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Abstract

Effective last mile (LM) delivery is critical to efficient functioning of supply chains. In addition to speed and cost of delivery, environmental and social sustainability are increasingly important factors in last mile logistics (LML), especially in urban areas. Sustainable solutions involve application of various modern technologies. Autonomous vehicles and drones have attracted special attention of researchers in recent years, with their vast application potential. Despite potential benefits of deployment in LML, future of drone logistics is uncertain due to a number of barriers. Aim of this study is barriers analysis, evaluation and ranking, to identify those that prevent wider application of drones in LM to the greatest extent. For solving the defined problem this study used the fuzzy Delphi ANP (fuzzy DANP). Results indicate that the most critical barriers to implementation are lack of regulations, drone tracking, drone owners' liability and obstacle and collision avoidance. Higher perceived risk and short flight range are of lesser impact. The contribution of this study is in the fact that the analysis of barriers to the implementation of drones is assessed from different perspectives and interests of different stakeholders, which represents a new approach compared to previous research in this field.

***Keywords**: drone logistics, barrier analysis, last mile, city logistics, fuzzy Delphi, fuzzy ANP*

1 Introduction

City is a location of the greatest concentration of people, economic and social activities, and logistics is extremely important for its functioning. Therefore, city logistics (CL) is a very important area of planning due to its close connection with the sustainable development of urban areas [1]. Globalization, the growth of the consumer society, the change of the production paradigm, the development of Industry 4.0 and the development of e-commerce cause various challenges in terms of achieving efficient and sustainable logistics, especially in urban areas [2]. The consequence of the aforementioned is the fragmentation of the market, an increase in home deliveries, an increase in the demand for more rapid deliveries, an increase in the frequency of delivery, a decrease in the volume of delivery, as well as the occurrence of personalized consumption patterns [3]. This significantly complicate the Last Mile Logistics (LML) processes. LML is the last stage of the supply chain where contact with the final consumer is made. It is often described as the most complex, expensive, inefficient and polluting part of the supply chain [4]. Some studies estimate that Last Mile (LM) delivery accounts for 13-75% of total supply chain costs, depending on the influence of various factors [5]. Some of them are the complexity of the urban environment and the adaptability of the infrastructure to the operations of logistics providers, the occupancy rate of delivery vehicles, restrictions imposed by local authorities, the length of LM, the size and homogeneity of shipments, the required delivery times, traffic congestion, etc. In addition to the impact on economic sustainability, ineffective planning and management of LML has a negative impact on environmental and social sustainability. This is the conseqeunce of the creation of congestion, air pollution, increased noise, reduced traffic safety, and damage to the infrastructure network.

According to research from the World Economic Forum in 2020, the number of

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deliveries in cities is expected to increase by 36% by 2030. This will generate a 32% increase in greenhouse gas emissions from delivery traffic, an increase in congestion by over 21% and an additional 11 minutes of commuting for of every passenger on a daily level. These figures show the substantial importance, but also the pressure of the logistics sector in cities. Therefore understanding LML, as well as its effective planning and management, is of vital importance for obtaining economic, environmental and social sustainability of cities. Notwithstanding the problems founded in changes in supply chains, technological innovations enable the application of modern solutions for the delivery of LM. In addition to rate and cost of delivery, which are the most important factors for LML, environmental and social sustainability are taking on an increasingly important role. In this perspective, solutions such as autonomous vehicles and drones as a type of these vehicles can be a good choice both in terms of transport speed and sustainability. Being electrically powered, drones may reduce environmental impact and reduce road congestion as they do not interfere with land infrastructure [6]. Despite the potential advantages, the usage of drones is not widespread, and its future is uncertain due to several barriers such as regulations, legislation, a threat to privacy, security, public and psychological perception, and environmental, economic, and technical issues.

The aim of this study is to analyze the barriers to the application of drones for the delivery of LM. This is done by taking into account the conflicting demands of different stakeholders: providers and users of services, the city and regulatory bodies, the public and the population. In order to determine the priorities for resolving them, the , fuzzy Delphi ANP multi-criteria decision-making method (fuzzy DANP) is used. In the first step, the structure of the problem is defined, that is, the definition of barriers and their grouping. Afterwards an analysis is performed in order to determine the mutual influence of barriers and the intensity of that influence.

