conway et al. (2012), Gevaers et al. (2014) and Diziain, Ripert, & Dablanc (2012) report significant reductions in CO_2 emissions and VKT by investigating first pilots. Nevertheless, economically viable UCCs without subsidies are hardly found in Europe (Janjevic & Ndiaye, 2017). One of the scarce examples working profitably can be found in Antwerp (Kin, Verlinde, van Lier, & Macharis, 2016). Also UPS is operating a profitable UCC with cargo cycles in downtown Hamburg (BWVI, 2015). TNT's mobile UCC based on a semi-trailer was ceased after the pilot due to missing revenue (Verlinde, Macharis, Milan, & Kin, 2014).

Parcel service providers are in the urge to find suitable and inexpensive space for their logistics activities. The installation of UCCs or even larger urban DCs at central locations is nearly undoable since such estates are hardly offered on the market. In consequence, the parcel service providers apply pressure to municipal authorities in order to receive subsidies or the possibility to rent publicly owned facilities. However, public interventions are only indicated, if the subsidized delivery concept generates net welfare gains by reducing external costs. Associated with this measure, public authorities must not violate the law of supporting a single party (or company) due to the general prohibition on state aid under Article 87(3)(a).

The increase of speed-delivery (SD) options provided by online retailers like Amazon requires urban DCs. In contrast to the traditional overnight delivery scheme (OND) SD is a special feature of same day delivery which promises deliveries within a one to two hour time span after an online order has been completed. Startups like *Liefery* or big players like *Amazon Prime Now* offer SD in cities like New York, Paris and Berlin for subscribers (Kirchhoff, 2016; zur Nedden, 2016). Such distribution systems require storage space and consolidation facilities within the city center limits or at least very close to them. The short time spans constraint to serving a very limited number of different recipients with one vehicle. Due to the advantage of cargo cycles bypassing congestion, these electrically-assisted vehicles seem well suited for SD.

In this paper we analyse economic aspects of different delivery concepts, their impact on vehicle kilometers travelled and the associated emissions with a simplified economic aspatial model (SEAM). This includes the financial viability for the private sector and the overall welfare effects, Apart from the possibility to investigate economic and environmental issues the model also enables assessing the necessary conditions fostering the one or the other delivery concept. Generally, the term "UCC" is used in this paper in the sense of a micro UCC. We investigate the following five concepts by using SEAM, which is explained in detail in section 2 (Table 1 presents the types of vehicles, which are considered):

Last-mile delivery concept with cargo cycles:

(1) ODN with UCC using a cargo tricycle,
(2) SD with UCC using a cargo bicycle.

Last-mile delivery concept with motorized vehicles:

(3) OND with DC using a delivery van,
(4) SD with DC using a small van,
(5) SD with UCC using a small van.

Table 1. types of vehicles

	Cargo tricycle	**Cargo bicycle**	**Delivery van**	**Small van**
Visual				
Width/length/height (approx.) [m]	1.0/1.2/1.5	0.5/0.8/0.5	1.2/3.3/1.8	1.1/1.8/1.2
Volume [m³]	1.5 – 2.0	0.16 – 0.28	7.5 – 8.5	2.0 – 2.4
Payload [kg]	150 – 350	100	800 – 1,300	500
Travel speed [km/h]	15	15	15	15
Brand example	Radkutsche Musketier, EVOLO Z2, Cycles Maximus, Cargo Cruiser	Harry vs. Larry E-Bullitt, Riese&Müller Load, urban arrow	Mercedes Benz Sprinter, Ford Transit, GM/Chevrolet Express, Workhorse	VW Caddy, Citroen Berlingo, Renault Kangoo, GM/Chevrolet City Express

Description of applied simplified economic aspatial model (SEAM)

In this section, the applied model (SEAM) is presented. Undoubtedly, a multi agent micro simulation (microscopic model) is a trustworthy approach to address mentioned issues (van Duin et al., 2012). However, a lots of personnel resources and reliable data about demand and supply, origin and destination, infrastructure networks, vehicles, and costs is require to set-up, update and maintain such models. In consequence, this reason often prevents decision makers (public or private) from exploiting such models for model-based decision making. Therefore, we developed SEAM which exhibits organizational, economic, and ecological aspects of different delivery concept.

