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## ASSESSMENT OF ECONOMIC AND ENVIRONMENTAL EFFICIENCY OF UNMANNED AERIAL VEHICLES IN GREEN CITY LOGISTICS

*The paper aims to confirm the high demand for Unmanned Aerial Vehicles in urban logistics, highlighting the essence and composition of and the potential to reduce delivery costs and improve urban sustainability, emphasizing the growing importance of last-mile logistics. The practical significance of the research results lies in assessing external and internal costs, which provides a comprehensive and responsible approach to planning and organizing urban transportation of small loads, which are the object of last-mile logistics. The basic parameters of both transport options were determined, including technical characteristics, route structure and duration, and direct internal costs (wages, depreciation, fuel/electricity, repair and maintenance, other operating costs) and external costs (road accidents, air pollution, climate change impact, noise, congestion) are calculated. The calculation model is based on a two-dimensional approach to cost analysis, which makes it possible the assessment of the economic, social and environmental impact of delivery. The calculation result shows the advantages of using systems of unmanned aerial vehicles for delivery compared to cars. It shows that introducing a drone into operation can be an affordable delivery method, especially considering internal and external costs. The calculation algorithm is a valuable tool for planning and improving the "last mile" delivery processes, particularly for solving the difficulties of optimizing costs, reducing environmental impact, and ensuring sustainable development and quality of services, considering various aspects affecting the economy, society, and the environment. The work results are proposed to be considered when planning policies and incentives to support new challenges in urban delivery, as well as for the formation of policies and incentives aimed at the implementation of environmentally friendly transportation technologies.*

**Keywords:** unmanned Aerial Vehicle, drone, city logistics, last-mile delivery, parcel delivery, direct (internal) transport costs, external transport costs

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### INTRODUCTION

At present, last-mile delivery, the last stage of the supply chain, from the warehouse or distribution center to the client, is often inefficient and cost-consuming in terms of the total cost of delivering goods. At the same time, such delivery is an essential part of logistics since it directly relates to customer satisfaction. The potential use of drones for delivering parcels, food, medicine, and other items has become one of the most discussed innovations in logistics and transportation in recent years. The capacity of unmanned aerial vehicles to offer speedy and effective delivery services has made their usage in urban supply chains more and more common. The challenge of integrating them in general air traffic is still open, and the research topic encompasses all facets of aircraft operations, even though the technology of these machines is already at a high level and continually improving, like all fields of aviation.

Therefore, with comprehensive support of effectiveness estimation, their use in Ukraine should be rational, as UAVs can completely alter how items are transported in urban lo-

gistics. Their usage can result in earlier deliveries, lower costs, ensuring sustainability and more safety. Nevertheless, issues still need to be resolved to integrate drones into regular air traffic and guarantee their responsible and safe operation.

The **PURPOSE** of the paper is to identify the efficiency of drone application in city logistics, comparing traditional options for light parcels' last-mile delivery. The tasks were established to realize the purpose set as to highlight competitive advantages and pitfalls of UAVs' use in last-mile logistics; to identify outcomes of drone implementation in existing operations; and to analyse the efficiency of UAVs in the last-mile via a two-dimensional cost analysis. The object of the research is unmanned aerial vehicles in the last-mile logistics activity. The research subject is the efficiency of unmanned aerial vehicles used in urban supply chains for parcel delivery.

### RESEARCH METHODS

The research applies empirical analysis, synthesis, and comparison to evaluate the efficiency of UAVs in last-mile logistics. The model estimates direct (internal) and external

costs of parcel delivery by drones and conventional courier cars, based on cost and environmental indicators derived from European and Ukrainian data sources. The cost model takes into account direct financial costs and the impact of transport operations on society and the environment.

## RESULTS

Understanding the cost structure of last-mile activity is critical to optimizing delivery procedures and increasing the sustainability of urban delivery. Along with other factors, the costs borne also take into account the number of urban delivery vehicles required, the volume of parcels delivered, and the distance between customers. The model considered in [1-2] takes into account a two-divisional analysis of costs: direct (internal) and external costs of transport. Internal costs refer to the direct monetary costs (planning, construction, management, maintenance, disposal) for the person or organization carrying out the transportation activity. For various delivery methods, including cars and drones, all internal costs are associated with last-mile delivery, such as salary, depreciation, fuel, maintenance and repair, and other operating costs.