The study is organized in five sections. The following section describes the problem. Afterwards, a methodology is proposed implying a combination of methods for determining the significance and ranking the barriers for the use of drones. In the fourth section, the obtained results are presented. Finally, the last section presents conclusions and recommendations for future research.

2 Description of the problem

Delivery of goods by drones represents an innovative, promising and significant solution to many problems in LML. This has an impact on all participants and stakeholders. Customer demands are increasingly complex in terms of the availability of the desired product and the rate of delivery [7]. These issues can be addressed by efficient drone delivery [8], contributing to decrease in delivery costs, emissions and traffic congestion in cities. However, it should be taken into account that the application and acceptance of drones for the delivery of goods depends on many factors that must be further investigated and resolved.

Existing studies on consumer acceptance of delivery drones reveal that the privacy and sensitive personal data risk is one of the primary challenges when it comes to the acceptance of drone delivery technology [9]. In addition, security risk, fear of drones falling, risk of injury or loss of personal belongings are factors that influence the acceptance of new technology, while on the other hand, innovation and environmental acceptability are the main reasons for its adoption [10, 11].

Previous research has identified barriers to the implementation of drones that may be grouped into several categories [12]:

- Privacy and security
- Regulations and legislation
- Public acceptance and psychological perception
- Environmental issues
- Economic aspects
- Technical issues

2.1 Privacy and security (Ps)

The commercialization of drones may pose a threat to public privacy, particularly in the context of the delivery by drones. They may be equipped with cameras and other sensors that can collect data about people and objects on the ground, which might lead to:

1. Identity theft and collection of private information
2. Unauthorized non-consensual photographing and recording
3. Unauthorized usage of data and blackmail
4. Complex identification of unauthorized drones

5. Unauthorized usage of drones
6. Violations of rights
7. Physical attacks, obstruction and phishing
8. Intentional hacking, cyber attacks and terrorism

Many people are resistant to drones due to concerns about their privacy or safety due to the possibility of photographing, recording and monitoring private spaces without consent. In addition, it is complex to identify unauthorized drones, and determine when and who is performing filming [13].

Drones used for logistics applications may be very effective in delivering products to customers. However, in spite of the fact that they are primarily only used to collect basic information about the route and location of the delivery [14], they may additionally collect other data: information about customers, their addresses and locations of movement, the products they buy, payment cards information, the environment. However, these data may be used without the consent of the owner, and in this way the privacy and security of the user may be endangered. Given that drones can be easily accessible, there is concern that they might also be used without authorization. They can carry out illegal activities such as spying and the transfer of illegal substances (drugs, dangerous substances).

In addition to being used in logistics applications, drones may be used for other purposes, including terrorist activities, posing a serious risk to national security. They may be programmed to transport explosive devices or weapons and can be used to execute attacks on public places or critical infrastructure. Drones may be misused for cybercrime purposes. Drones may be hacked, which would allow attackers to take control of them and perform cyber attacks on systems located in the drone's operating zone [15,16]. They can be used for obtaining personal information, such as credit card information and other sensitive data. In addition to drones, drone transportation systems are vulnerable to cyber-attacks. They can be utilized to take control of drones and steal sensitive information about flight and other drone operations, which may lead to collisions between drones, collisions with other objects and/or people, and generate serious incidents.

2.2 Regulations and legislation (Rl)

The government is responsible for regulating the use of drones in the delivery of goods in urban areas in order to protect the interests of the community and ensure the safety and privacy of residents [13]. The regulation of drone delivery aims to prevent possible accidents and property damage due to drone crashes or collisions with other objects. The regulation is also important to protect citizens' privacy and to prevent unauthorized surveillance that might be performed using drones. There are several barriers that may affect the implementation of drones in the delivery of LM, and they are related to regulations and legislation [12]:

1. Liability for drone owners
2. Drone routes
3. Insurance obligations
4. Operator certifications and training
5. Congested airspace for manned aircraft
6. Establishing liability
7. Lack of aviation regulation

Restrictions on the use of drones in certain airspace zones or altitudes and restrictions on the weight and size of drones may make it difficult to utilize drones for LM deliveries in urban areas. There are concerns that drones might pose a safety and security risk to air traffic. They might fly in close proximity to manned aircrafts, especially in urban areas, where airspace may be congested with scheduled commercial flights. Determining liability may be a barrier for the implementation of drones in LML. It is important to determine liability in the event of accidents or damage and identify regulations that govern this.