Since the costs of a distribution system is mainly driven by the three activities *transshipment*, *spatial overcome* and *handling over*, a simplified and approximate model will constitute the basis for the cost calculations. The following subsection describes the different applied distribution concepts and how the transformation in an aspatial model is performed. In the end of this section, the applied cost model and its parameters are shown.

Specifications of the simplified distribution system

The basic assumption of the simplified distribution system is that customers (i.e. private households, businesses, etc.) are uniformly distributed over a homogeneously populated urban area. Similar to reality, distances between stops follow a mixture between the Manhattan distance and Euclidean distance.

The delivery activities start from a DC outside the urban area to be supplied. For the division of the urban area we distinguish two cases:

1. DC concept (Fig. 1(a): The whole urban area is served by the DC, i.e. the UCC is omitted.
2. UCC concept (Fig. 1(b): The urban area is subdivided into several catchment areas. Each catchment area is served by one UCC.

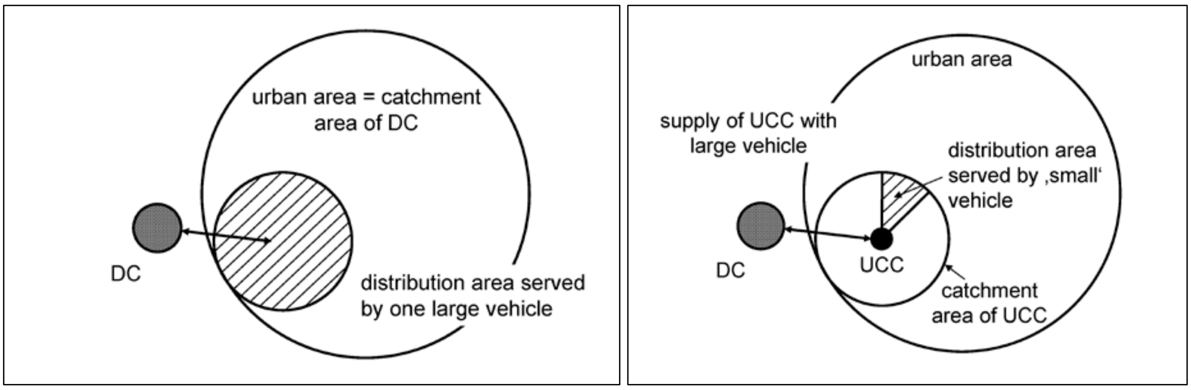

Fig. 1 (a) UCC concept; (b) DC concept

Each catchment area is divided into several distribution areas. Each distribution area is served by one vehicle. In all concepts the urban area has 400 km² and 100 parcels per square kilometer per day are delivered which results in 40,000 parcels are day. The operation time is twelve hours per day. Accordingly, the delivery tours of the vehicles can be subdivided into two types of trips: firstly, the trip between origin and delivery area and, secondly, trips between each stop at a customer where (at least) one parcel is handled over to the recipient.

Dependent on the delivery concept vehicles leave only once per day from the DC or return to the DC in order to pick up new parcels and restart tours. The number of tour starts (*waves*) from the UCC or DC, respectively– varies from 1 to 6. By using this wave concept, speed deliveries (SD) can be modelled, alongside the classic overnight delivery concept (OND).

Table 2. specifications of investigated delivery concepts

Delivery Concept	**1. Tricycle [UCC, OND]**	**2. Long John [UCC, SD, 6 waves]**	**3. Van [DC, OND]**	**4. Small van [DC, SD, 6 waves]**	**5. Small van [UCC, SD, 6 waves]**
catchment area of one UCC	33.3	33.3	400	400	33.3
No. of catchment areas	12	12	1	1	12
Parcels/day and catchment area	3,330	3,330	40,000	40,000	3,330
delivery waves	1	6	1	6	6
time to (re)fill vehicle [h]	0.2	0.08	0.5	0.15	0.15
capacity of vehicle [no. of parcels]	30	7	160	30	30
No. of stops/delivery wave	20	7	100[†]	8	14

The specifications of each delivery concept (Table 2) underlay the following assumption:

1. All concepts have identical size of urban area, operation time, and number of parcels per day.
2. The UCC concepts consider a 100% shift from OND to SD.
3. The fulfillment is performed by a parcel service provider.

