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THE ROLE OF SMALL ELECTRIC VEHICLES IN "LAST MILE DELIVERY"

Branislav Aleksandrović[a], Aleksandra Tanasković[b], Milan Lončar[c]

[a] Professor of professional studies, Academy of Professional Studies Šumadija, Kosovska 8, Kragujevac, Serbia, baleksandrovic@asss.edu.rs, orcid.org/0009-0005-7313-4899

[b] Teaching Assistant, Academy of Professional Studies Šumadija, Kosovska 8, Kragujevac, Serbia, atanaskovic@asss.edu.rs

[c] BSc in Mechanical Engineering, AMSS Centar za motorna vozila d.o.o., Mitropolita Mraovića 13, Belgrade, Serbia, lone@cmv.rs, orcid.org/0009-0001-6146-3047

Abstract: The volume of delivery in urban areas is becoming larger due to the expansion of electronic commerce, thus creating a need for more efficient and environmentally friendly solutions in last mile logistics. Small electric vehicles - such as electric bicycles, tricycles, quadricycles and mini delivery vans - represent a sustainable alternative to conventional vehicles, as they enable the reduction of traffic congestion, noise and harmful gas emissions. The paper analyzes their technical and exploitation characteristics, legal classification according to the ZOBS of the Republic of Serbia, as well as examples of good practice in European cities (La Rochelle, France) and companies (IKEA, Wolt, DHL). A mathematical model of delivery optimization that shows the advantages of electric cargo bikes in areas with limited traffic is also presented, as well as a model of a one-way delivery vehicle. The results indicate that by choosing the right type of vehicle in relation to the characteristics of the route, volume of deliveries and urban conditions, significant savings in time and costs can be achieved, while increasing the sustainability of urban transport.

Keywords: small electric vehicles, delivery, logistics, sustainable transport

1. INTRODUCTION

The development of electronic commerce and changes in consumer habits have led to an increase in the volume of goods delivered in urban areas. A special challenge is the delivery of the last mile, that is, the final stage of transporting goods from the distribution center to the end user. A large number of individual deliveries, short transport distances and frequent vehicle stops make this phase particularly demanding. The increased delivery volume contributes to traffic jams, taking up parking space, increasing noise and emissions of harmful gases. That is why more and more attention is being paid to the application of alternative solutions in urban logistics, among which small electric vehicles occupy a significant place. Electric bicycles, cargo electric bicycles, electric tricycles, as well as small electric vehicles with four wheels can represent an effective alternative to conventional delivery vehicles. Their compact dimensions, good manoeuvrability and electric drive enable easier movement through traffic-heavy zones and access to locations that are less suitable for larger vehicles.

2. CHARACTERISTICS OF SMALL ELECTRIC VEHICLES

Small electric vehicles represent a group of vehicles that use electricity for propulsion and whose dimensions, mass and energy requirements are adapted to movement in urban areas. Thanks to their compact dimensions, simple management and the possibility of using an electric drive, these vehicles have significant potential for application in various areas, especially in the delivery of goods over short distances.

Depending on the design and purpose, small electric vehicles can include electric bicycles, electric cargo bikes, electric tricycles, quadricycles and small electric delivery vehicles. The differences between the mentioned categories are reflected primarily in the number of wheels, dimensions, mass, load capacity, volume of the cargo space, power of the drive system and battery capacity. The choice of a certain type of vehicle depends on the characteristics of the transport task, the quantity and type of goods, as well as the length of the route and traffic conditions.

The characteristics of small electric vehicles directly determine their suitability for different types of delivery tasks. A vehicle with a smaller load capacity and a shorter range can be very efficient for the delivery of smaller shipments over short distances in central city areas, while for larger quantities of goods and longer routes, a vehicle with a larger cargo space, battery capacity and carrying capacity is more suitable.

According to the above, when choosing a vehicle, only one parameter cannot be singled out as decisive. It is necessary to simultaneously observe the technical, energy, transport and exploitation characteristics of the vehicle. By choosing the right vehicle, it is possible to better adapt the delivery capacity to the actual transport requirements and achieve a more efficient organization of the last mile delivery.

Precisely because of the different requirements set by certain types of delivery, in the next part of the work it is necessary to separately analyze the categories of small electric vehicles and their characteristic representatives, in order to enable their mutual comparison.