In addition, the use of drones for LM delivery may require special permits, training, certifications and licenses to operate drones. This requires additional time and resources. Drone owners are often liable for damage or accidents that occur during the usage of drones. This presents an additional challenge in terms of insurance and other measures to protect against potential damages.

Non-compliance of aviation and other regulations with new technologies and innovations may lead to uncertainty regarding the legal framework. This imposes challenges to planning and implementation of an effective strategy for the application of drones. The lack of aviation regulation may also lead to disparate market conditions between companies that use drones and those that do not, which may affect competitiveness and innovation.

2.3 Public acceptance and psychological perception (Pp)

According to a Polish study, 43% of the population expressed skepticism about the implementation of drones, implying the existence of social barriers to the adoption of drone delivery of goods [17]. Other studies in urban areas in Australia point out that traditional postal services are preferred over drone delivery despite recent advances in e-commerce and technology [18]. Societal anxiety about automation contributes to skepticism towards drones [12].This is particularly due to the perception that they are mainly intended for military and surveillance purposes and/or are owned by terrorist groups [19]. Additionally, people express strain that the use of drones might lead to the disappearance of traditional retail, resulting in decrease of vacancies, increased stress levels, decreased social interactions, and the creation of an elite mode of mobility [20]. Social inequality is considered to be another significant barrier to the implementation of drone delivery due to the anxiety that drones would be available only to the wealthy [21]. In addition, social anxiety and security concerns are caused by the so-called cyber security of drones [16, 22]. Intolerance towards the usage of drones may be further reinforced by users' distrust in automation and technology. There is a concern that the drone or the package that it carries, might fall, thus posing a potential risk. Additionally, the inability to distinguish drones in the sky, i.e. non-transparency, can lead to mistrust towards drones and further rejection of their usage, as it may not be possible to distinguish between a drone used for commercial purposes and a drone used for illegal activities or terrorist attacks.

In the literature, barriers related to public acceptance and psychological perception are divided as follows [12]:

1. Greater perceived risk
2. Awareness of drone technology
3. Non-transparency
4. Social anxiety about automation
5. Annoyance of the public
6. Usage of drones in the private sector
7. Drones and theft

2.4 Environmental issues (En)

The attitude of users towards the delivery of goods by drone largely depends on the extent of the impact their usage poses on the environment. Large-scale deployment of drones has been found to reduce pollution more effectively in rural than in urban areas [23].

Drones cause noise pollution as well, CO2 emissions and visual pollution [24–27]. Drones are powered by engines, which emit gases into the atmosphere, including CO2 and other harmful gases. The amount of CO2 emissions produced by drones is relatively small compared to other types of transport, such as internal combustion vehicles. However, if drones are used on a large scale, the emissions may gradually accumulate and contribute to the total emissions, especially if the drones have to travel longer distances [28].

Studies that tested the impact of drone noise near busy and less busy roads show that sound disturbance on busy roads is concealed by traffic noise and is only 1.13 times higher than without drone noise, compared to less busy roads where sound disturbance generated by drones is 6.4 times higher. This indicates that planning drone routes near busy roads would significantly reduce noise pollution [29].

Shadowing is another impact that drones pose on the environment [16]. Since drones fly above the ground, they may produce sounds and noise that may affect animals and people nearby. In addition, the shadows of drones in flight may also cause "visual pollution" and disrupt people and animals on the ground. Adverse weather conditions (wind storms, snow storms, poor visibility and thunderstorms) represent a major challenge for the undisturbed delivery with drones [18, 30].

