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METHODOLOGICAL FRAMEWORK FOR THE DEVELOPMENT OF URBAN ELECTRIC CARGO BIKE SYSTEM IN SHIPMENT DISTRIBUTION

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Abstract: *Practical research in the recent past has shown that city logistics with light cargo vehicles requires good locations for hubs in the distribution network, robust processes, cooperation between customers, logistics service providers and suppliers, good insight into the costs involved, modern ICT and good organization. A comprehensive approach should include a balanced strategy aiming to tackle orgware, software and hardware perspective of the innovative value proposition for the cargo distribution in the urban city center. Policy framework as the fourth pillar should provide a solid base for an innovative value proposition. In this paper, the methodology for the development of an urban electric cargo bike system is described and the main drivers and barriers for its implementation in a case of the postal logistics system of Belgrade are emphasised.*

Keywords: *electric cargo biking, parcel delivery, postal logistics*

1. Introduction

Traffic jams in cities represent one of the most important problems for the local authorities. Growth in the van traffic significantly contributes to this situation. The speed of adoption of e-commerce and Internet shopping by consumers where almost every delivery is served by van becomes an additional contributing factor to worsening the congestion in cities.

Digital economy has also a significant impact on the performances and trends in postal logistics. Having in mind the trend of reducing the volume of letter post items, the providers of universal postal service are increasingly changing their focus to the delivery of parcels which are usually based on e-commerce. These changes imply the need to deliver a large number of commodity-based shipments to a large number of addresses. The shift in the structure of the shipments (from letters to parcels) has also a significant environmental impact, so called environmental footprint of postal operators, since the parcels' delivery requires much higher level of logistical and transport capacity than the delivery of letters. The delivery in large cities is of particular challenge. In this case, the organization of the delivery is dependent not only on the volume of parcels but also the traffic conditions in central areas (traffic jams, parking spaces, street capacities etc.), traffic regulations as well as the trend of prioritizing the environmentally friendly urban delivery vehicles. This is the reason why many postal operators nowadays use new electrical delivery methods. Electrically assisted cargo bikes have significant potential to replace vans in urban areas. E-cargo bikes take less road space, have zero-emission, they are less intrusive than vans in city centers and they can often make use of cycle lanes.

This paper describes a comprehensive approach for the design of the e-cargo bike system in shipment distribution with a consideration of parcels distribution in postal logistics of Belgrade. The approach is based on a balanced strategy which includes orgware, software, hardware and policy dimensions for provision of the innovative value proposition for the cargo distribution developed in the framework of the project SolutionsPlus (SolutionsPlus, 2020). Orgware dimension includes the design of collaborative network composed of all, directly and indirectly, involved stakeholders. Software dimension includes determining an optimal location of transhipment points as well as the design of vehicle routes for serving the customers from/to these hubs. More specifically, the first step would be to solve a location-allocation problem based on a number of alternative locations in order to minimize the distances between the demand points and the set of hubs. Optimal e-cargo routes and delivery times subject to different variables (such as travel speed, weight of shipments, slope of streets, etc.) represent the aim of the vehicle routing problem. Hardware dimension includes an optimal design of e-cargo bikes and the sizing of the transhipment points. In this stage, the experiences from other locations should be considered. For example, the main barriers to using e-cargo bikes in Amsterdam were (van Amstel et al., 2018):

- Cargo capacity;
- Battery charging time;
- Availability of charging infrastructure;
- Range;
- Maintenance;
- Turning radius;
- Parking allowance.

Based on related experiences from other locations and identified barriers as well as the barriers related to a considered city (based on surveys), the design of the optimal cargo vehicles can be defined. Within the policy dimension, the existing legislation should be analyzed and a set of recommendations should be proposed for facilitating the establishment and functioning of e-cargo bikes system. All the dimensions must co-evolve in order to enable successful implementation and positive effects of the innovative e-cargo biking value proposition.

The paper is organized as follows. The second section describes the organisational perspective of the approach. Optimal design of e-cargo bike system (software perspective) is analyzed in the third section. E-cargo bike design and micro hub dimensioning (hardware perspective) are elaborated in forth section. The fifth section considers legal framework (policy perspective). Concluding remarks are given in the sixth section.