[†] Gevaers et al., (2014) report 1 stop every five to eight minutes according to expert interviews. We assume a shift is usually approximately 9 hours. Therefore, we assume that 100 stops per tour are adequate.

Cargo cycle deliveries are usually carried out in distances from 0.5 km to 5 km around an UCC. We assume twelve catchment areas, each with a radius of about 33.3 km² to cover the whole urban area of about 400 km². Table 2 presents the specifications of the investigated delivery concepts.

Calculation of cost drivers

From the spatial setting mentioned above, it is possible to deduce the quantities of the cost drivers. Cost drivers are: (i) capital cost of vehicles, (ii) cost of UCCs, (iii) wages. Thus, it is necessary to determine the number of vehicles in utilization and the personnel hours of labor force. Both factors, however, are influenced by the length and duration of tours. The number of tours to fulfil the distribution task is determined by spatial, temporal and capacity constraints. Distances between stops and costs are calibrated using insights of microsimulations which were conducted by Zhang et al. (2017). Following rules are stated:

- Vehicles return to the UCC as soon as the last package is delivered.
- Vehicles return to the UCC and participate in the subsequent delivery wave (if applicable).
- The volume of cargo at the beginning of each tour is determined by the maximum capacity of the vehicle and by the number of deliveries within each wave.
- Idle time until the beginning of the subsequent wave is used for additional tours (multiple tours per wave are possible).
- The operation time is from 9am to 9pm.
- In cases of multiple waves, all shipments are distributed uniformly over these waves.
- Continuous approximation assumption: all model parameters are real numbers.

From these rules and from the logic to deduce the cost drivers, following central relationships can be deduced:

$$npack = \rho \cdot A/w \tag{1}$$

Where $npack$ is the number of packages to be delivered in one catchment area and one wave and A is the area of the catchment area. W is the number of waves per day and ρ represents the demand density [parcels per km^2] in this area.

$$dtrans = \sqrt{A}/2 \cdot 1{,}2 \tag{2}$$

Where $dtrans$ is the distance from the UCC to and from a delivery area.

$$dapp = 1/\sqrt{\rho/w} \cdot 1{,}2 \tag{3}$$

Where $dapp$ is the distance between two stops.

$$ttour = dtrans/v + cap \cdot dapp/v + cap \cdot tcont + tload \tag{4}$$

Where $ttour$ represents the tour duration [h], $tcont$ is the time per customer contact [h], $tload$ is the loading time [h] to load the vehicle whether in a DC or in a UCC. Cap is the capacity of a vehicle [no. of parcels per vehicle] and v describes the travel speed [km/h] within the urban area.

In cases of capacity constrained tours, multiple tours are possible, and the number of vehicles per catchment area is calculated as follows:

$$nvec = npack/cap/twave \cdot ttour \tag{5}$$

Where $nvec$ contains the number of required vehicles and $twave$ is the wave duration [h]. In cases of time constrained tours (i.e. the factor 'time' constrains the number of parcels being delivered, not the factor 'load capacity') the utilized load capacity is calculated by solving following relationship:

$$ttour - tload - dtrans/v = rcap\ \cdot (dapp/v + tcont) \tag{6}$$

Where $rcap$ is the reduced vehicle capacity. The number of vehicles per catchment area is:

$$nvec = npack/rcap \tag{7}$$

Due to high stop density and urban road congestion, we assumed no travel speed advantage of (small) vans in comparison to cargo cycles. A detour factor is introduced in order to simulate real routing since the aspatial model would only consider direct point to point connections. The detour factor takes into account that bicycle are able to bypass congestion, cross also parks and greeneries and use some one-way-roads in both directions. Therefore, the detour factor is higher for motorized vehicles than for cargo cycles.