Table 1. Characteristics of small electric vehicles

Characteristic	E-bike	E-cargo bike	E-tricycle	E-quadricycle	E-van
Number of wheels	2	2–3	3	4	4
Payload capacity	low	medium	medium/high	high	very high
Cargo space	very small	medium	medium/high	high	very large
Maneuverability	excellent	excellent	very good	good	limited
Parking requirements	minimal	minimal	low	low/medium	high
Suitability for narrow streets	excellent	excellent	very good	good	lower
Range	low/medium	medium	medium	medium/high	high
Suitability for large shipments	poor	medium	good	very good	excellent

2.1. Overcoming traffic jams and accessibility

Small electric vehicles can play a significant role in greater efficiency, sustainability and more flexible organization of last mile delivery, especially in urban areas. Their basic role is to enable the transportation of smaller quantities of goods from the distribution center, store or micro-distribution center to the end user, with less burden on the city's traffic infrastructure.

Their application is especially evident with short delivery routes, a large number of delivery stops and areas with traffic congestion and parking problems. Unlike classic delivery trucks,

small electric vehicles take up less space and move more easily through narrow city streets, and in certain cases they can also enable faster delivery.

Drivers of traditional HGVs (vans) often waste time searching for free parking or blocking lanes. Micro vehicles (small electric vehicles) can be parked directly in front of the entrance or on the sidewalk without obstructing traffic. Cargo e-bikes can use bike lanes, which drastically shortens the delivery time per package in urban centers.



Figure 1. Electric delivery tricycle [7]

2.2. Synergy with Micro-hubs

Delivery by micro-vehicles works best in combination with the concept of local micro-warehouses. Large trucks or vans bring goods to the outskirts or to smaller distribution points in the city, from where small electric vehicles pick up smaller packages and deliver them efficiently to end customers within a radius of a few kilometers.

Cargo e-bikes are mainly used in retail, food delivery, letters and small packages in a tight center. Access to bike lanes and pedestrian zones allows them to be the fastest in traffic jams.

E-tricycles and small quadricycles are used for express shipments, groceries, e-commerce packages in residential areas. They have more stable operation in winter conditions, have a higher load capacity (200-500 kg), and also have protection from the weather.

Mini e-vans are used for larger shipments, delivery of white goods or collective deliveries for several facilities. They are characterized by a larger volume of cargo space while maintaining a compact vehicle width.

The implementation of small electric vehicles, in the delivery of the last mile, not only drastically lowers the operating costs of logistics companies, but also represents the basic pillar of creating sustainable and smart cities.



Figure 2. An example of a micro warehouse [8]

3. VEHICLE CLASSIFICATION ACCORDING TO THE LAW ON ROAD TRAFFIC SAFETY (ZOBS) OF THE REPUBLIC OF SERBIA

ZOBS in Serbia does not use the term "small electric vehicles" as a general category for all small electric delivery models. The law specifically defines "light electric vehicle", whereby that definition refers to what is recognized in practice as an electric scooter.

According to Article 7, paragraph 31a of the Law on Traffic Safety, the definition of a light electric vehicle reads: "a light electric vehicle is a motor vehicle with at least two wheels, with mechanical steering, without a seat, whose permanent nominal power of the electric motor does not exceed 0.6 kW, whose maximum design speed does not exceed 25 km/h and whose curb weight does not exceed 35 kg".

ZOBS does not recognize the category of "small electric vehicles" which would include e-cargo bikes, electric tricycles, quadricycles and small electric vans. On the contrary, "light electric vehicle" is a separate legal category, while other vehicles are classified according to other categories. The Agency for Traffic Safety expressly states that "light electric vehicle" means scooters that meet the prescribed conditions, and that this does not include bicycles, mopeds, etc. The vehicles that would be suitable for "last mile delivery" are shown in the following table.

Table 2. Classification of small electric vehicles

Category	ZOBS classification
Electric bicycle	**Bicycle**
Electric cargo bicycle	**Bicycle**
Electric scooter	**Light electric vehicle**
Electric moped	**L1 – moped**
Electric light tricycle	**L2 – light tricycle**
Electric heavy tricycle	**L5 – heavy tricycle**
Electric light quadricycle	**L6 – light quadricycle**
Electric heavy quadricycle	**L7 – heavy quadricycle**
Small electric delivery vehicle/van	**N1 – light commercial vehicle**

4. EXAMPLE OF SHIPPING TO THE CITY OF LA ROCHELLE, FRANCE

The city of La Rochelle, France, as part of the ELCIDIS project, among the first in Europe in 2001, launched the distribution of goods in the historic center of the city with the application of an environmentally friendly approach. The ELCIDIS platform includes two different types of activities: package delivery and the provision of ancillary services using electric vehicles. The ELCIDIS project was designed not only to encourage deliveries by electric vehicles, but also to relieve traffic in the city center through the reorganization of deliveries. To this end, a new traffic regulation was adopted: heavy goods vehicles (ie those whose total permissible mass exceeds 3.5 tons) are allowed to make deliveries within a certain zone only between 6:00 and 7:30 in the morning. By the end of 2005, the results of this experiment were mostly satisfactory, although there were certain limitations in terms of organization, size and age of vehicles, delivery zones, types of services and the like, which limited the possibility of expansion and long-term survival of the entire system. Table 3 lists the vehicles used in this project.