It should also be taken into account that the unsustainable development of the transport sector causes significant costs to society in terms of indirect consequences: traffic jams, obstacles to mobility, accidents, cost of services, etc., social impacts on people, health, and environmental impacts, such as emissions of greenhouse gases, air pollution, noise, habitat loss, etc. Thus, any transport scenario must also be evaluated in terms of such costs (indirect, external costs, or externalities). External costs or externalities refer to the concept of uncompensated environmental, mostly in modern practice, or social consequences, i.e., as a rule, a negative impact on a third party from the production or consumption of goods.

Due to the internalization of these costs, external factors become part of the decision-making process of transport users. This can be achieved through regulative command and control measures or by providing appropriate incentives to transport users through market instruments such as taxes, charges, emissions trading, etc. The European Commission published the first Handbook on External Costs of Transport, that is used focusing on "marginal external costs of transport as a basis for determining internalization policies, as well as on total and average external transport costs, through the EU, Switzerland, and Norway" [3].

The methodology proposed by Comi & Savchenko [4] will be used in this research and indicates direct, internal, and external costs, which include an emphasis on internal / external direct effects considered in traditional cost-benefit analysis. In addition, the analysis is performed at the strategic level, leaving the tactical and operational aspects for evaluating such delivery strategies for other specific studies. The following calculations will consider salary costs, amortization costs, fuel costs, maintenance and repair costs, and other operational costs as components of internal costs. The total direct internal costs for daily deliveries of all parcels, during all working shifts and through delivery mode, can be calculated as a sum of all components.

Salary costs are assumed to be calculated by dividing the monthly salary for each working shift by the average number of working days in a month. Amortization costs are defined as the fraction of the cost of the vehicle divided by its

useful life  $t_{ai}$  (in years) and the number of months in the year. The resulting annual depreciation is multiplied by the number of transport units  $NN_i$  and the number of changes. The fuel consumption depends on the travelling speed and the route length. The cost of fuel ( $C_{fi}$ ), is equal to route length is multiplied by the average fuel consumption  $c_{fi}$  and the number of transport units. Maintenance and repair costs are determined based on average annual costs for maintenance of each UDM of type  $i$  during 12 months, as multiplied by the number of shifts and the number of transport units. Other costs due to operations, as well as to the management of delivery vehicles (e.g., tyres, wipers, etc.), can be assumed, at first instance, equal to 50 % of maintenance and repair costs and other costs per day.

The direct external costs for each considered transport mode were estimated starting from the available national statistics and literature [3], based on the specific mode of transportation, fuel type, emission class, and urban/rural location. The following external cost elements are taken into account in the calculations [4]:

- *Air pollution*: the expenses related to air pollution brought on by the method of transportation. Drone air pollution costs are taken for electric motorcycles;

- *Climate change*: the expenses incurred due to greenhouse gas emissions that cause climate change. UAV costs are considered zero, as this mode is sustainable (uses electricity as a fuel, more eco-friendly concept, etc.);

- *Noise*: the expenses of noise pollution produced by the method of transportation. Drone costs are assumed to be 10% of the respective car values;

- *Congestion*: the expenses related to traffic congestion brought on by the method of transportation. UAV's congestion expenses are regarded as zero because this method doesn't directly utilize roads.

An example that allows indicating the pros and cons of using UAVs compared to direct competitors is a car such as Renault Dokker, Citroën Berlingo – detailing the various components of internal and external costs and avoiding compensatory effects arising from considering different types and sizes of market operators. The intended UAV may be the M-6-3T «Zhayvir», designed by the National Aviation University. Vehicle is intended for transporting loads weighing up to 4 kg in automatic mode over a distance up to 800 km, with a minimum steady flight speed in take-off and landing of 50-55 km/h and cruising speed of 80 km/h [5].

Assumed standard delivery parameters for the considered vehicles are presented in Table 1, referring to a 7-hour working day (e.g., from 10:00 to 17:00 or other specifications), 240 working days per year, and an average number of parcels to deliver per day is 100 items. Specific indicators like average parcel characteristics (weight and volume) are provided to identify vehicle weight and volume capacity constraints ( $n_i$ ) are calculated by formula:

$$n_i = \min \left[ INT \left( \frac{q_i}{q} \right), INT \left( \frac{v_i}{v} \right) \right].$$

Prior to calculations, it is necessary to obtain the number of delivery vehicles needed to serve the daily delivery demand ( $NN_{ij}$ ), which is the target function of the model that requires minimization, as well as the need to identify the maximum number of routes per shift ( $M$ ), route travel time ( $T_{ij}$ ), and a number of parcels to deliver in a route ( $N_{ij}$ ). This value is calculated using an optimization algorithm to mini-

mize the number of vehicles required for delivery. The variable is the number of customers in a route ( $N_{ij}$ ). This value is calculated using an optimization algorithm to minimize the number of vehicles required for delivery.

