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Real time Learning with Light Electric Freight vehicles for urban freight distribution

A living lab approach

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Abstract

Due to population growth in cities the demand for the transport is rising and therefore a growth of transport movements by trucks and vans can be observed. These movements have a negative effect on air quality, liveability, noise and safety. LEFVs (Light Electric Freight Vehicles) can be a good solution for last mile deliveries. Today one can observe a lot of enthusiasm for these types of vehicles. At the same time also the number of LEFV suppliers is rapidly growing. However, many companies are still reluctant to initiate their business with LEFVs. To overcome this problem new knowledge needs to be developed how to use LEFVs in city logistics concepts. This paper presents the real-life experiences with a living lab for urban freight distribution based on LEFVs.

Introduction

UNESCO (2019) states that about 55% of the world's population lives in urban areas. This proportion is expected to increase to 75% by 2050 (UNESCO, 2019). Due to this growth commercial establishments, commuters, residents and tourists demand more goods in the cities. Furthermore, it leads to more employment, more businesses and a growth of supporting services such as waste collection. Obviously more space for logistics activities is needed. In their search of space the logistics real estate is pushed out of the city, i.e. logistics sprawl. (Dablanc, 2011).

More and more logistics service providers are confronted with the consequences of mobility and accessibility problems that occur around major cities. Also, the cities and municipalities are increasingly struggling with congestion problems due to an increase in last mile deliveries, deterioration of air quality and the accessibility of city centres. Moreover, most cities (in the Netherlands) have set their targets towards zero emissions by the year 2025/2030 as an ambitious answer to the Paris Climate agreement (GreenDealZes, 2019).

To cover problems of fast delivery, clean delivery (low/zero-emission) and less space in dense cities the Light Electric Freight Vehicle (LEFV) can be the answer for an innovative solution. This is in line with the UN Headquarters by saying that '*fresh new ideas can transform the ways we live, and innovation can be simple indigenous ideas, or complex frontier technology*'.

According to Nestrova and Quak (2016) realising a transition in the field of city logistics is extremely difficult. Many experiments and tests have been executed, still major transitions are lacking. Due to the involvement of many different stakeholders without having one single problem-owner the nature of city logistics issues is quite complex to solve (van Duin, 2012). Simple solutions brought forward by a single stakeholder seldom provide a sufficient answer to tackle city logistics' challenges. Therefore a new approach of Living Lab is applied in this research as a way to increase the Joint Knowledge Production (Hegger et al., 2012) in the city logistics system and at the same time a way to increase the Shared Situation Awareness (Kurapati et al., 2012) to the highest level for all the actors involved. In the literature of Light Electric Freight Vehicles (LEFVs) this approach has been seldom applied in practice. The learning experiences are unique as they are based on real-life experiments. Another interesting aspect of a Living Lab is the educational embedding in a minor course. During a period of a half year the students are operating a city hub as their own company. This implies that they experience the last mile delivery from reception of the goods to the final delivery of the products to the shopkeepers in the inner-city. The students are operating as 'running researchers' as they observe, measure and evaluate different types of delivery systems based on light electric freight vehicles. As a part of the Living Lab the stakeholders, (i.e. the logistics service provider, the shopkeepers and the municipality) can experience the effects of this new way of last mile delivery. In this Living Lab experiment the following research question is raised:

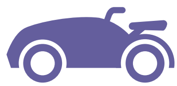
How can the last mile delivery of a logistics service provider be executed without any emission in such a way that customer service to shopkeepers is maintained and the operational cost can be reduced?

To answer the research question this paper has the following structure. After this introduction section 2 gives the definition of light electric freight vehicles, followed by a brief literature review on the evaluation of light electric freight vehicles in urban distribution concepts. Section 3 contains a description of the Living Lab in terms of stakeholders and vehicles used. Section 4 provides benchmarking results between traditional delivery and delivery with LEFVs. The paper ends with the conclusions from the Living Lab setting.