Research suggests that drones may affect animals in different ways [22, 31]. For example, flying drones may disturb birds and alter their natural behavior. Moreover, birds and other animals may be physically harmed in the event of collision with drones [13]. There are additional concerns that flying drones might affect the migration of birds, since they use sound as a navigation tool, therefore drone noise may disrupt their ability to navigate. Hence, it is important to use drones in a responsible manner, in compliance with legislation and regulations, in order to minimize the negative impact on animal life.

Accordingly, when considering the usage of drones for LM delivery, the environmental impact should also be taken into account [12]:

1. CO_2 emission
2. Impact on animals and birds
3. Visual and sound pollution
4. Particle emission

2.5 Economic aspects (Ec)

Although the usage of drones may be more efficient and decrease costs compared to traditional delivery methods, there are economic challenges to consider as well. Investing in drones and related technologies can be costly. In addition to the drone itself, it is necessary to make further investments in software, sensors, surveillance cameras and other technologies required for the safe and efficient operation of the drone. Moreover, operator training and certification costs imply additional resources and expenses.

As with other technological innovations, the introduction of drones in the logistics industry may lead to changes in the labor market. Although package delivery drones create new vacancies, the reduction in the use of trucks and other vehicles in logistics may lead to a reduction in the need for drivers and other personnel in the logistics sector. The introduction of new technologies may contribute to an increase in the economic gap between the rich and the poor, thus exacerbating existing social inequalities and socioeconomic problems [16]. From the economic aspect, the barriers are grouped into [12]:

1. High initial costs
2. Economy and employment
3. Disruption of the transport industry
4. Uneven distribution of income

2.6 Technical issues (Te)

There are several crucial technical performance challenges that affect the successful deployment of drones [12]:

1. Short flight range
2. Navigation
3. Adverse weather conditions
4. Obstacle and collision avoidance
5. Drone tracking
6. Limited transport capacity

Drones are limited by their autonomy and battery life, which is a challenge for more extensive flights or for operations in remote locations [32]. Furthermore, drones may encounter technical barriers, such as adverse weather conditions that may interfere with safe flight and result in damage to the drone or other material damages [16]. Delivery risk is also an important factor affecting public acceptance of drones as a means of delivery. It refers to the probability that the drone might not be operable and/or might be unable to deliver the product [11]. With the application of appropriate safety measures and training, the risk of technical problems with drones in adverse weather conditions may be reduced to an acceptable level. This might increase further usage of drones in various fields, including logistics. In addition, drones have several other technological disadvantages, such as difficulties in avoiding obstacles such as buildings, structures, other drones, aircrafts, and birds [33], as well as low transport capacity [34].

3 Methodology

The fuzzy Delphi based fuzzy ANP method (fuzzy DANP) was used in this paper to solve the problem of prioritization. The first step of applying the method is defining the structure of the problem, that is, defining barriers and grouping them. For the problem defined in this way, an analysis is performed in order to determine the mutual influence of barriers and the strength of that influence. The analysis implies a comparison of all pairs of barriers from the perspective of different stakeholders. A linguistic scale was used for comparison, which can be converted into triangular fuzzy numbers shown in Table 1.

Table 1. Fuzzy scale for comparing elements

Linguistic term	Abbreviation	Fuzzy Scale
None	NI	(1, 1, 2)
Very low	VN	(1, 2, 3)
Low	N	(2, 3, 4)
Fairly low	UN	(3, 4, 5)
Medium	S	(4, 5, 6)
Fairly high	UV	(5, 6, 7)
High	V	(6, 7, 8)