The results of preliminary calculations are provided in Table 2. Internal cost parameters were obtained through the use of formulas 1-5, and the results are summarized in Table 3.

The European Commission's vision is to consider the following types of transport externalities: congestion costs, traffic accident costs, traffic noise costs, air pollution costs, and climate change costs, which will be reflected in the current study. The values of specific cost types will be used in the calculations in the current subsection, taking into account values from the Handbook [23]. It is shown that utilizing a car to deliver one parcel results in much higher total external expenses than a UAV. However, employing a UAV to deliver the parcels results in substantially cheaper external costs of just 2,14 euros for 1 UAV annually. It becomes clear from comparing the two delivery methods that a car incurs far greater external expenses than a UAV, because road ve-

hicles have far greater external costs for congestion and accidents on the road. Also vehicles' external costs related to climate change and air pollution are higher. As a result, this data emphasizes the advantages of employing UAVs for delivery over autos in terms of lowering external transport costs. Table 4 details the internal and external costs associated with the delivery of one parcel by car or UAV.

The overall internal expenses for one car are 62,53 euros, while the total internal costs for one parcel delivered by a car are 3,13 euros. Five cars are typically utilized, resulting in an internal cost of 15006,6 euros for each vehicle annually. If we add the external costs, each parcel will cost 3,3 euros. The general internal expenses for one drone are 45,81 euros, while the total internal costs for one parcel delivered by a UAV are 3,21 euros. Seven UAVs have to be used, resulting in an internal cost of 10993,5 euros per vehicle for the entire year. Considering the small external costs for UAVs in last-mile logistics, the total delivery costs for one parcel will be 3,21 euros, which is less than that by car.

Table 1 – Standard delivery parameters for the considered vehicles

Cost parameter	Car	UAV
Average parcel weight, $q$ , kg	1,5	
Average parcel volume, $v$ , m <sup>3</sup>	0,001	
Weight capacity, $q_i$ , kg	200	2
Volume capacity, $v_i$ , m <sup>3</sup>	0,6	0,027
Average distance between customers on a typical delivery route, $l_{cc}$ , km	1	0
Average length of the first and last trip of the delivery route, $l_0$ , km	5	5
Average speed during route plan execution, $V_{ij}$ , km/h	15	30
Average time for delivering item to customer, $t_{1ci}$ , h	0,17	0,03
Average preparatory-final time for a delivery route, $t_{prep}$ , h	0,5	0,1
Price of a UDM, $P_i$ , EUR	30000	3000
UDM time of use, $t_{ai}$ , years	5	
Cost of fuel/electricity for 1 UDM, $c_{fi}$ , EUR/km	0,1	0,05
Salary of 1 operator/driver, $S_{ij}$ , EUR/month	600	800
Cost of maintenance and repair of 1 of a UDM, $R_i$ , EUR/month	200	100

Table 2 – Preliminary parameters of the delivery route during the shift

Parameter	Formula or designation	Car	UAV
Number of parcels to deliver in a route	$N_{ij}$	24	1
The average route distance, km/day	$L_{ij} = 2 \cdot l_{0i} + (N_{ij} - 1) \cdot l_{cci}$	33	10
Time on a route, h	$T_{ij} = t_{prepi} + L_{ij} / V_{ij} + N_{ij} \cdot t_{1ci}$	6,78	0,46
Maximum number of routes per shift	$M = t_i / T_{ij}$	1,03 ~ 1	15,11 ~ 15
Number of UDM needed	$NN_{ij} = [N / (M \cdot N_{ij})] \rightarrow \min$	4,17 ~ 5	6,67 ~ 7

Table 3 – Direct internal costs of proposed delivery route, EUR

Delivery mode	Components of internal costs					Total internal costs	Number of vehicles used	Total internal costs for one vehicle	Total annual internal costs for one vehicle	Total internal costs per item
	Salary	Amortization	Cost of fuel	Maintenance	Other expenses					
Car	150,00	125,00	16,50	4,17	14,89	312,64	5	62,53	15006,60	3,13
UAV	280,00	17,50	3,50	2,92	15,27	320,64	7	45,81	10993,50	3,21