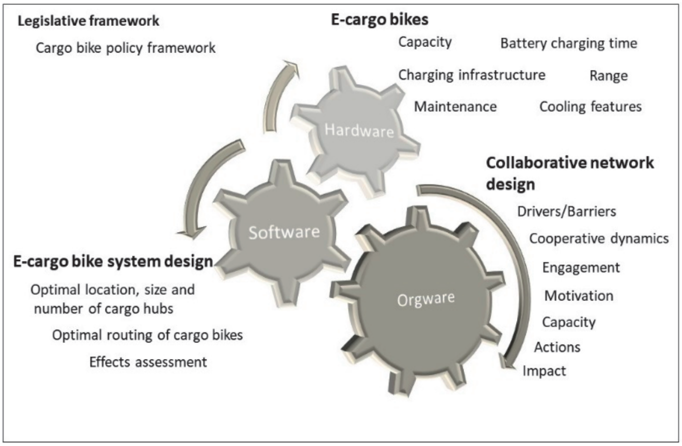

Figure 1. Framework for the design e-cargo bike distribution system

2. Orgware: Building a collaborative e-cargo distribution network

Urban freight transport market is characterized by a variety of stakeholders with different motives, barriers and values that they identify with the development of e-cargo biking system. Stakeholders involved in urban freight transport are supply chain stakeholders (shippers, transport operators, receivers, consumers), resource supply stakeholders (infrastructure providers and operators, landowners), public authorities and other stakeholders (manufacturers, residents, visitors/tourists). The conflicts usually arise between the interests of residents and transport operators while public authorities try to balance the interests of both sides. There are also conflicts between residents and tourists/visitors as consumers. Tourists/visitors want goods to be available in shops whereas residents complain about traffic congestion, noise and environmental pollution.

In this phase, it is needed to build a collaborative e-cargo biking distribution network by incorporating different interests, motives and barriers of the main stakeholders.

For this purpose, a collaborative business and governance model needs to be designed. An appropriately designed business model should enable closer and more efficient relationship among the stakeholders in the e-cargo bike system. Governance model represents a mechanism for the stakeholders to gain a competitive advantage and create value from the proposed business model. By a governance model the network organisational structure is specified in the sense of which actors are involved, who orchestrates the network, how the roles and responsibilities are distributed and how the decision making process is organised.

In order to build a cooperative business model, it is important to assess and align the needs and requirements of all the stakeholders involved. A useful approach for value alignment in a multi-value multi-actor environment (such as in urban freight system) is Value Case Methodology (VCM). The aim of VCM is to unite multiple stakeholders by creating a broad set of values associated with a cooperative business model and to capture the innovations and wishes of the stakeholder involved (Dittrich and van Dijk, 2013). The main steps of VCM are as follows (Figure 2.):

- Value identification: All network participants that impact on the value that e-cargo bike system delivers to the end customers are identified, their roles, interests, motives and barriers are assessed.
- Value quantification: All qualitative effects from the first step will be quantified. For this purpose multicriteria decision making method (such as Analytic Hierarchy Process (AHP) or conjoint analysis (CA) can be used.
- Value sensitivity: Analysis and visualization of points sensitivity of stakeholder in terms of acceptance the new e-cargo biking concept is performed in this step.
- Value alignment: This step represents a structured process aimed to obtain an overall acceptable solution by analysing identified misalignments and defining a set of "compensation" measures.

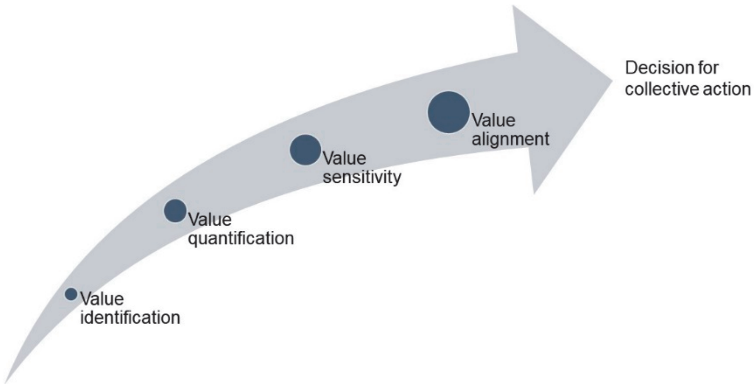

Figure 2. Value Case Methodology (Dittrich and van Dijk, 2013)

Based on this activity different stakeholder engagement strategies can be designed. Some of them are freight quality partnerships, freight advisory boards and forums or introduction of an intermediary for orchestrating the stakeholder's network.