Unit costs

Table 2 documents the cost calculation. The capital cost per cargo bicycle is €4/day, per cargo tricycle €10/day, for a small van €24/day, and for a delivery van around €48/day (Gabler, Schröder, Friedrich, & Liedtke, 2013). The average cost for a blue collar logistics driver including taxes, insurances etc. accumulates to €20/h for the parcel service provider in Germany. Assumptions and parameters for the calculation are based on interviews with practitioners conducted in the run of several research projects, and presented in Table 4 (Appendix). The cost for an UCC with a one-wave delivery concept is around €1,010 per day. And, a six-wave delivery concept costs around €3,050 per day. The results are shown in following Table 3.

Table 3. cost drivers and cost calculation

Delivery Concept	**1. Tricycle [UCC, OND]**	**2. Long John [UCC, SD, 6 waves]**	**3. Van [DC, OND]**	**4. Small van [DC, SD, 6 waves]**	**5. Small van [UCC, SD, 6 waves]**
Travel speed [km/h]	15	15	15	15	15
Stop duration (parking and handling over parcel) [min]	3	3	6	6	6
Detour factor	1.2	1.2	1.4	1.4	1.4
Capital cost per vehicle and day [€]	12	4	48	24	24
Energy cost per km [€]	0.1	0.1	0.28	0.14	0.14
Duration of delivery wave [h]	12	2	12	2	2
Distance (to and fro) between DC and distribution area [km]	4.2	4.2	16.8	16.8	4.8
Journey time (to and fro) between DC and distribution area [h]	0.28	0.28	1.12	1.12	0.32
Distance between stops [km]	0.12	0.29	0.14	0.34	0.34
Travel time between stops plus stop duration [h]	0.06	0.07	0.11	0.12	0.12
No. of trips per delivery wave *[cap_constraint]*	167	79	400	833	40
Time per tour *[cap_constraint]*	1.94	0.92	12.55	2.30	2.24
multiple tours per delivery wave *[cap_constraint]*	6.19	2.18	1.00	1.00	1,00
Degree of capacity utilization	1	1	1.00	0.90	0.98
No. of vehicles regarding catchment area *[cap_constraint]*	27	36	402	931	41
Vehicle kilometers travelled per tour *[cap_constraint]*	6.6	6.3	30.7	19.3	9.5
Vehicle kilometers travelled regarding catchment area	1,099	2,977	12,353	107,539	2,311
No. of vehicles regarding urban area	323	437	402	931	488

Results

1.1. Costs and vehicle kilometers travelled

Figure 2 presents the results of the model calculations. First of all, the results show that the classic OND concept (1) with €2.98 per delivered parcel and (3) with €2.04 per delivered parcel is the most efficient concept under given assumptions. In this case cargo tricycles (3) beat traditional vans (1). This result holds for a densely populated area with a dense concentration of businesses. SD concepts depend pretty much on the vehicle which

is in use and whether a UCC can be used or not. Here, the most economical solution is again a concept with cargo cycles (concept (4): €3.47 per parcel), followed by concept (5) using small vans and UCCs (€4.23 per parcel). The most expensive concept (2) with cost of €6.52 per parcel uses utility vehicles for SD from a DC.
In all concepts, labour cost represents by far the largest fraction of the total costs. Vehicle and fuel cost are less relevant. The installation and operation of a UCC is the 2nd largest cost position. But it should be noted that UCC cost is more driven by the cost for the goods transport (driver, truck, fuel) from the DC to the UCC than by the cost of the facility itself. A sensitivity analysis by doubling all assumptions for cycles and motorized vehicles separately proofed the robustness of the model: the cost order of the concepts does not change.