State of the art of LEFV evaluation studies

Before starting the literature survey it is good to define the types of vehicles that belong to the group of light electric freight vehicles (LEFVs). A light electric freight vehicle is a bike, a moped or a compact vehicle with electric support or drive mechanism, equipped for the distribution of urban freight goods with limited speed. In general the LEFVs are (very) quiet, flexible in usage, emission-free, and need less space than conventional delivery vehicles (Balm et al. 2018). Three types of LEFVs are defined (see Table 1):

Table 1 Three types of LEFVs (Balm et al., 2018)

	Electric cargo bike	Electric cargo moped	Small electric distribution vehicle
Loading capacity	50 – 350 (kg)	100 – 599 (kg)	200 – 750 (kg)
Vehicle weight	20 – 170 (kg)	50 – 600 (kg)	300 – 1000 (kg)
			

The electric cargo bike looks the most as real bike and therefore agile with a payload 350 kilograms at maximum. The bikes are suitable for small volumes such as food delivery, mail and parcel delivery services.

The electric cargo moped is really a moped which means that cycling is not needed. The maximum payload is 500 kilograms. Small amounts of construction materials and more heavier loads (like a keg of beer) can be delivered with this vehicle.

The small electric distribution vehicle looks most like a mini-van. The vehicle has a maximum payload of 750 kg. The vehicle is most often used for retail and residential streams such as waste collection, street cleaning and catering services. Manoeuvring and parking are much easier in dense city areas compared to a van. However, it is less agile compared to the bike and the moped.

While the supply of different types of LEFVs has increased and also the performances of the LEFVs in terms of loading capacity, action radius and ease of usage have increased, many companies are still hesitative to make the switch to use the LEFVs. Fleet decision makers and city logistics operators show serious doubts about using LEFVs, as there are still many small engineering companies optimizing the design of the LEFVs instead of providing a full professional service of the LEFVs.

In the scientific literature only a few successful cases for LEFVs have been found (Schliwa et al. 2015; Lenz & Riehle, 2013). Simulation approaches and ex-ante analyses (Melo & Baptista, 2017; Gruber et al., 2014; Tipagornwong et al. 2014; Arnold et al. 2018; Zang et al., 2018; Gruber & Naryanan, 2019; Sheth et al., 2019) are the most common approaches. Fiori & Marzano (2018) developed an EFVs energy consumption model. The estimated model was validated by collecting real-world data of 144 observed trips for pickup/delivery with five EFVs operating in the city of Rome. The only real case in literature was carried out by Browne et al. (2011). They performed an in depth case study of Gnewt Cargo in London. The trial was proven successful from company's perspective in transport, as well in environmental and financial terms as the total distance travelled and the CO_2 emissions per parcel delivered dropped by 14% and 55% as a result of the LEFV usage. In the end of the project they decided to continue the delivery operations with the LEFVs.

In the scientific literature it can be concluded that the literature on ex-post-analysis based on real cases with LEFVs usage is rather limited. In 2018 Balm et al. (2018) investigated for which types of goods the LEFVs are most promising within the framework of city logistics. Four crucial criteria have been identified for LEFV usage: small and light shipments, high network density, time-critical shipments and sufficient opportunities for growth and innovation. In line with these findings they came up with the sectors mail, parcel and local retail deliveries, and smaller shipments in food, construction and service logistics that meet all the criteria. Moolenburgh et al. (2019) performed case-based research. Several experiments were set up in different towns in the Netherlands to test and collect knowledge. Stakeholder consultation was done to obtain the feedback of the LEFV usage. Also the LEFVs were monitored with GPS loggers and cameras to obtain the real-life measurement. Ten business companies volunteered to join these experiments in order to experience the usage of LEFVs. In the academic literature it can be concluded that no Living Lab with LEFV initiatives are found.

Still, in the grey literature (professionals) some Living Lab initiatives with cargo bikes have been found, which are mentioned hereafter.

The first Living Laboratory initiative funded by the EU was Cyclelogistics (2014). The initiative strived to bring the topic and potential of the use of freight bicycles under the attention to stakeholders in the logistics service sector and government. The project tried to encourage logistics service providers to use their bicycles for the transportation of heavier goods. Several European cities participated in the project. TRE Lab (2019) is another project which was testing the potential of cargo bikes in Rome in high congested areas of Rome. The approach in this project followed the Living Lab methodology. The main partners were the logistics provider UPS and the department for transport of the city of Rome. In the Living Lab they developed the best logistics concepts with LEFVs, experimented and evaluated the performance. In the end they investigated the scalability of the concepts to other areas (Trelab, 2019). Although these Living Lab initiatives have provided new knowledge and experiences with LEFVs, no scientific publications have appeared yet.

