

Research Article

Novel Spherical Fuzzy MARCOS Method for Assessment of Drone-Based City Logistics Concepts

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Technological innovations from the last few years, in the combination with city logistics (CL) initiatives, make the definition of novel, complex, sustainable CL solutions possible. Unmanned aerial vehicles (drones) as a technology attracted lots of attention in the literature. Various researches focused on different drone-based delivery approaches, but there are only a few articles dealing with drones as the elements of complex CL concepts. The goal of this paper is to evaluate different drone-based CL concepts. Based on the existing ideas of drone application in delivery, the main group of CL concepts and their variants are defined, which represents the main contribution of the article. The evaluation and ranking of concepts are performed from the aspect of all CL stakeholders and the defined set of criteria by applying measurement of alternatives and ranking according to compromise solution (MARCOS) multicriteria decision-making (MCDM) method in spherical fuzzy environment, which represents another contribution of the article. The results indicate that the potentially best CL concept, with the final score of 0.408, is the one that refers to the transformation of the logistics system into a two-echelon system with the implementation of micro-consolidation centers (MCCs), in which the delivery of goods to MCCs is realized with rail transportation mode and the last delivery phase with drones. It is followed by the concepts that imply MCCs, and rail transportation in the function of mobile depots for drone launching and MCCs and ground delivery vehicles (GDVs), with the final scores of 0.395 and 0.390, respectively.

1. Introduction

For decades, the effects of logistics activities in urban areas have negative effects on sustainability [1]. The mistreatment of city logistics (CL), as the consequence of misunderstanding the core of its problems and inappropriate approach in their solving [2], leads to great traffic congestions, time losses, safety violations, inefficient logistics processes, etc., in urban areas [3].

Globalization and the growth of consumer society, the shift in production paradigm, which is based on individualization, personalization, and shorter life-cycles, the development of industry 4.0, the development of e-commerce, sustainability, and other social trends cause intensive changes in logistics demands and the ways of their realization [4–6]. Logistics planning becomes

increasingly complex with growing number of users, their varied locations, the uncertainty of orders, extreme competitive pressure to reduce inventory costs, etc. [7]. The aforementioned leads to the rise of coordination complexity of logistics service, especially the last-mile distribution [8]. This forces the logistics in urban areas to adapt in order to become able to respond to new demands, while the traditional approaches in CL planning and the application of succeeding, classical technologies are unable to achieve sustainability [9]. Emerging technologies that rely on automatization, electrification, crowd-sharing, alternative transportation modes, etc. give potential to transform current approaches in last-mile realization [10], yet they cannot achieve full potential with existing regulatory limitations that hinder their further development and widespread use.

In the last two decades, the interest in solving CL problems is growing [3]. Aside from the pressure, new trends, especially the technological ones, allow sustainable CL planning. The literature is especially interested in the application of technologies that will reduce the participation of road transportation in urban areas. The application of unmanned aerial vehicles (drones) in goods delivery has, after 2013, attracted lots of public and scientific attention [11].

Mobility, lower operational costs, and lower air-pollutant emissions, compared with road transportation, make drones competitive for urban goods delivery [12]. Up until now, a vast number of concepts/variants of drone-based delivery were analyzed in the literature. However, no research has analyzed and compared complex drone-based CL concepts. An obvious research gap in the scientific literature exists regarding the definition and selection of the most appropriate (sustainable) drone-based CL concept. The literature lacks a comprehensive framework for defining and evaluating such solutions. This article fulfills this gap by providing a framework for defining and evaluating feasible drone-based CL concepts.

The focus of this article is set on defining modern, creative, and sustainable drone-based CL concepts and their evaluation from the aspect of CL stakeholders, which represents its main contribution. The article is based on the following hypotheses. The first hypothesis is that it is possible to define practically feasible drone-based CL concepts. The second hypothesis states that a comprehensive set of criteria used for the evaluation of drone-based CL concepts could be defined in such way to include the opinions and goals of all stakeholders. The third hypothesis states that the most feasible drone-based CL concepts refer to multiechelon systems that include different types of logistics centers and alternative transportation modes. All drone-based delivery variants that were analyzed in the existing literature are taken into account and served as the base for defining complex drone-based CL concepts. Another hypothesis states that it is possible to develop an adequate multicriteria decision-making (MCDM) method in the spherical fuzzy environment for evaluating the observed CL concepts under ambiguous and imprecise information. For the evaluation of drone-based CL concepts, the measurement of alternatives and ranking according to compromise solution (MARCOS) MCDM method is developed in the spherical fuzzy environment, which represents another contribution of the article. The last hypothesis claims that the developed spherical fuzzy MARCOS method provides a reliable solution and is competent with other spherical fuzzy MCDM methods used in the literature.