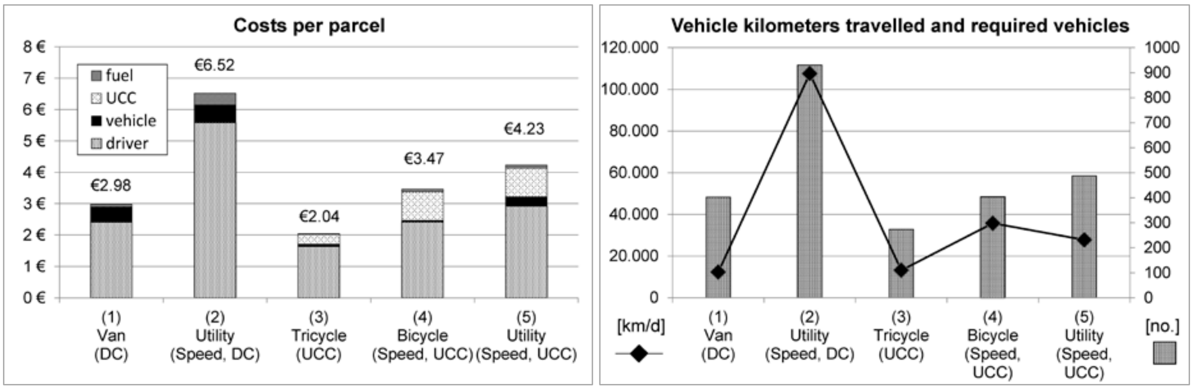

Fig. 2 (a) costs per parcel for each delivery concept; (b) VKT for each delivery concept

Concept (2) means a tremendous increase of required vehicles, personnel, and VKT as in figure 2 (b) is shown. The amount of VKT in comparison to the other SD option with motorized vehicles (5) even triples, although the concept considers a very close DC to the city limits. The least amount of VKT can be achieved in OND concepts (1) -12,353 km- and (3) -13,200 km- while concept (3) involves a smaller number (273) of vehicles than concept (1) with 402 vehicles.

1.2. Emissions

Appendix A.3 presents the emissions (tailpipe and CO2) for each concept according to VKT (Fig. 2 (b)) calculated with SEAM. The emission factors are based on the Handbook of Emission Factors for Road Transport (HBEFA) (Hausberger, Rexeis, Kühlwein, & Luz, 2014). The basic assumptions for the emission factors are given in Appendix A.2. For SD concepts the emissions for the UCC supply are considered. The assumption is that one trailer truck can serve two UCC in one wave and drives approx. 50 km per wave. In terms of emissions, the cheapest concept (1) is also the most environmental-friendly concept. The supply of an UCC in six waves –in contrast- results in a lot more emissions. Also in terms of emissions concept (2) is by far the worst concept.

Implications

In this paper an effective way of simulating different parcel delivery concepts is presented. With a simple MS-Excel-based economic aspatial model (SEAM) multiple issues can be addressed:

(1) Economic assessment of different parcel distribution concepts, i.e. SD and the use of cargo cycles;
(2) Ecologic assessment in terms of VKT and amount of tailpipe emissions and CO2;
(3) Assessment of regulative conditions influencing (1) and (2).

The calculations show that SD with cargo cycles is possible – technologically and economically. The model calculations proof the profitability of SD concepts using cargo cycles in combination with UCC. Under the given assumptions, the concept is even more cost effective than a classic OND concept (1) with DC and delivery vans. Due to the possibility to drive and park very close to the recipient's door (e.g. on the sidewalk), parking plus walking to the recipients' building requires less time. This fact has a major impact, since labor cost figures generally the largest cost fraction of the overall parcel delivery cost. Furthermore, in reality most of the DCs may be located rather farer away from the distribution area as assumed, which means, that VKT may be remarkable higher as represented. Admittedly, the cost for renting an UCC is very low as long as the parcel service provider can rent public space from the city for setting up a container (swapping body), as UPS does in Hamburg. If the parcel service provider is forced to use an unsubsidised proper logistics facility (private space) costs for rent and transloading parcels would probably increase. Dependent on the price to rent the space, the project may be profitable or not. Nevertheless, the UCC has to be installed in a very densely populated area or in an area with a high density of businesses.

The conducted calculations consider free flow for cargo cycles since bypassing congestion is possible by e.g. using bicycle infrastructure. Even shortcuts through parks can be realized. The cost advantage in highly congested areas would even increase in comparison to all concepts using motorized vehicles. We also investigated only cases using one transport mode for the whole area. Concepts using multiple transport modes for different areas seem more likely.