The last part of the orgware dimension is the design of a framework for transition from a current situation to the new cooperative model. The main components of this framework are:

- The general system context;
- The governance model;
- Cooperation dynamics and actions.

The system context determines opportunities and constraints, or the drivers and barriers, and impacts on the dynamics of the cooperation among the stakeholders in the network. Proposed governance model evolves within the general system context which represents the host of all legal, environmental and other impacts that affect or are affected by the e-cargo biking system. The dynamics of cooperation represents an iterative interaction of cooperative engagement, shared motivation between the actors and capacity building. The main output from the cooperative model is the cooperative actions which result from the strategy developed during the cooperative dynamics, and represent the efforts aimed to achieve the objective of e-cargo biking cooperative model.

3. Software: Optimal design of e-cargo bike system

Software dimension includes two tasks:

- Optimal location and size of micro-hubs;
- Optimal routing of e-cargo bikes.

Determining optimal locations for micro-hubs can be solved mathematically. Location-allocation models represent the most efficient methods for optimizing public facility locations. There are four types of location-allocation models (Tao et al., 2018):

- The p-median problem;
- The maximum covering location problem;
- The location set covering problem;
- The p-center problem.

The most popular is p-median problem. It represents a classical optimization problem whose objective is to find p locations out of a set of potential locations for transhipment points such that the sum of weighted distances between each demand points and its closest facility is minimized. The distances between each demand point and its closest facility location can be weighted by the demand that is sent to that point. This problem belongs to a class of NP-hard problems for which the exact solution most probably can not be found in polynomial time (Niels et al., 2018). Dakins and Maas (2015) present a classical formulation of the problem and describe various metaheuristics for finding a solution of p-median problem. In case when there are many criteria for selecting the optimal location it is needed to solve multi criteria location problem. Hekmatfar and SteadieSeifi (2009) made a comprehensive review of multi criteria decision making methods for solving location-allocation problems. The non-existence of micro-consolidation nodes in postal logistics of Serbia represents one of the reasons why postal operators mainly use vans for parcels delivery in Serbia. Capacity utilization of vans may differ depending on the category of parcels for delivery.

The second task includes finding the optimal routes for delivering shipments from the selected micro-hub locations to the customers. For each subset of delivery locations, the problem of finding optimal routes can be modelled as a variant of the Vehicle Routing Problems (VRP). Toth and Vigo (2014) give an overview of different VRPs and the heuristics for their solving. A critical factor of cargo bikes is their travel speed which depends on the load and the slope of the streets. Therefore, the load dependent travel speed should be included. Since different deliveries have strict or less strict delivery times, delivery times can also be included. Ignoring the load dependent travel times can lead to underestimation of travel time in such a way that the time windows are violated. The resulting model is a capacitated vehicle routing problem with time windows and load dependent travel times. A recent comparison of this model with classical capacitated vehicle routing problem with time windows on a cargo bike routing problem resulted in significantly reduced travel time (Fontaine, 2019).

4. Hardware: E-cargo bike design and micro-hub dimensioning

"Hardware" phase of the e-cargo bike system development includes the design of e-cargo bikes and dimensioning of micro hubs. Both aspects are connected with "software" phase in terms of the demand – the intensity and structure, spatial distribution, time windows and location of transhipment points.