The article is organized as follows. The next section presents a short literature review regarding drone-based delivery and the application of the MARCOS method. Section 3 describes the development of the MARCOS method in the spherical fuzzy environment. In Section 4, all drone-based CL concepts that are analyzed, and the criteria used for their evaluation, are defined and described. In Section 5, the application of the developed method is demonstrated for solving the problem of selecting the best

drone-based CL concept, and the results and discussion of its application are presented. The last section contains concluding remarks and directions for future research.

2. Literature Review

The research in the field of CL covered a wide set of different initiatives, measures, solutions, and technologies [13], intending to promote sustainable CL planning. Flow consolidation, as the foundation of modern CL understanding, has attracted lots of attention in scientific research because of its flexibility and convenience for combining with other CL initiatives, measures, solutions, and technologies [14, 15]. In the physical sense, two forms of consolidation exist—macro-consolidation (at the outskirts of urban areas, through urban consolidation centers—UCCs) [16] and micro-consolidation (in the delivery zone, through micro-consolidation centers—MCCs) [17]. Integration of demands, based on some homogeneity aspect, through consolidation achieves significant positive effects on sustainability and represents the base for further planning and development of CL systems. The development of adequate categories of logistics centers provides the core of the Physical Internet in urban goods distribution and represents the necessary means to achieving hyperconnected CL [18]. Hyperconnected CL relies on interconnected networks, alternative transportation modes, standardization, and an encompassing horizontal collaboration among all participants [19]. Physical Internet and hyperconnected CL are an emerging idea of sustainable CL, yet it is only a theoretical blueprint for that sustainability [20] whose wide acceptance and application are directly dependent on the identification, development, and implementation of sustainable CL concepts/solutions.

In the last few years, a wide range of customers is willing to pay an extra fee for the same delivery or instant delivery [21]. On the other hand, the development of modern technologies and their application in logistics gives the opportunity for defining new, sustainable CL solutions [22]. Having that in mind, drones gained lots of popularity in scientific research as a potential element of future, sustainable CL systems. Although low carrying capacity, limited battery endurance, and the absence of adequate regulation for their widespread use are the main impediments of their practical application [23], through the combination with other CL concepts, their efficient application is possible [24]. A wide variety of drone-based delivery variants are covered in the literature, and the following text presents a short review of those researches.

The initial research analyzed drones as delivery auxiliaries for ground delivery vehicles (GDVs) [25]. The idea, known in the literature as ground vehicle-drone tandem, uses drones for delivery to certain locations during the serving of other locations by the GDV. This variant requires complete synchronization of drones and the GDVs, because the drones are bound to their native GDVs [26], while the launching of drones is possible only when the GDV stands still. Many articles covered this variant, especially in the domain of its operational planning [27]. Firstly, the variant

where a GDV carries only one drone [25, 26] is analyzed, but later, the research that analyzed a greater number of drones carried by the GDV [28, 29] emerged as well. Wang and Sheu [30] developed a model for operational planning of ground vehicle-drone tandem delivery where the interchange of drones between GDVs is possible. Popović et al. [31] analyzed a heterogeneous structure of GDVs where only certain vehicles are carrying a drone, while [32] proposed a cooperative delivery scheme through movement synchronization between delivery resources—drones and autonomous ground vehicles. The literature also analyzed the variants where a drone could be launched along an arc in the network [33]. Most of the research covered drone-based delivery only, but the research that included pickup and delivery by drones [34] exists as well. A distinct variant of drone and GDV cooperation is analyzed in the article [35]. Here, the drones were used to resupply GDVs to make the system able to instantly realize newly generated demands, even though the vehicle has left the central depot.

The second drone-based delivery variant present in the literature also combines drones with larger transportation vehicles, while those larger vehicles serve as mobile depots. The role of moving depots is to bring the goods and drones closer to the delivery zone, from where the last phase of the delivery is realized only by drones. In the literature, the variants differ mainly in the vehicle type used as mobile depots—GDVs [36], public transportation vehicles (trams) [37, 38], barges [39], or even flying warehouses (airships) [40–42]. In the case of using GDVs as moving depots, reserved parking spots are required for drone launching, while, in the case of combining drones with public transportation vehicles, barges, or floating warehouses, the delivery is realized without the need for mobile depot stopping. There are also articles in the literature that analyzed the variant, in which the drones are not bound to particular vehicles of public transportation but are flexible in deciding in which way they would reach the delivery zone [43, 44].