Different evaluations of the stakeholders' representatives were combined using the following equations, which are part of the fuzzy Delphi method [35]:

$$\tilde{\delta}_{ij} = \left(\alpha_{ij}, \beta_{ij}, \gamma_{ij}\right) \qquad (1)$$

$$\alpha_{ij} = Min\left(l_{ijl}\right),\; l = 1,...,o \qquad (2)$$

$$\beta_{ij} = \left(\prod_{l=1}^{o} m_{ijl}\right)^{1/o},\; l = 1,...,o \qquad (3)$$

$$\gamma_{ij} = Max\left(u_{ijl}\right),\; l = 1,...,o \qquad (4)$$

where α_{ij}, β_{ij} and γ_{ij} are the lower, middle and upper values of the unified fuzzy evaluation δ_{ij}, respectively, and $\alpha_{ij} \le \beta_{ij} \le \gamma_{ij}$. l_{ijl}, m_{ijl} and r_{ijl} are the lower, middle and upper values of the triangular fuzzy evaluation $\tilde{a}_{ijl}$ which implies the significance of the element (barrier) *i* in relation to the element *j* from the stakeholder *l* point of view. *o* is the number of stakeholders' representatives who made the evaluations.

By applying the relations (1)-(4), unified evaluations of the pair-vise comparisons are obtained, based on which fuzzy decision matrices $\tilde{\Delta}$ are formed in the following way:

$$\tilde{\Delta} = \begin{bmatrix} / & \tilde{\delta}_{12} & \cdots & \tilde{\delta}_{1n} \\ \tilde{\delta}_{21} & / & \cdots & \tilde{\delta}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{\delta}_{n1} & \tilde{\delta}_{n2} & \cdots & / \end{bmatrix} \qquad (5)$$

For each pair wise comparison matrix, it is necessary to obtain the priority vector in order to form different sub-matrices of the supermatrix. The priority vector from the fuzzy matrix $\tilde{\Delta}$ can be obtained in various ways. This paper uses "logaritmic fuzzy preference programming" (LFPP) method [36] which approximates the fuzzy value $\tilde{\delta}_{ij}$ from the matrix $\tilde{\Delta}$ by the relation:

$$\ln\tilde{\delta}_{ij} \approx \left(\ln l_{ij}, \ln m_{ij}, \ln r_{ij}\right),\; i, j = 1,2,...,n \qquad (6)$$

To determine the priority value of the elements (w_i), it is necessary to solve the following non-linear priority model:

$$Min\,J = (1-\lambda)^2 + M \cdot \sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\left(\varepsilon_{ij}^2 + \eta_{ij}^2\right)$$

$$s.t.\begin{cases} x_i - x_j - \lambda\ln\left(m_{ij}/l_{ij}\right) + \varepsilon_{ij} \ge \ln l_{ij}, \\ \quad i = 1,...,n-1;\; j = i+1,...,n, \\ -x_i + x_j - \lambda\ln\left(r_{ij}/m_{ij}\right) + \eta_{ij} \ge -\ln r_{ij}, \\ \quad i = 1,...,n-1;\; j = i+1,...,n, \\ \lambda, x_i \ge 0, i = 1,...,n, \\ \varepsilon_{ij}, \eta_{ij} \ge 0, i = 1,...,n-1;\; j = i+1,...,n, \end{cases} \qquad (7)$$

where $x_i = lnw_i$ for $i = 1,...,n$, and M is a constant of sufficiently large value such as $M = 10^3$. ε_{ij} and η_{ij} for i=1,...,n-1 and j=1,...,n are non-negative variable deviations that are introduced to prevent λ from taking a negative value. It is desirable that the values of the variable deviations be as small as possible, and the following inequalities must be fulfilled:

$$\ln w_i - \ln w_j - \lambda\ln\left(m_{ij}/l_{ij}\right) + \varepsilon_{ij} \ge \ln l_{ij},$$
$$i = 1,...,n-1;\; j = i+1,...,n,$$

$$-\ln w_i + \ln w_j - \lambda\ln\left(r_{ij}/m_{ij}\right) + \eta_{ij} \ge -\ln r_{ij},$$
$$i = 1,...,n-1;\; j = i+1,...,n.$$

Let $x_i^*\left(i = 1,...,n\right)$ be the optimal solution of the model (7). Normalized values for the fuzzy comparison matrix $\tilde{\Delta} = \left(\tilde{\delta}_{ij}\right)_{n\times n}$ are obtained as:

$$w_i^* = \frac{\exp\left(x_i^*\right)}{\sum_{j=1}^{n}\exp\left(x_j^*\right)},\; i = 1,...,n, \qquad (8)$$

where exp() is an exponential function, that is, $\exp\left(x_i^*\right) = e^{x_i^*}$ za i=1,...,n.