In general LEFVs are bicycles or compact vehicles with electric pedal assistance or electric drive designed for distribution of goods on public roads with a limited speed (≤ 45 km/h). In comparison with vans, LEFVs have a smaller capacity and lower speed, ability to use different infrastructure and requirements imposed on the driver (van Amstel et al., 2018). According to the LEFV-Logic project (van Amstel et al., 2018) there are three types of vehicles that are smaller than a delivery van and can transport up to 750 kg:

- Cargo bikes with electrical pedal assistance – loading capacity 50-350 kg, vehicle weight 20-170 kg;
- Electric moped with pedals and no covered cab – loading capacity 100-500 kg, vehicle weight 50-600 kg;
- Compact distribution vehicle with electric drive – loading capacity 200-750 kg, vehicle weight 300-1000 kg.

Regarding legal requirements, according to LEFV-LOGIC project (case of Netherlands) all LEFVs fall into following legal vehicle categories (van Amstel et al., 2018):

- Cargo bikes for which national testing procedures and registration are not obligatory, for which power of the electrical motor is up to 0.25 kW and the maximum speed is 25 km/h.
- Vehicles for which national testing procedures or approval by the Ministry is required. Registration is not obligatory. The maximum speed of these vehicles is 25 km/h.
- L-category vehicles which are light vehicles ranging from bicycles with an auxiliary engine to mini delivery vans for which a European type approval and registration are required. The maximum speed of these vehicles is up to 90 km/h.

Regarding the costs of electric cargo bikes/mopeds, the following components are included in cost estimation (€):

- Investment: 3000-13000
- Operational lease per year: 1800-3500
- Fuel for 10000-15000 km per year: 400-1000
- Insurance: 200-400
- Parking and charging infrastructure: 1000

Regarding the design of cargo bikes, there is an increasing demand for high payload vehicles to improve the ratio between payroll costs and payload. Bikes and trikes are also available with functionalities such as a hot or cold box for the transport of food and beverages. On London's market, there is a range of cargo bikes available on the market (Figure 3.). 42% of cargo bikes, 50% of cargo trikes and all quadricycles are offered with electric assistance.

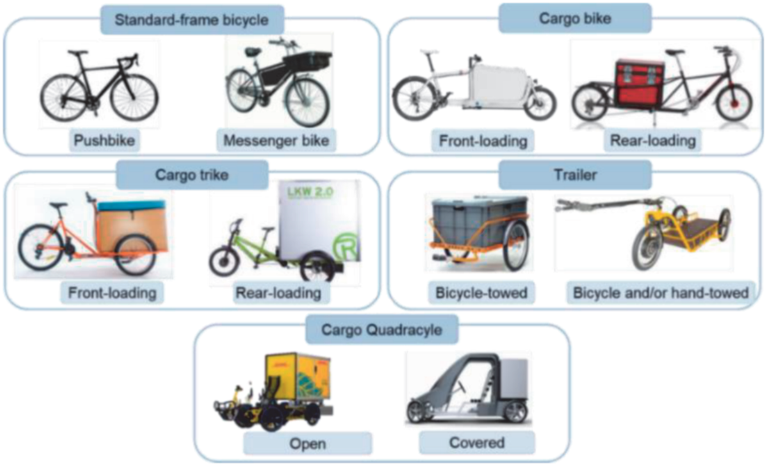

Figure 3. Cargo bikes: London market overview (CLSRTP, 2019)

La post (French national postal operator) has the largest fleet of electric vehicles in the world. Currently, it possesses a fleet of 35000 electrical vehicles of which 24000 (69%) are electrically assisted bicycles. Serbian postal operator (Post of Serbia) does not possess a fleet of electrical bikes. The delivery of parcels is usually conducted on traditional ways by the postmen (by foot and by motor scooters), vans and cars. Croatian postal operator "Hrvatska posta" acquired 180 electrical bikes in 2015 in order to replace motor scooters. It was estimated that the overall cost savings are approximately 85%, while CO_2 emissions are lower by 100 tonnes annually (Cairns and Sloman, 2019).

Manufacturers offer a range of "functional" boxes for various applications, these include hot/cold boxes for transporting food and medicine. The option of custom made bikes/trikes is also available to suit individual needs. This includes customization of the length/width and battery size as well as the functionality of the cargo box itself. Required battery capacity depends on vehicle speed, weight of the load and driving distance. For example, for a speed of 20 km/h, a load of 200 kg and driving distance of 70 km required battery capacity is 2.9 kWh.