The literature also recognized the potential of drones in multiechelon delivery systems. In multiechelon systems with drones, larger vehicles deliver the goods to locations that serve as drone-launching stations for last delivery phase realization [45]. In such delivery variants, drones and GDVs work independently, which was proven to be an efficient way for goods delivery [24]. Kim et al. [46] analyzed building rooftops as launching station for drones in two-echelon delivery systems. Aside from efficiency, multiechelon delivery systems with drones are characterized by greater complexity in planning and realization [47]. To this day, no research analyzed alternative transportation modes for first delivery phase realization in such systems.

Although the existing literature is abundant with different variants of drone-based delivery, some of the variants remain unexplored, especially those that rely on micro-consolidation and the application of alternative transportation modes. Furthermore, no research in the existing literature has compared different variants and evaluated their feasibility for practical implementation. The only article that analyzed different drone-based delivery variants in the context of CL concepts is that of Tadić et al. [48]. The article

proved that different forms of flow consolidation, at the outskirts of urban areas and again in the close proximity of flows generators, in the combination with drones for the delivery in the last phase, indicate sustainability. The contribution of this article is in the selection of the most appropriate drone-based CL concept.

The diversity of CL problems justified the application of a wide set of methods for their solving: exact approaches (e.g., [49]), simulation (e.g., [50]), heuristics (e.g., [51]), metaheuristics (e.g., [52]), MCDM methods (e.g., [14]), etc. MCDM methods are especially convenient for problem-solving where a larger set of criteria and stakeholders exist, which is mostly the case in CL.

Before any of the aforementioned approaches could be applied, especially MCDM methods, it is important to determine the problem structure and elements, involved stakeholders, their goals and opinions, and potential solutions to the problem. This requires a multiactor-multicriteria analysis (MAMCA) approach towards the problems of CL [53], in order to include all relevant elements into the problem-solving process. The importance of such an approach has directed the research in the field of CL on developing comprehensive frameworks and models that would incorporate the goals of different stakeholder groups into the decision-making process and define the set of relevant criteria, approaches, and potential solutions to the problem [54]. Aside from the MAMCA approach, there are other frameworks and approaches with the goal of better understanding and structuring CL problems [55–58].

The literature is abundant with different MCDM methods and models. The MARCOS MCDM is a relatively new method that gains momentum in the literature by solving a high variety of different decision-making problems. By defining the relationship between the alternatives and the ideal and anti-ideal solution as reference points, the MARCOS method determines the utility functions of alternatives and outputs a compromise ranking of alternatives [59]. Greater efficiency, ease of structuring and optimization of the decision-making processes, more precise determination of the utility degree in relation to reference points, greater stability and robustness of results in situations of changing measurement scales, absence of the rank reversal problem, etc. [59] are some of the advantages of the MARCOS method when compared to other methods (such as TOPSIS, MABAC, SAW, WASPAS, and EDAS).

The MARCOS MCDM method found its application in its conventional form [59–62], as well as in the fuzzy [63], intuitionistic fuzzy [64], grey [65], and D numbers [66] environment. Aside from its standalone application, the MARCOS method was combined with other methods, such as AHP [67], SWARA [48, 68], Delphi and FARE [69], BWM [70–72], FUCOM [73, 74], CCSD and ITARA [75], CRITIC, FUCOM, and DEA [76], and FUCOM and PIPRECIA [77]. Due to its advantages and strengths, as well as the fact that it was not developed in the spherical fuzzy environment, this article expands the existing literature by developing the spherical fuzzy MARCOS method for the first time, which represents its final contribution.

3. Spherical Fuzzy MARCOS Method

This section describes the procedure for applying the MARCOS MCDM method in the spherical fuzzy environment. The MARCOS method found its place in the literature as a stable, efficient, and reliable problem-solving tool. The idea of the method is to determine the utility functions of alternatives in comparison with the ideal and anti-ideal solution [59]. In the following text, the application of the spherical fuzzy MARCOS method is described. The first three steps refer to problem structure definition and the extraction of criteria weight coefficients. The rest of the steps refer to the application of the MARCOS method.

Step 1. Define the problem structure, and identify the stakeholders and their goals, demands, and preferences. Form the set of alternatives and criteria used for their evaluation.