The results also show that by following concept (4) a parcel service provider could offer SD in waves of only two hours for only €0.49 more per parcel in comparison to concept (1). The number of drivers is nearly equal. VKT triples but due to the fact that the ecological impact of electrically-assisted cargo cycles is marginal, the concept should be preferred. It also offers higher comfort for the customer. The model also proofs that SD with large cargo tricycles may not necessarily be more cost effective than using smaller, more agile cargo bicycles: the constraints are, firstly, the time handling over parcels to recipients, and secondly, the time overcoming longer distances between recipients. OND should be carried out with tricycles and UCC (3) since environmental impact is smallest and for the companies the concept is the most cost effective concept off all. By offering SD according to concept (4) a parcel service provider can realize a unique selling point (advantage against competitors) without increasing the parcel price for the customer. But, the framework and regulative conditions have to be adjusted to each use case. In cases, where space cannot be rented from the city for an UCC, the viability of the concepts needs to be reassessed. Probably, such simple set-ups using a container in the city center on public space won’t be accepted at larger scales by the authorities.

The comparison between a SD concept using a UCC and cargo cycles with a UCC and small vans leads to a critical aspect: since vehicle and fuel costs are such low in comparison to labor costs, concept (5) can also be realized under an acceptable surplus of costs in contrast to concept (4). The concept requires triple as much VKT, than concept (1) which means triple as much tailpipe emissions and CO2. This concept should be avoided for ecological reasons as well as from transport-related reasons. The calculations show that SD options should only be conducted by cycles or electric vehicles, where cargo cycles are definitely preferred due to their little impact on traffic and environment.

The presented cost calculation may totally change as soon as deliveries can be performed driverless (autonomous or automated) favoring electric delivery vans. This development will tremendously decrease delivery costs as labor cost has the largest share of parcel delivery costs. If technological and legal hurdles have been overcome and the ‘handing over’ process can be conducted fully automated, too, the investigated delivery concepts must be reassessed against driverless delivery concepts. Constantly driving vehicles may have a negative impact on overall VKT conducted for parcel deliveries, but has to be investigated in future research.

On the one hand SEAM is a robust easy-to-use aspatial model to assess different delivery concepts. On the other hand further delivery alternatives e.g. the option receiving parcels in a very narrow time frame cannot be simulated with this model since such an assessment would require spatial and time accurate demand. The trend offering this delivery option can be observed amongst all parcel providers. Only by using a microscopic simulation model, such an assessment could be carried out. Another limitation of the current model is the inability to simulate a larger urban distribution center. There is a lack of reliably information about operation costs of such a facility.

We are convinced that cargo cycles will be economically viable where areas are hard to access with motorized vehicles or where access restrictions are local policies. Also, in heavily congested areas cargo cycles offer a reliable and viable alternative – even to electric delivery vans. A reliable delivery time is a prerequisite for SD. In consequence, the use of cargo cycles may increase when parcel providers want to increase their portfolio of SD option and/or available articles (increase of SD market share). Cargo cycles could also be an option for delivering businesses in pedestrian precincts all day long. But this requires access exemptions only for cargo cycles, which must be discussed with local authorities. Everywhere, where these conditions are not given, probably electric vans will continue to dominate over electric cargo cycles.

Appendix

A.1. Assumptions and parameters for the cost calculation of a UCC

Delivery Concept	UCC [overnight, 1 wave]	UCC [speed delivery, 6 waves]
no. of delivery waves	1	6
costs for truck/swap body per day [€]	100	100
no. of trucks	6	6
costs for all trucks per day [€]	600	600
costs for driver per hour [€]	20	20
no. of manoeuvring hours per truck	2	12
costs per driver per day and track [€]	40	240
costs for all drivers per day [€]	240	1,440
fuel costs per wave per truck (50km/wave; 1,4 €/l; 40l/100km) [€]	28	28
fuel costs per truck and day regarding no. waves [€]	28	168
fuel cost for all trucks per day [€]	168	1,008
rent for public space for UCC (35 m² á €1/m²/month) [€]	2	2
Total costs for UCC [€]	**1,010**	**3,050**