Sizing of micro hubs will depend on their number and the demand for delivery generated by commercial activities in the gravitating area as well as the delivery times. The demand can be subject to variability in terms of magnitude (number of deliveries per day) and time (from one day to another).

5. Legislative framework

Recent initiatives in European cities for urban e-cargo biking revealed that there is a certain resistance to the use of e-cargo bikes on existing cycling infrastructure. Fear for the safety of other road users is also present. The main questions in this stage are how do the e-cargo bikes fit into urban infrastructure and what measures can cities/municipalities take to support the development of e-cargo biking system. Cities/Municipalities may have regulatory, coordinate, facilitative, stimulatory or experimentation role (ROB, 2012):

- Regulatory role concerns the introduction of restrictive measures such as the establishment of environmental zones with limited or forbidden access to some types of vehicles. In some cities (such as Utrecht) cargo bike service operators have the freedom to deliver all day in pedestrian areas.
- Coordination role includes actions related to bringing together supply and demand related actors. Amsterdam municipality, for example, links companies who want to charge vehicles with companies which offer innovative charging solutions. Governments may also coordinate the supply and demand for storage and transhipment facilities. Municipalities can share real-time local traffic data to transport management system providers.
- The stimulatory role includes financial incentives for supporting the development of e-cargo viking system. For example, the Hague and Maastricht subsidized the use of cargo bikes with the amount from 1500 to 4000 EUR. Cities can stimulate the development of e-cargo biking system by adjusting their own logistics activities or to encourage suppliers of inbound goods to use light e-cargo bikes.
- The experimental role relates to the use of electric bikes by the municipalities for their activities.
- Facilitating the innovation uptake is the aim of the facilitative role. Introducing bicycle in the streets or speed limits or making the real estate available to logistics service providers at a lower rate are some of the facilitative measures imposed by the municipalities.

6. Conclusions and recommendations

Based on the experiences from many EU cities, e-cargo bikes proved to be very efficient in dense urban areas where the delivery cycles are very short. In most cases, e-cargo bikes are introduced as pilot projects by the public sector in order to encourage its wider adoption on the market. Since e-cargo biking is not present in the national postal logistics system, the actions on all stages are needed. Building a collaborative e-cargo bike network requires a detailed analysis of the main actors on the market, their motives/barriers and selecting the adequate business and governance model which will enable long-term collaboration between the actors. Location and the sizing of micro-consolidation points in urban areas from which cycle logistics companies can operate should be defined. E-cargo bike routing should be facilitated by ICT-supported software tools. E-cargo bike fleet composition (mix and size) should be based on a compromise between the requirements of the market and objectives of e-cargo biking operators. Special attention should be given to existing legislative measures for facilitating sustainable urban distribution such as the regulatory measures (time-based measures, volume of weight restrictions, emission-based restrictions), market-based measures (congestion charges, subsidies), infrastructure-based measures (on-street loading and unloading bays) and measures related to new technologies (vehicle technologies, ITS and ICT).

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Rezime: Istraživanja sprovedena u prethodnom periodu ukazuju na to da „city” logistika zasnovana na lakim teretnim vozilima zahteva dobre lokacije za pretovarne čvorove, robustne procese, kooperaciju između aktera, detaljnu analizu svih troškova, modernu ICT infrastrukturu i dobru ogranizaciju. Sveobuhvatni pristup razvoju sistema distribucije zasnovanog na električnim kargo biciklima treba da obuhvati organizacionu, softversku i hardversku perspektivu inovativne vrednosti za distribuciju pošiljaka u gradskoj zoni. Zakonodavni okvir predstavlja četvrtu dimenziju i treba da pruži osnovu za inovativnu vrednost. U ovom radu predložena je metodologija za razvoj sistema gradskih kargo bicikala. Osnovni motivi i prepreke za primenu u slučaju poštanskog logističkog sistema grada Beograda su analizirani.

Ključne reči: električni kargo bicikli, distribucija pošiljaka, poštanska logistika

METODOLOŠKI OKVIR ZA RAZVOJ SISTEMA GRADSKIH ELEKTRIČNIH TERETNIH BICIKALA ZA DISTRIBUCIJU POŠILJAKA

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