Step 2. Define the set of linguistic terms with corresponding spherical fuzzy values used for criteria importance evaluation from the aspect of stakeholders,

$$\tilde{w}_j = \left\{ \left[1 - \prod_{d=1}^D \left(1 - (\mu_j^d)^2 \right)^{w_d} \right]^{1/2}, \prod_{d=1}^D (\vartheta_j^d)^{w_d}, \left[\prod_{d=1}^D \left(1 - (\mu_j^d)^2 \right)^{w_d} - \prod_{d=1}^D \left(1 - (\mu_j^d)^2 - (\rho_j^d)^2 \right)^{w_d} \right]^{1/2} \right\}, \quad (1)$$

where w_d represents the relative importance of the stakeholder d such that $\sum_{d=1}^D w_d = 1$.

Step 4. Evaluate and rank the alternatives by applying the spherical fuzzy MARCOS method. The input parameters for the method are the set of alternatives (A_i), the number of alternatives (m), the set of criteria (C_j) with spherical fuzzy weight coefficients (\tilde{w}_j), and the decision matrix \tilde{X} which consists of the alternative evaluations regarding the criteria (x_{ij}). In the spherical fuzzy MARCOS method, the alternatives are evaluated with linguistic terms that could be transformed into spherical fuzzy values $\tilde{x}_{ij} = (\mu_{ij}^x, \vartheta_{ij}^x, \rho_{ij}^x)$, where μ_{ij}^x , ϑ_{ij}^x , and ρ_{ij}^x are the membership, nonmembership, and hesitancy degrees, such that $(\mu_{ij}^x)^2 + (\vartheta_{ij}^x)^2 + (\rho_{ij}^x)^2 \leq 1$ applies. The spherical fuzzy MARCOS method is developed according to the classical MARCOS method [59] and the basic operations and properties of spherical fuzzy sets [78].

Step 4.1. Expand the decision-making matrix \tilde{X} with the ideal (A_{id}) and anti-ideal (A_{ai}) solution:

and the evaluation of alternatives with regard to the criteria. Linguistic terms and the corresponding spherical fuzzy values used in this article are presented in Table 1.

Step 3. Form the stakeholder criteria evaluation matrix. Perform the prioritization of the criteria. The prioritization is performed according to the stakeholder criteria evaluation. The evaluation is performed according to the linguistic terms in Table 1, which can be transformed into corresponding spherical fuzzy values. Let $\alpha_j^d = (\mu_j^d, \vartheta_j^d, \rho_j^d)$ be the spherical fuzzy evaluation of criteria j significance from the aspect of stakeholder d , such that $(\mu_j^d)^2 + (\vartheta_j^d)^2 + (\rho_j^d)^2 \leq 1$ applies, and let n be the number of criteria. In that case, the criteria prioritization can be performed by applying the spherical weighted arithmetic mean (SWAM) [78]. The result of applying the SWAM operator is a set of spherical fuzzy criteria weights $w = (\tilde{w}_1, \tilde{w}_2, \dots, \tilde{w}_n)$, while the individual spherical criteria weights $\tilde{w}_j = (\mu_j^w, \vartheta_j^w, \rho_j^w)$ are calculated according to

$$\tilde{X} = \begin{matrix} & \begin{matrix} C_1 & C_2 & \cdots & C_n \end{matrix} \\ \begin{matrix} A_{ai} \\ A_1 \\ A_2 \\ \vdots \\ A_m \\ A_{id} \end{matrix} & \begin{bmatrix} \tilde{x}_{ai1} & \tilde{x}_{ai2} & \cdots & \tilde{x}_{ain} \\ \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \\ \tilde{x}_{id1} & \tilde{x}_{id2} & \cdots & \tilde{x}_{idn} \end{bmatrix} \end{matrix}. \quad (2)$$

Let C^{\max} be the set of all maximization criteria, and let C^{\min} be the set of all minimization criteria. In that case, A_{id} and A_{ai} can be determined:

$$A_{ai} = \min_{1 \leq i \leq m} x_{ij}, \quad j \in C^{\max}, \quad \max_{1 \leq i \leq m} x_{ij}, \quad j \in C^{\min}. \quad (3)$$

$$A_{id} = \max_{1 \leq i \leq m} x_{ij}, \quad j \in C^{\max}, \quad \min_{1 \leq i \leq m} x_{ij}, \quad j \in C^{\min}. \quad (4)$$

TABLE 1: Linguistic terms and corresponding spherical fuzzy values.