A.2. Emission factors based on HBEFA (Hausberger et al., 2014)

Emission factors [g/km]	Type of vehicle	CO	NOx	PM	CO2
Light duty vehicle	N1-3 (<3.5t)	0.00029	0.55187	0.001	146.61589
Heavy duty vehicle	Solo (>20-26t)	1.48114	4.14875	0.0423	631.24261
Heavy duty vehicle	Semi (>34-40t)	1.74481	4.12078	0.0488	783.34320
Small Van/ Passenger car	Ø Diesel	0.03804	0.63930	0.0091	124.17002

A.3. Tailpipe emissions and CO2 for each delivery concept

Delivery concept	VKT [km]	Delivery Vehicle	VKT [km] (UCC supply)	Vehicle (UCC supply)	CO [kg]	NO [kg]x	PM [g]	CO2 [kg]
(1)	12,353	LDV [N1-3]	0	-	0.004	6.8	12	1,811
(2)	107,539	Small van	0	-	4.11	68,8	977	13,353
(3)	13,200	-	300	HDV [>34-40t]	0.5	1,2	15	235
(4)	35,758	-	1,800	HDV [>34-40t]	3.1	7,4	88	1,410
(5)	27,759	Small van	1,800	HDV [>34-40t]	4,2	25,2	340	4,857

*LDV = Light duty vehicle, **HDV = Heavy duty vehicle

References

Allen, J., Browne, M., Woodburn, A., & Leonardi, J. (2012). The Role of Urban Consolidation Centres in Sustainable Freight Transport. *Transport Reviews, 32*(4), 473-490. doi:10.1080/01441647.2012.688074

Browne, M., Allen, J., & Leonardi, J. (2011). Evaluating the use of an urban consolidation centre and electric vehicles in central London. *IATSS Research, 35*(1), 1-6. doi:http://dx.doi.org/10.1016/j.iatssr.2011.06.002

Conway, A., Fatisson, P.-E., Eickemeyer, P., Cheng, J., & Peters, D. (2012). *Urban micro-consolidation and last mile goods delivery by freight-tricycle in Manhattan: Opportunities and challenges*. Paper presented at the Conference proceedings, Transportation Research Board 91st Annual Meeting.

Dablanc, L. (2012). City logistics. *The International Encyclopedia of Geography*.

Diziain, D., Ripert, C., & Dablanc, L. (2012). How can we Bring Logistics Back into Cities? The Case of Paris Metropolitan Area. *Procedia - Social and Behavioral Sciences, 39*, 267-281. doi:http://dx.doi.org/10.1016/j.sbspro.2012.03.107

Gabler, M., Schröder, S., Friedrich, H., & Liedtke, G. (2013). Generierung der Nachfragestrukturen für die mikroskopische Simulation des städtischen Distributionsverkehrs im Lebensmittelhandel. In U. T. Clausen, C. (Ed.), *Wirtschaftsverkehr 2013* (pp. from p. 32). Berlin Heidelberg Springer Verlag

Gevaers, R., Van de Voorde, E., & Vanelslander, T. (2014). Cost Modelling and Simulation of Last-mile Characteristics in an Innovative B2C Supply Chain Environment with Implications on Urban Areas and Cities. *Procedia - Social and Behavioral Sciences, 125*(Supplement C), 398-411. doi:https://doi.org/10.1016/j.sbspro.2014.01.1483

Gruber, J., & Rudolph, C. (2016). Untersuchung des Einsatzes von Fahrrädern im Wirtschaftsverkehr (WIV-RAD).

Hausberger, S., Rexeis, M., Kühlwein, J., & Luz, R. (2014). HBEFA 3.2: Update of Emission Factors for EURO 5 and EURO 6 vehicles for the HBEFA Version 3.2. download: http://www.hbefa.net/d/documents/HBEFA32_EF_Euro_5_6_TUG.pdf.