Living Lab HRCargo

The Living Lab approach forms a practice-based methodology for evaluating new solutions in the city logistics sector. To understand the full added value of a new solution in city logistics the evaluation must be done with representatives from all stakeholders. The living Lab methodology has it basement in the multi-stakeholder commitment in the project although each stakeholder can have its own stakes. In a controlled environment the stakeholders are heavily involved by providing them performance measurements and asked them about their opinions on these performances. Also different experiments can be realised in a short time, which provide new insights for all stakeholders (Nestrova & Quak, 2016). Our Living Lab is called HRCargo as a conjunction of HR (Hogeschool Rotterdam) and the logistics service provider (Ned)cargo.

Stakeholders

In our case the following stakeholders have themselves committed to the Lab: a logistics service provider (Nedcargo), a hub owner (GroenCollect), a LEFV rental service (Dockr), a software developer of (bike)tour optimisation (Routigo), the municipality, shopkeepers (clients of Nedcargo) and Rotterdam University of Applied sciences (Hogeschool Rotterdam (HR))

Nedcargo

Nedcargo is a big logistics service provider in the Netherlands. They are specialised in freight forwarding and logistics (mainly food and beverages). Nedcargo supplies their customers in city centres by lorries. Nedcargo wants to prepare itself for the future goals set by the municipality to deliver with zero emissions. They want to learn from the experiences with the new delivery method by LEFVs. For Nedcargo the important question arises whether they should implement the new delivery method themselves or should they outsource it to an external partner. To determine the success of the new concept Nedcargo has specific interest in the operational costs, the accessibility and traffic flow in the area, the reduction of emissions and the customer satisfaction. Besides Nedcargo wants to profile themselves as an interesting company where students would like to work and to show their customers that they are working on future challenges.

Municipality Rotterdam

The aim of the municipality is to make Rotterdam a more liveable and sustainable city. Therefore the municipality is very interested in projects that influence the development of a future-proof city. The delivery concept by means of sustainable freight vehicles such as LEFVs can ensure improvements of accessibility and traffic flows. Besides zero emission of the LEFVs the delivery method could lead also to improvement of the traffic safety in the city, meanwhile making the city more attractive for new businesses and residents.

Furthermore, it can be said that the municipality of Rotterdam has a high influence on projects related to electrical city distribution. They are able to directly influence distribution in the city by setting legislation. In the Living Lab they can experiment with the legislation.

Shopkeepers

The most important interest of the customers is that they are delivered at the right time, the right quantity and in good condition according to the agreements. As long as the delivery agreements are met by Nedcargo, customers will remain satisfied. In addition, customer satisfaction could increase when the customers are supplied by sustainable means of transport.

Rotterdam University of Applied Sciences

The students from the RUAS run the logistics operations from a city hub by delivering the goods to Nedcargo's clients in the city centre of Rotterdam by using different types of LEFVs. In this way they are able to make a good assessment of the different vehicles by gathering all data of their operations. The assessment is executed on efficiency, costs, sustainability and customer satisfaction. The assessment is also applied as a benchmark to compare to the regular truck delivery operations. Beside the theoretical analyses the students can experience the real practical logistics operations with the LEFVs.

Types of LEFVs

In the current situation Nedcargo supplies the city centre of Rotterdam with a truck, i.e. the Volvo FM 330 with a euro 6 engine. Customer deliveries start from the distribution centre in Waddinxveen where the truck is driven by one driver to the customers in Rotterdam. In the new situation the truck will drive to the consolidation centre in M4H area in Rotterdam, and from there the LEFVs will start their routes to the final customers.