Table 3. Vehicles used in the project in the city of La Rochelle [2]

Vehicle	Battery type	Payload capacity [kg]
FAAM Jolly 1200 (electric van)	Lead-acid	900
Citroën Saxo (electric car)	Nickel-cadmium	300
Citroën Berlingo (electric car)	Lithium	700

5. EXAMPLES OF COMPANIES DEVELOPING DELIVERY MODELS WITH SMALL ELECTRIC VEHICLES

A significant shift to electric vehicles and micromobility is underway, especially among larger organizations. Companies such as Amazon and Ingka Group (the largest IKEA retail franchise operator) are leading the decarbonisation of last-mile deliveries through the use of electric vehicles.

IKEA is also investing in city center stores to reduce travel distances for customers. These stores serve as micro-hubs for the delivery of orders. Cargo bikes and foot deliveries are increasingly used in densely populated areas where motorized vehicle access is difficult. An example of the above: Ingka Group has already implemented small vehicles with low emissions for city deliveries.

Wolt, a fast food delivery company, has introduced several types of environmentally sustainable vehicles and is conducting pilot projects to evaluate their suitability for different markets. The company, in cooperation with financial institutions, launched a leasing and financing program, in order to provide its partners-couriers with access to modern vehicles with zero emission of harmful gases and reduce the emissions generated during delivery.

Despite some delays in the supply chain, express delivery companies (CEP) such as DHL and retail chains such as Ingka Group are working with OEMs – including Renault and MAN – to market dedicated zero-emission fleets.

Vehicle manufacturer Hero MotoCorp and electric vehicle rental service Vammo are driving electric vehicle adoption by addressing high initial costs through financing options and overcoming range limitations with battery-swapping technology, while Evolectric is converting existing internal combustion engine fleets to electric vehicles at a cost around 50% of the cost of new electric medium-duty trucks.

6. "LAST MILE DELIVERY" - APPLICABLE MATHEMATICAL MODELS

Researchers from the University of Bari, Italy, have formed a system that includes two levels of distribution. The objective of the model is to minimize the total costs of both levels, taking into account the costs of movement, the initial investment in vehicles, the costs and wages of drivers, as well as the costs of micro-depots. The proposed model highlights the advantages of using electric cargo bikes in areas with limited traffic in terms of energy savings and investment costs.

A linear programming model with mixed integer variables was formed, where the first level refers to the urban zone, and the second to the zone with limited traffic. The connection between the first and second levels is made by the transshipment point, where electric delivery vehicles (vans) deliver goods by electric cargo bikes, in accordance with the requirements of customers located in areas with limited traffic.

Based on the above, the transshipment point is a depot for the second level, where electric cargo bikes are parked. The whole of the first level consists of a depot, a set of customers, a set of fictitious stations and a transshipment point. A set of dummy stations allows for multiple visits to each charging station. Synchronization between the first and second levels is established through a transshipment point, where the quantity of goods at that point is defined as the sum of customer requests at the second level. Accordingly, the entire daily volume of goods is delivered to customers, so there are no inventory holding costs at the transshipment point.

The extended mathematical model of the proposed 2E-EVRPTW-PR based on Keskin and Çatay (2016) is formulated as follows:

$$f_1(x) = (c_v{}^{v^I} + c_d{}^{v^I}) \cdot w^I + (c_v{}^{v^I} + c_d{}^{v^{II}}) \cdot w^{II} + c_m + \sum_{k\in K^I} \sum_{i,j\in V^I_{dN1+1},\ i\neq j} d^I_{ij} \cdot c_e^{v^I} \cdot x^I_{kij} + \sum_{k\in K^{II}} \sum_{i,j\in V^{II}_{dN2+1},\ i\neq j} d^{II}_{ij} \cdot c_e^{v^{II}} \cdot x^{II}_{kij} \quad (1)$$

A comparison was made between the EVRPTW-PR model (Case 2.a) and the 2E-EVRPTW-PR model (Case 2.b) with the aim of minimizing total costs, which include movement costs, initial vehicle acquisition costs, driver salary costs and micro-depot costs.
Case 2.a:

$$f_4(x) = (c_v{}^{van} + c_d{}^{van}) \cdot w^I + \sum_{k\in K^I} \sum_{i,j\in V^I_{dN1+1},\ i\neq j} d^I_{ij} \cdot x^I_{kij} \cdot c_e^{van} \quad (2)$$

Where:
$c_v{}^{van}$ - The initial cost of investing in a van,
$c_d{}^{van}$ - The cost of the driver's salary for the vehicles,
w^I - Number of vehicles,
d^I_{ij} - Distance between points i i j,
x^I_{kij} – Binary decision variable,
c_e^{van} – The cost of the vehicle's electricity.