Table 4 – Total costs of proposed delivery route, EUR

Delivery mode	Total internal costs	UDM used	Total internal costs for 1 UDM	Total annual internal costs	Total annual external costs	Total int. costs per parcel	Total external costs for parcel	Total costs for a parcel
Car	312,64	5	62,53	15006,60	4153,18	3,13	0.1730	3,30
UAV	320,64	7	45,81	10993,50	2,14	3,21	0.00008	3,21

The algorithm may aid calculations, accounting for various aspects that influence the economy, society, and environment. Additionally, these calculations imply that introducing a drone into operations may be an affordable delivery method, especially when considering internal and external costs.

### CONCLUSIONS

Improving delivery processes and increasing transportation sustainability requires understanding the cost structure of last-mile logistics. At the same time, the proper rules and incentives can be developed to encourage the use of environmentally friendly transport. Understanding the cost structure of this activity is essential if one is to comprehend the economic, social, and environmental effects of various transportation scenarios, including traffic jams, accidents, service costs, health effects, and environmental effects like greenhouse gas emissions, air pollution, noise, and habitat loss. Consequently, it is necessary to include these expenses while

evaluating any transit scenario.

Overall, using drones for last-mile deliveries can assist in lowering costs and have a less negative impact on the environment. The estimates made in this scenario aid in understanding the economic, social, and environmental effects of employing drones for delivery. By evaluating their internal and external costs, we can determine the efficiency and sustainability of various delivery techniques, such as employing automobiles or drones. The above findings are suggested to be considered when planning policies and incentives to support new challenges in urban delivery. The evaluation of external and internal costs according to the proposed methodology will allow a comprehensive and responsible approach to the planning and organizing of urban transportation of small cargoes, which is the object of application of last-mile logistics.

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**ОЦІНЮВАННЯ ЕКОНОМІЧНОЇ ТА ЕКОЛОГІЧНОЇ ЕФЕКТИВНОСТІ БЕЗПІЛОТНИХ ЛІТАЛЬНИХ АПАРАТІВ У ЗЕЛЕНІЙ МІСЬКІЙ ЛОГІСТИЦІ**

Визначено загальні параметри для доставки транспортними засобами з урахуванням впровадження принципів зеленої логістики: автомобілем і безпілотним літальним апаратом, параметри маршруту доставки, прямі внутрішні зовнішні витрати запропонованого маршруту доставки. Основними причинами впровадження систем безпілотних літальних апаратів визначено потребу у скороченні часу доставки, зменшенні витрат на перевезення, подоланні обмежень транспортної інфраструктури у перевантажених міських зонах та мінімізації негативного впливу транспорту на довкілля. Встановлено, що дрони здатні уникати заторів, забезпечувати прямі та швидкі маршрути до споживачів, а також ефективно обслуговувати віддалені чи важкодоступні райони. Результати розрахунку показують переваги застосування дронів для доставки порівняно з автомобілями й те, що впровадження дрона в експлуатацію може бути доступним методом доставки, особливо з урахуванням внутрішніх і зовнішніх витрат. У ході моделювання показано істотне зниження зовнішніх витрат у застосуванні безпілотного літального апарата, що зумовлено відсутністю викидів від двигунів внутрішнього згорання, мінімальним шумовим впливом та виключенням участі в дорожньому русі. Алгоритм розрахунку є інструментом планування та вдосконалення процесів доставки «останньої милі», зокрема для вирішення труднощів з оптимізацією витрат, зменшення впливу на навколишнє середовище та гарантуванням сталого розвитку та якості послуг, враховує різноманітні аспекти, що впливають на економіку, суспільство та навколишнє середовище. Результати роботи запропоновано враховувати у плануванні політики та стимулів для підтримки нових викликів у міській доставці, зокрема алгоритм може бути застосовано на етапах планування оптимізації транспортних процесів, зменшення негативного впливу на довкілля та підвищення стійкості логістичних систем.

**Ключові слова:** безпілотний літальний апарат, дрон, міська логістика, доставка «останньої милі», доставка посилок, прямі (внутрішні) транспортні витрати, зовнішні транспортні витрати