TukTuk

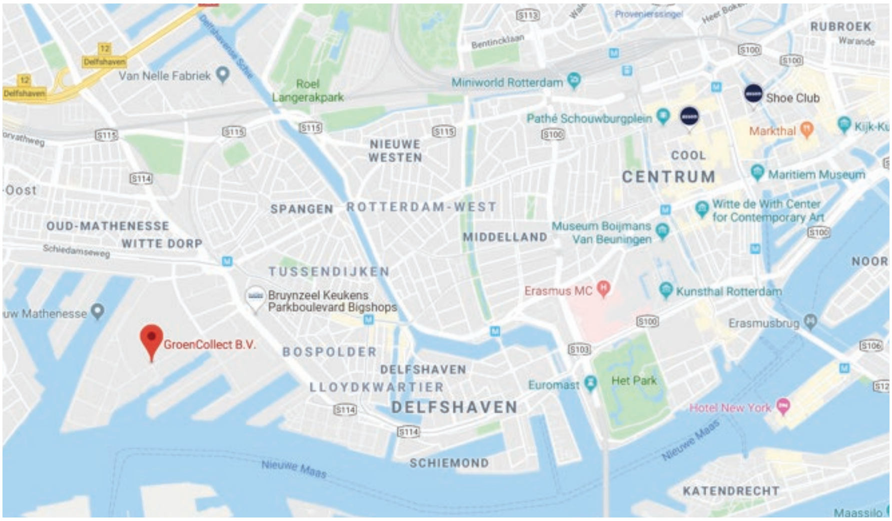
A TukTuk is a three-wheeled vehicle, also known as a trike (TukTuk, 2019), which is a synonym for tricycle, i.e. a vehicle with three wheels (see Figure 1, left vehicle). Such a tricycle falls under the category of special vehicles and therefore certain requirements are needed to use this special vehicle. Incidentally, a moped car, mobility scooter, scooter and quad fall under the category of special vehicles (Special vehicles, 2019). For this type of TukTuk the same traffic rules apply as for a passenger car. To drive a TukTuk, the driver must be at least 18 years of age and also be in possession of a valid driving license. The TukTuk has a loading capacity of approximately 200 to 250 kgs and a volume of 1,000 litres. It has an action radius of 60 kilometres. The recharging time takes between 6-8 hours. The maximum speed is 45 kilometres per hour.

E-cargo Bike L

The E-cargo Bike L is an electric cargo bike that has several purposes. There are versions for people with children in the form of a Family and a Shorty version, but also a Cargo and Tender version is available to deliver goods. The E-cargo Bike L has a maximum load capacity of 200 kgs and a volume of 1,000 litres. It has an action radius of 70 kilometres and recharging time of 5 hours. The maximum speed is 25 kilometres/hour. Figure 1 (right vehicle) shows the E-cargo Bike L Cargo version.

Living Lab HRCargo with the TukTuk *(left)* and the E-cargo Bike L *(right)*.

Location of the UCC and demand data



Location of the urban consolidation centre (GroenCollect B.V.)

The distance from the warehouse in Waddinxveen to the UCC (GroenCollect) in Rotterdam is 45.6 kilometres vice versa (Google Maps, 2019). Execution of the first measurements took place in the period September-October 2019. The following demand needs to be delivered in the city centre:

Table 1 Demand in the city centre

Customer	# Colli
Customer1	2827
Customer2	2894
Customer3	2381
Customer4	2256
Customer5	4288
Customer6	1983
Customer7	1417
Customer8	1959
Customer9	2076
Customer10	1805

These customers represent 57% of the total volume (colli). The data for the traditional delivery are derived from as set of 314 orders. To obtain a detailed insight 12 orders of the traditional way of delivery are randomly selected from this set. It takes too much time to analyse more trips from the databases of the logistics service provider (as many times the information wanted is incomplete, for instance registration on being on time). The subset selection of trips, however, have been proven to be representative for the traditional way of delivery. The data collection for the LEFVs took place from the beginning of September 2019 until half October 2019.

Benchmarking results between traditional delivery and delivery with LEFVs

Based on the stakeholder analysis the following performance indicators are defined to make the comparison between the traditional way of delivery by truck and the new way of delivery by LEFVs: trip performance, operational logistics performance, logistics cost, environmental cost and other learning experiences.

General trip performances

Based on the sample set the logistics service provider delivered with a truck 186.6 km in the inner-city and 547.2 km were driven outside the inner-city (based on 12 trips). It is noticeable that most kilometres are driven to and from the distribution centre in Waddinxveen.

Table 2 Performances of the trips realised

Transport Indicator	Traditional Delivery (sample)	E-cargo Bike L	TukTuk	Total LEFVs
Number of trips	12	25	45	70
Number of stops	39	48	84	132
Number of driven kilometres	186.6	249.85	545.02	794.87
Number of orders	40	48	84	132
Number of boxes	321	506	1,285	1,791
Number of kilogrammes	3,021	4,035	8,542	12,577

As the LEFVs depart from the urban consolidation centre (as shown in Figure 2) the number of driven kilometres is quite low as expected. The average values can be derived based on Table 3.