Jacques Leonardi, M. B., Julian Allen, Simon Bohne, Martin Ruesch (2014). Best Practice Factory for Freight Transport in Europe: Demonstrating how 'Good' Urban Freight Cases are Improving Business Profit and Public Sectors Benefits. *Procedia - Social and Behavioral Sciences, 125*, 84-98. doi:https://doi.org/10.1016/j.sbspro.2014.01.1458

Janjevic, M., & Ndiaye, A. (2017). Investigating the financial viability of urban consolidation centre projects. *Research in Transportation Business & Management*. doi:http://dx.doi.org/10.1016/j.rtbm.2017.05.001

Kin, B., Verlinde, S., van Lier, T., & Macharis, C. (2016). Is there Life After Subsidy for an Urban Consolidation Centre? An Investigation of the Total Costs and Benefits of a Privately-initiated Concept. *Transportation Research Procedia, 12*, 357-369. doi:http://dx.doi.org/10.1016/j.trpro.2016.02.072

Kirchhoff, P. (2016). Warten war gestern. *FAZ*. Retrieved from http://www.faz.net/aktuell/rhein-main/liefer-start-up-auf-ware-warten-war-gestern-14115844.html (09/20/2017)

Lenz, B., & Riehle, E. (2013). Bikes for urban freight? Experience in Europe. *Transportation Research Record: Journal of the Transportation Research Board*(2379), 39-45.

Maes, J., & Vanelslander, T. (2012). The Use of Bicycle Messengers in the Logistics Chain, Concepts Further Revised. *Procedia - Social and Behavioral Sciences, 39*, 409-423. doi:http://dx.doi.org/10.1016/j.sbspro.2012.03.118

Nordtømme, M. E., Bjerkan, K. Y., & Sund, A. B. (2015). Barriers to urban freight policy implementation: The case of urban consolidation center in Oslo. *Transport Policy, 44*, 179-186. doi:http://dx.doi.org/10.1016/j.tranpol.2015.08.005

Roca-Riu, M., & Estrada, M. (2012). An Evaluation of Urban Consolidation Centers Through Logistics Systems Analysis in Circumstances Where Companies have Equal Market Shares. *Procedia - Social and Behavioral Sciences, 39*(Supplement C), 796-806. doi:https://doi.org/10.1016/j.sbspro.2012.03.148

Schliwa, G., Armitage, R., Aziz, S., Evans, J., & Rhoades, J. (2015). Sustainable city logistics — Making cargo cycles viable for urban freight transport. *Research in Transportation Business & Management, 15*, 50-57. doi:http://dx.doi.org/10.1016/j.rtbm.2015.02.001

Stuttgarter Zeitung. (2015). Stuttgarter Zeitung (2015). Feinstaub in Stuttgart. Bürger klagen gegen zu hohe Schadstoffwerte; Stuttgarter Zeitung. Retrieved 02/22/2015; on: http://www.stuttgarter-zeitung.de/inhalt.feinstaub-in-stuttgart-buerger-klagen-gegen-zu-hohe-schadstoffwerte.a58aba1f-e02b-482b-bd4b-b8a2b4bfa9a3.html.

Verlinde, S. (2015). Promising but challenging urban freight transport solutions: freight flow consolidation and off-hour deliveries. *PhD diss., Vrije Universiteit Brussel and Universiteit Gent*.

Verlinde, S., Macharis, C., Milan, L., & Kin, B. (2014). Does a Mobile Depot Make Urban Deliveries Faster, More Sustainable and More Economically Viable: Results of a Pilot Test in Brussels. *Transportation Research Procedia, 4*, 361-373. doi:http://dx.doi.org/10.1016/j.trpro.2014.11.027

zur Nedden, C. (2016, 05/11/2015). Test: Hält Amazon Prime Now das Versprechen „Lieferung in 60 Minuten"? *wired.de*. Retrieved from https://www.wired.de/collection/business/amazon-prime-now-wired-testet-die-neue-1-stunden-lieferung-berlin (09/20/2017)

Zhang, L., Matteis, T., Thaller, C., Liedtke, G. (2017). Simulation-based Assessment of Cargo Bicycles in Urban Parcel Distribution. Annual meeting of the Transportation Research Board in Washington DC. (Accepted for presentation).