Spherical fuzzy value	Abbreviation	Linguistic term
(0, 1, 0)	EP	Extremely poor
(0.1, 0.9, 0.1)	VP	Very poor
(0.2, 0.8, 0.2)	P	Poor
(0.3, 0.7, 0.3)	MP	Medium poor
(0.4, 0.6, 0.4)	M	Medium
(0.5, 0.5, 0.5)	MG	Medium good
(0.6, 0.4, 0.4)	G	Good
(0.7, 0.3, 0.3)	VG	Very good
(0.8, 0.2, 0.2)	EG	Extremely good
(0.9, 0.1, 0.1)	EX	Excellent

Step 4.2. Form the weighted decision matrix $\tilde{V} = [\tilde{v}_{ij}]_{m \times n}$ by multiplying the elements of matrix \tilde{X} with corresponding criteria weight coefficients:

$$\tilde{v}_{ij} = \tilde{w}_j \cdot \tilde{x}_{ij} = (\mu_{ij}^v, \vartheta_{ij}^v, \rho_{ij}^v). \quad (5)$$

The multiplication of matrix \tilde{X} elements and criteria weight coefficients \tilde{w}_j is performed with the multiplication operation of two spherical fuzzy numbers [79]:

$$\tilde{w}_j \cdot \tilde{x}_{ij} = \left\{ \mu_j^w \cdot \mu_{ij}^x, \left[(\vartheta_j^w)^2 + (\vartheta_{ij}^x)^2 - (\vartheta_j^w \cdot \vartheta_{ij}^x)^2 \right]^{1/2}, \left[\left(1 - (\vartheta_j^w)^2 \right) \cdot (\rho_{ij}^x)^2 + \left(1 - (\vartheta_{ij}^x)^2 \right) \cdot (\rho_j^w)^2 - (\rho_j^w \cdot \rho_{ij}^x)^2 \right]^{1/2} \right\}. \quad (6)$$

Step 4.3. For every alternative, determine the utility degrees K_i^+ and K_i^- . In this variant of the spherical fuzzy MARCOS method, K_i^+ and K_i^- represent the spherical distances of alternatives from $A_{i,d}$ and A_{ai} respectively. Spherical distance of alternative i from $A_{i,d}$ (i.e., A_{ai}) is determined by [78]

$$K_i^+ = \frac{2}{n \cdot \pi} \sum_{j=1}^n \arccos(\mu_{ij}^v \cdot \mu_{i,dj}^v + \vartheta_{ij}^v \cdot \vartheta_{i,dj}^v + \rho_{ij}^v \cdot \rho_{i,dj}^v). \quad (7)$$

$$K_i^- = \frac{2}{n \cdot \pi} \sum_{j=1}^n \arccos(\mu_{ij}^v \cdot \mu_{aij}^v + \vartheta_{ij}^v \cdot \vartheta_{aij}^v + \rho_{ij}^v \cdot \rho_{aij}^v). \quad (8)$$

Step 4.4. Calculate the final scores of alternatives (F_i) according to

$$F_i = \frac{K_i^+ + K_i^-}{1 + ((1 - f(K_i^+))/f(K_i^+)) + ((1 - f(K_i^-))/f(K_i^-))}, \quad (9)$$

where $f(K_i^+)$ and $f(K_i^-)$ represent the utility functions of alternatives in comparison with $A_{i,d}$ and A_{ai} , calculated according to

$$f(K_i^+) = \frac{K_i^-}{K_i^+ + K_i^-}, \quad (10)$$

$$f(K_i^-) = \frac{K_i^+}{K_i^+ + K_i^-}. \quad (11)$$

4. Defining the Drone-Based CL Concepts

In this section, the drone-based CL concepts are defined. The concepts are defined according to existing CL concepts in the literature, but also regarding the general possibilities of drones' application. The concepts differ in the system structure, the combination with different transportation technologies, and the role of drones. The concepts are classified into 4 main groups, while certain groups consist of a subset of different variants that will be evaluated. The assumption is that flow consolidation at the outskirts of urban areas represents an integral element of every concept.

4.1. Concept 1. In this concept (C1), goods delivery is realized with synchronized ground GDVs and drones [25, 26, 31]. The GDVs carry one or several drones. During the delivery to a customer, the GDV can release the drones to serve other customers (Figure 1). This approach enables parallelization of drone and GDV activities but requires their synchronization in the delivery process. The advantage of this concept is its flexibility and relatively simple implementation, while its main disadvantage is the need for synchronization between drones and GDVs, which reduces its efficiency. Furthermore, concept C1 mainly relies on the road transportation mode in the city zone.