Table 3 Average operational performances of the trips realised

Indicator	Traditional Delivery (sample)	E-cargo Bike L	TukTuk
Number of driven kilometres Inner-City	15.55	10.42	12.47
Number of stops per trip	1.8	2.52*	2.52*
Number of orders per stop	1.11	1	1
Number of boxes per trip	132.51	20.24	28.56
Number of boxes per stop	73.51	10.54	15.30
Number of kilogrammes per trip	N.A.	161.40	189.82
Number of kilogrammes per stop	N.A.	84.06	101.69

The biggest differences between traditional delivery and LEFV-delivery can be seen in the performance indicators *number of boxes per trip* and *number of boxes per stop*. It is clearly that the volume and size of the trucks influences this number strongly. There is some slight difference between the E-cargo Bike L and the TukTuk in terms number of boxes and kilogrammes in favour of the TukTuk.

Operational logistics performances

Table 4 Average logistics performances on the trips realised.

	Traditional Delivery (sample)	E-cargo Bike L	TukTuk
Average unloading time(min)	12:02	10*	10*
Average load factor	0.62	0.74	0.85
Delivery time reliability (%)	84	100	100
Average time per trip (h:m:s)	1:25:00	0:53:00**	0:53:00**

* *Based on the expert judgement of the students, real measurement of the activity was not possible yet*
** *Based on the averages of E-cargo Bike L and TukTuk*

As expected the average loading time takes some more time in the traditional situation. The average number of boxes per stop is clearly more. As shown in Table 4 the students could not make an exact measurements of the unloading activity as it took them too much time to register. In the new measurement period the software of Routigo has been updated for this issue. Now an easy push-button allows the timing of the (un)loading activities can be registered. Most significant improvements can be seen in terms of *Delivery time realibility* and *Average load factor*. Both LEFVs outperform the traditional way of delivery. The TukTuk shows also better performances than the E-cargo Bike L likely due to a more easy way of loading. A 100% score on the Delivery time reliability is of course the best score hoped for. This also can be reflected in the shopkeepers' appreciation for the new way of delivery. 20% of the shopkeepers evaluated the same service level. However 40% of the shopkeepers experienced a better service and even 40 % of the shopkeepers experienced a much better service. Also positive scores were perceived by the shopkeepers on the delivery conditions, undamaged deliveries and completeness. The Average trip length of the traditional delivery takes more time. Many times the driver needs a significant time to search for a loading place and sometimes illegal parking is needed to deliver on time. (van Duin et al., 2018).

Logistics cost

The most important indicator for the logistics service provider is cost Due to confidentiality of the logistics service provider only the cost of the traditional way of delivery are not shown. However, for the LEFVs a more detailed cost price calculation is shown in Table 5.

Table 5 Monthly cost of operations (€)

Operational cost	(per Month)	Labour cost	(per Month)
Type of cost	Amount in €		Amount in €
Location/hub	800	Team leader (1.0)	2,200
TukTuk	450	Couriers (1.2)	2,340
E-cargo Bike L	325		
Planning system	150		
Other	200		
Subtotal	1,925	Subtotal	4,540
Total cost	6,465		

Based on these cost the integral cost price per kilometre was determined for the TukTuk on €11.67 and for the E-Cargo Bike L €12.46. It should be mentioned here that the current calculations are based the current volumes which are still quite low. It is possible to operate more trips a day and therefore the cost of operation and labour can be divided by more kilometres

To get more insight how many stops are needed to become breakeven some calculations have been made. As a norm it was assumed that 1 courier can operate 112 trips per month. The calculations have shown that the break-even point holds for 93 trips per month (IGODIS012.1, 2019). For a national logistics service provider this number of trips seems to be possible if they extend their freight flows with other products.