In order to control the results of the method, it is necessary to calculate the Consistency Ratio (CR) for each matrix and the overall inconsistency of the hierarchical structure.

Form the initial super-matrix whose elements are the optimal solutions of the nonlinear model (7) and obtain the limit super-matrix. By raising the initial super-matrix to the power of *2p + 1*, where *p* is a sufficiently large number, the matrix converges, that is, the values in the rows of the matrix converge to the same values for each column of the matrix [37]. The newly obtained matrix is called the limit super-matrix.

4 Solution of the problem

The barriers described in section 3 were evaluated by members of different stakeholders: service providers, service users, residents and city administration. Stakeholders' representatives compared all pairs of barriers, both within groups and between groups, thus establishing internal and external dependencies of barriers. The importance of the mutual influence of barriers was evaluated using linguistic evaluations that can be transformed into triangular fuzzy numbers using the relations given in Table 1.

By applying equations (1) - (4), the transformed fuzzy ratings are combined, thus forming fuzzy comparison matrices. By solving the nonlinear priority model (7) for each of the matrices, the weights of the elements (barriers) were obtained, from which the initial super-matrix was formed. This matrix was then raised to the *2p + 1* power to obtain a limit super-matrix. These values are adopted as weights (importance) of the observed barriers. The obtained results are shown in Table 2.

Table 2. Results of evaluation of obstacles using the fuzzy DANP method

Barrier	Weight (significance)	Barrier	Weight (significance)
En1	0.007	Ec1	0.032
En2	0.042	Ec2	0.037
En3	0.029	Ec3	0.002
En4	0.012	Ec4	0.005
Pp1	0.049	Te1	0.047
Pp2	0.042	Te2	0.034
Pp3	0.008	Te3	0.006
Pp4	0.029	Te4	0.057
Pp5	0.034	Te5	0.064
Pp6	0.015	Te6	0.005
Pp7	0.020	Ps1	0.022
Rl1	0.058	Ps2	0.021
Rl2	0.024	Ps3	0.022
Rl3	0.010	Ps4	0.012
Rl4	0.019	Ps5	0.020
Rl5	0.031	Ps6	0.032
Rl6	0.037	Ps7	0.027
Rl7	0.069	Ps8	0.023

Based on the obtained results, it may be recognized that the lack of aviation regulations, drone tracking, drone owners' liability and obstacle and collision avoidance are of the most crucial importance. They are followed by the problems such as higher perceived risk and short flight range. From the perspective of a group of barriers, technical barriers, legislation and regulations are of the highest priority.

Non-compliance of aviation and other regulations with new technologies and innovations may lead to uncertainty regarding the legal framework and make it challenging to plan and implement an effective strategy for the implementation of drones. The lack of aviation regulation may also lead to disparate market conditions between companies that use drones and those that do not, which may affect competitiveness and innovation.

5 Conclusion

The popularity of drones is increasing in the general public as well as in science. However, the uncertainty of their future application is also increasing. This study uses the fuzzy Delphi ANP method (fuzzy DANP) to resolve the issues of prioritizing the barriers for the application of drones in LML. The analysis of barriers to the implementation of drones in LM is evaluated from different perspectives and interests of different stakeholders, which represents a new approach compared to previous research in this field.

The results indicate that the most critical barriers to the implementation of drones in LM are lack of aviation regulations, drone tracking, drone owners' liability and obstacle and collision avoidance. They are followed by higher perceived risk and short flight range.

Overall, based on the groups of barriers, the study concludes that legislation and regulations, as well as technical issues, are the most critical barriers to drone implementation. Public acceptance and psychological perception and environmental issues are medium critical. Privacy and security and economic aspect are the least critical barriers identified. Therefore, due to the lack of regulations and legislation, the possibilities of a large-scale usage of drones in LML are currently small. For future research, the same analysis may be performed with additional barriers identified with the development of drone technology and its commercialization.

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