4.2. CL Concept 2. This concept (C2) refers to the application of large delivery vehicles in the function of mobile depots. The role of moving depots is the transportation of goods to

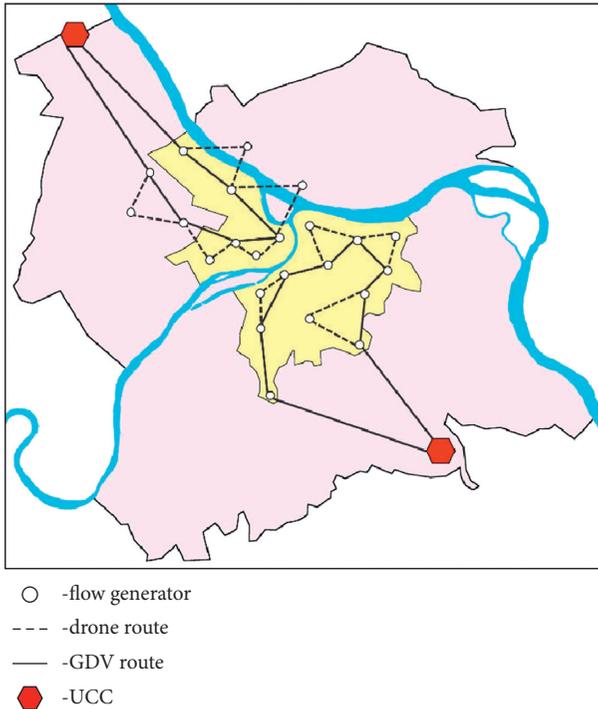


FIGURE 1: CL concept 1: goods delivery with ground vehicle-drone tandem.

the proximity of a generator group, where the last delivery phase is executed with drones. There are several variants of this concept depending on the vehicles in the function of mobile depots—GDVs (C2V1), trams and passenger trains (C2V2), airships (flying warehouses) (C2V3), and barges (C2V4). C2V1 requires dedicated parking spots, developed at appropriate locations, for launching drones (Figure 2(a)), which are used in the last delivery phase [36]. The advantage of C2V1 is that it does not require large infrastructural investments aside from providing adequate parking spots dedicated for launching drones. The disadvantages are the interdependence of drones and GDVs, which means that the GDVs must wait for the drones to finish their deliveries in order to continue with their tour. C2V2 is based on the idea of integrating the distribution system with public transportation (cargo hitching) [38]. Public transportation vehicles (trams and passenger trains) play the role of mobile depots but respect their usual travel schedules (Figure 2(b)). The advantage of C2V2 is the reduction of road transportation involvement in goods delivery, but not completely because the drone delivery zone is limited to the zones where passenger rail transportation lines are established. Other disadvantages are the general low flexibility of rail transportation mode, the mixing of goods and passenger flows, and the dependency of drones towards rail transportation vehicles. Greater flexibility of the concept could be achieved by allowing drones to cooperate with different public transportation vehicles [43]. C2V3 refers to the application of airships (floating warehouses) in the function of mobile depots [40, 42]. Delivery to the customers is realized by launching drones from the airship when the airship flies above the service area (Figure 2(c)). The main advantage of

C2V3 is that it greatly eliminates ground-based transportation modes and does not require the development of additional infrastructure. Its disadvantages are the complex process of its implementation, the acceptance by logistics providers, and drone dependence on airships. In C2V4 (Figure 2(d)), barges are used as mobile depots for launching drones in goods delivery [39]. The advantage of the concept is the integration of river transportation in the goods delivery process, the reduction of road transportation involvement, and relatively low infrastructural investments (loading stations for barges). The main disadvantage of the concept is a narrow service area of drones around inland waterways, and the dependency on barges.