Environmental performances

To calculate the difference between the traditional situation and the new situation with the new LEFVs there is not much difference. For both situations a truck trip is needed to bring the goods to Rotterdam and vice versa. For the inner-city the situation is obviously different as the vehicles show different emission behaviours. A real comparison with the traditional delivery is not possible as it has not been realised in practice. Therefore it should be estimated. Based on the average number of boxes per trip (+/- 130 per truck) it is assumed that the E-Cargo Bike L (+/-20 boxes) needs 6 trips to deliver the same amount and the TukTuk (+/- 30) needs 4 trips to deliver that amount. For the E-Cargo Bike L it means that 25 deliveries can be done by 4 truck trips. For the 45 TukTuk trips it means 11 truck trips, which sums up to a total 15 truck trips equivalent.

Table 6 Environmental performances of the Truck and LEFVs

	Truck	E-Cargo-Bike L	TukTuk		
Trips (#)	15	25	45		
Average trip distance in the city (km)	15.5	10.42	12.47		
Total kms	232.5	260.5	561.15		
Energy consumption per kilometre	0.29/l	0.09/kWh	0.06/kWh		
CO_2 emission per kilometre (kg)*	0.94	0.0488	0.0296		
NOx emission per kilometre (g)*	0.21	0.0659	0.0399		
Total CO_2 emission (kg)*	218.55	12.71	16.61	LEFVs	29.32
Total NOx emission (g)*	48.83	17.17	22.39	LEFVs	39.56

** As the source of the energy supply is unknown the calculations are based on grey energy which implies 526 g CO_2 per kWh and 0.71 g NOx per kWh (Otten & Afman, 2015)*

As expected Table 6 shows clearly a significant improvement of the CO_2-footprint in the delivery operations. A decrease of 87% is quite impressive. For the NOx-footprint the decrease is about 19%. It should be mentioned here that the calculations are based on grey energy supply. This implies that both footprints of the LEFVs are even better if non-labelled energy is used. Non-labelled energy contains a mix of at least 35% green energy and 65% is grey energy. For non-labelled energy this means 355 g CO_2 per kWh and 0.49 g NOx per kWh (Otten & Afman, 2015).

Other learning experiences

From the interviews with the shopkeepers it can derived that the new service with LEFVs is perceived as (much more) satisfactory. The answers can be traced back to the shopkeepers' importance of zero emission deliveries. In terms of pricing the opinions seems more divers. It ranges from very important to not important at all. As shown in the cost calculations the price setting can therefore be a crucial factor.

The use of LEFVs had a positive influence on the accessibility of the hotel and catering establishments. The accessibility was positively influenced, especially when delivering the cargo bike. The main reason for this is that the cargo bike can use cycle paths, in addition, the cargo bike is also several times smaller than the cargo truck and you can park the cargo bike on the sidewalk in front of catering establishment. Due to the smaller size of the cargo bike, the number of unsafe traffic situations is reduced. The physical nuisance is also much less due to the smaller size of the cargo bike. The parking distance for unloading the products is therefore also very small. With the use of the cargo bikes, congestion is prevented and the time to find a release location is basically zero as the cargo bikes can be placed on the sidewalk. Hence the accessibility is strongly improved by the use of cargo bikes.

The same traffic rules apply to the delivery of the products with the TukTuk. The TukTuk may not use bicycle paths, but still the delivery with the TukTuk had a positive influence on the accessibility of the hotel and catering i. The mobility of the TukTuk is better compared to the truck because of the smaller size of the TukTuk. The average time for finding a separate place for the TukTuk is zero in 99% of the cases. Because of the small size, there is always a loading place available for the TukTuk. This also reduces the number of unsafe traffic situations and reduces congestion.

Not only advantages of delivery with the LEFVs have emerged in the Living Lab. Sometimes the pedal support tricycle is not strong enough to move forward heavily loaded (> 200 kg) from a standstill. As a result the heavy loads (>200kg) for the bike deliveries have to be executed with two persons. The second person could assist the driver getting started after leaving at a traffic light or stop. Also some cycle paths in the centre of Rotterdam are too narrow to catch up. The cargo bike is often faster than regular cyclists. This can cause unsafe traffic situations. When changing direction it is hard to indicate the new direction with one hand (as is obliged for cyclists). While cycling you must keep two hands on the handlebars to keep control of the cargo bike. Reaching out your hand and indicating direction is therefore impossible if you are driving alone. The Living Lab also has shown that the TukTuk has little stability on unpaved roads. At these type or roads the TukTuk starts to vibrate a lot, especially the steering wheel is vibrating which causes a feeling of safety. Also the TukTuk is sensitive to strong winds and sometimes adjustment of driving is needed.