Case 2.b The objective function (Eq. 1), with constraints, minimizes the total cost of both levels.

According to the results of the numerical application, the proposed "green" logistics solution (case 2.b) could be useful for logistics companies with a large number of daily

requests. The results indicated the advantage of using electric cargo bikes in areas with limited traffic in terms of minimizing total costs.

Electric motorcycles are single-track vehicles, which by their nature are far less resistant to collisions than delivery vehicles, are also less visible to other drivers, pedestrians and have less dynamic stability than two-track vehicles. Operating a motorcycle requires a different combination of physical and mental skills than those used in a vehicle. Delivery motorcyclists are more vulnerable to the hazards of weather and road conditions than drivers of delivery vehicles (vans).

The supporting structure of the delivery motorcycle is with an open space for the driver, fig. 4, unlike the closed space of a delivery vehicle. This means that in the event of a traffic accident, during the overturning of the motorcycle, there is no preservation of the integrity of the interior space. The mass of the driver and the motorcycle are of the same order of magnitude, unlike a passenger car. For this reason, any change in the rider's mass significantly affects the dynamic characteristics and behavior of the overall rider-motorcycle system, mark 2, in fig. 4, in contrast to a two-track delivery vehicle with elastic tires, which has its own directional stability without the driver's help, a motorcycle, as a single-track vehicle, has neither directional stability nor vertical, upright position stability, marks 3 NPr and 3 NPo, respectively in Fig. 4, without driver assistance. This is one of the reasons that the role of a motorcycle rider is very complex and demanding.

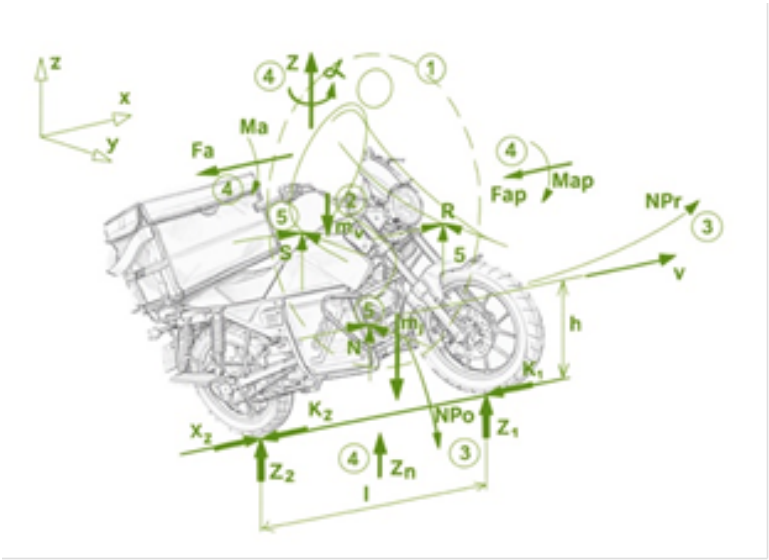


Figure 4. Geometrical and technical characteristics of the delivery motorcycle

The advantage of motorcycle delivery compared to vehicles is reflected in their agility, economy and efficiency. Motorcycles move more easily through city crowds, can use narrow streets and alternative routes, which significantly shortens delivery time. Motorcycles require less space for parking and storage, which makes them ideal for delivery in urban areas and for the so-called. "last mile". Thanks to their flexibility, they can also be used in areas where access to cars is limited, so they are often the fastest and most efficient solution for fast and ecological delivery.

7. CONCLUSION

Small electric vehicles significantly optimize the final stage of distribution of goods in urban areas, as they enable delivery with less space occupation, lower emissions of exhaust gases and noise, as well as easier parking and potentially greater efficiency on short urban distances.

However, it is important to emphasize that they are not a universal solution for all urban environments. Limitations are: limited payload, limited cargo volume, battery range, charging time, weather conditions and availability of appropriate infrastructure. The choice of a suitable small electric vehicle for last-mile delivery comes down to meeting the above-mentioned criteria with a detailed observation of the specific urban environment in which the vehicles are to be used.

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