4.3. CL Concept 3. This concept (C3) refers to the transformation of the logistics system into a two-echelon system (Figure 3) with the implementation of micro-consolidation centers (MCCs) in the delivery zone [24]. The delivery is realized in two phases, which are connected by MCCs. In the first phase, vehicles with larger capacities are used for goods transportation to MCCs, where the modal shift on air transportation (drones) takes place. According to the transportation mode used in the first echelon, four variants of this concept can be defined—the application of GDVs (C3V1), rail vehicles (C3V2), underground systems (C3V3), and air transportation mode (C3V4). The general advantages of concept 3 are better efficiency achieved with the system transformation into a two-echelon system. C3V1 uses GDVs for the realization of the first phase of the delivery. The advantage of C3V1 is greater flexibility in its planning and relatively lower infrastructural investments compared with other variants in this concepts group. C3V2 applies rail transportation in the first echelon and it could be split into two variants—the establishment of regular cargo tram lines or the integration with public rail transportation of passengers. The advantage of C3V2 is the reduction of road transportation participation in delivery, but its disadvantage is the general low flexibility of rail transportation mode. C3V3 refers to the development of underground logistics systems for goods delivery to MCCs in the city zone. The advantages of C3V3 are significant positive effects on sustainability. The main disadvantages are high infrastructural costs, long development period, and the inability of developing underground systems in some (historical) parts of the cities. In C3V4, specialized airships are used for goods delivery in the first echelon, while MCCs are developed at building rooftops. Its main advantages are the significant reduction of ground-based transportation and the development of MCCs at locations that do not require additional public space. The main disadvantages of this concept are its development complexity and high investments for such systems (design and procurement of airships, development of specialized logistics centers for serving and setting up of such vehicles).

4.4. CL Concept 4. Hybrid concepts (C4) are based on MCCs and mobile depots. This group of concepts refers to the application of road (C4V1) (Figure 4(a)), rail (C4V2)

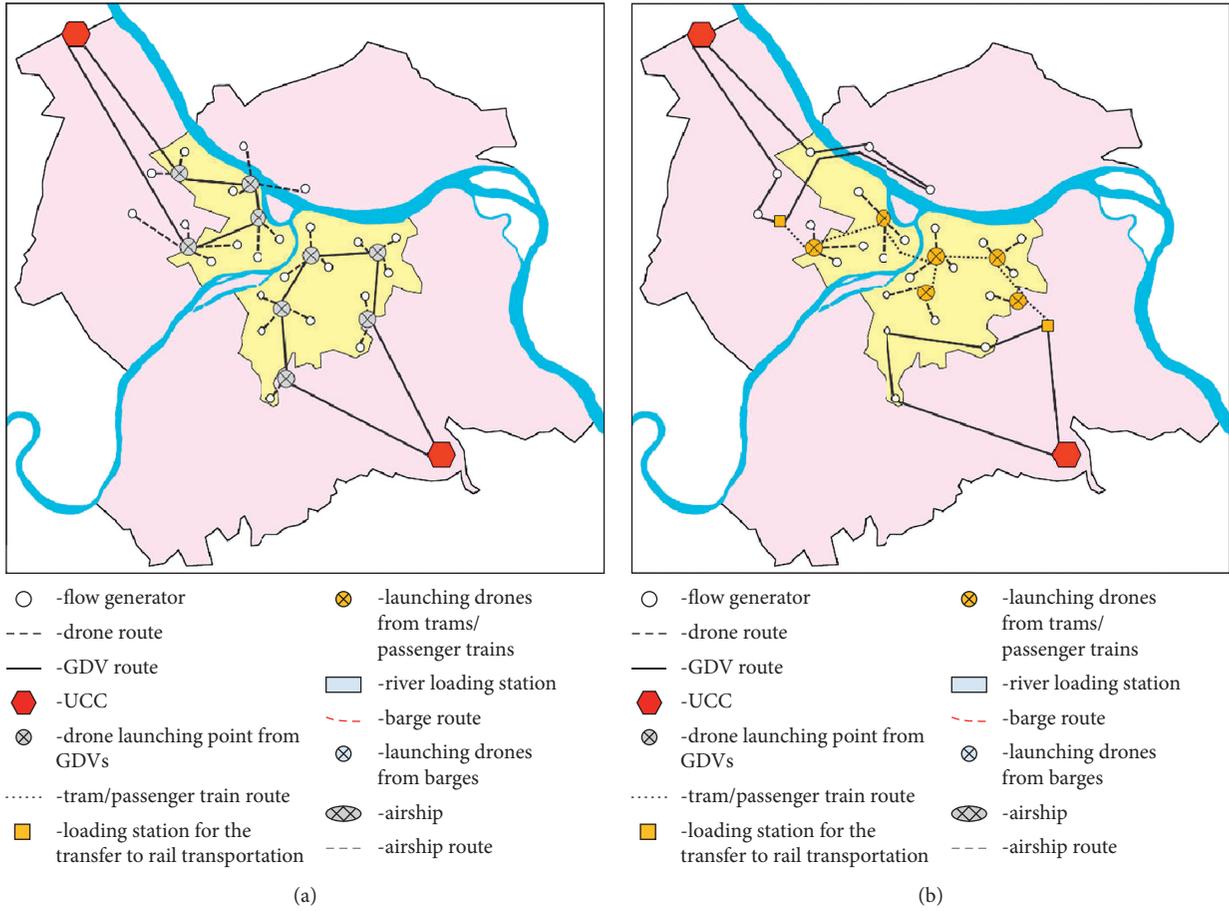


FIGURE 2: Continued.