Conclusions from the Living Lab setting

The Living Lab has provided all actors joint knowledge production (Hegger et al. 2012) and has contributed to an increase the shared situation awareness (Kurapati et al., 2012) of the last mile delivery with LEFVs. It can be concluded that the LEFVs are very easy to use in the city. The aim of the municipality of Rotterdam is to have all supplies in the city centre of Rotterdam done by emission-free vehicles from 2025 onwards. Compared to the current situation, the LEFVs (supplied by DOCKR) ensure that supplies can be made without emissions. In addition, deliveries can be made efficiently. The loading and unloading times are lower than the current situation because smaller quantities are used and relatively few kilometres are driven per ride, which means that several trips can be made. Also the loading and unloading times are lower than the current situation because smaller quantities are used. Both the E-cargo Bike L and the TukTuk suffer little from traffic jams. On sustainability obviously the LEFVs score great with a reduction of 87% CO_2-footprint reduction and almost 20% reduction of the NOx-footprint. This is fully in line with the goals set by the municipality. In addition to the sustainability and efficiency of the vehicles, the new way of delivery also led to positive responses from customers and the environment. Among other things, a higher customer satisfaction emerged from a survey with the hotel and catering industry.

Our cost calculations based on current volumes show high integral cost prices compared to the traditional truck delivery. Besides the current volumes the capacities of the TukTuk and the E-cargo Bike L are relatively low. This means that on average 2 customers are delivered per trip. This ensures that several trips per day must be driven due to the relatively low capacity. The advice is to ensure that in case of upscaling, the number of delivery addresses increases more frequently than the number of kilos per stop. The calculations have shown that the break-even point holds for 93 trips per month (IGODIS012.1, 2019), which is a likely volume that a national logistics service provider can attract. Still the distribution cost are significantly higher. This is also in line with the findings of Ehrler et al. (2019). They showed that trucks are more cost effective for greater distances from the DC, and for large volume deliveries to one stop. The only condition when cargo bikes generate lower cost than trucks if the conditions are met that the deliveries are in a close neighbourhood of the hub combined with the condition, the area of delivery has a high density of shops and the deliveries mainly concern low volume deliveries.

Ehrler et al. (2019) also suggest that slightly increased costs in city logistics is not an issue if customers value the zero emission delivery. However, at this moment, no one is willing to pay extra for the zero emission delivery (Ehrler et al., 2019). For the municipalities this is an important issue to recognise. Supporting measures could be provided to give the operating delivering companies with zero emissions so vehicles some beneficial (traffic) measures which could lead to improved efficiencies of the LEFVs.

The Living Lab made clear that the LEFVs' position in traffic, including the rules for the use of cycle lanes and pedestrian areas is ambiguous. The TukTuk is forced to use the main roads and streets and still it clearly shows off a better manoeuvrability. The E-cargo Bike L shows some teething problems with starting up after a stop. Weather conditions could have some negative influences on the driving behaviour. However, it can be concluded that real-life experimenting with LEFVs in a Living Lab leads to greater awareness, knowledge and behavioural change in urban freight distribution networks.

Various studies have indicated the potential of the use of LEVVs for the last mile. Cities that are striving for emission free zones can profit from distribution systems based on LEFVs for market segments in which a limited weight and volume is transported. In these the use of LEVVs contributes to an operational improvement of inner city delivery and forms a social value proposition based on the positive responses from its customers and the local inhabitants. The Living Lab approach has shown very successful way of implementing and improving the last mile delivery with LEFVs. All actors have taken positive measures to improve the new urban distribution system.

To end this paper it can be concluded that the students are very content with this way of education. All students have prepared a research report based on their experiences and measures in practice. These experiences and outcomes are shared again with the new groups of students who continue the research work. In this way the Living Lab allows us maintaining a continuous knowledge acquisition in the experiences with LEFVs for city logistics distribution.

Acknowledgments

The authors would like to thank the companies and organisations that have participated in the Living Lab. We also thank our students for their commitment to the project by delivering the goods to the shops and at the same time position themselves as researchers by writing interesting research reports. All presented research results are derived from (IGODIS012.1, 2019) & (IGODIS012.4, 2019).

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