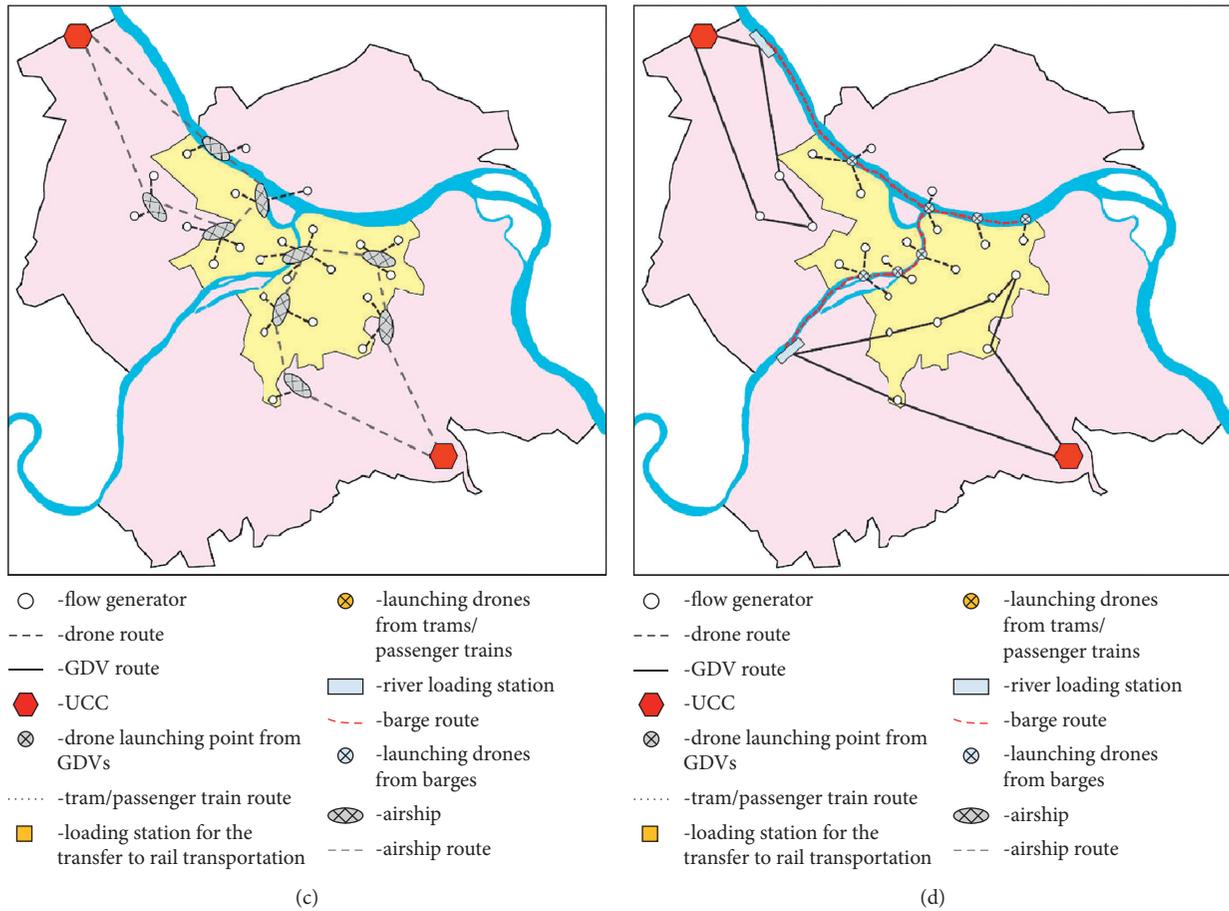


FIGURE 2: CL concept 2: goods delivery with mobile depots and drones. (a) GDVs as mobile depots; (b) trams/passenger trains as mobile depots; (c) airships as mobile depots; (d) barges as mobile depots.

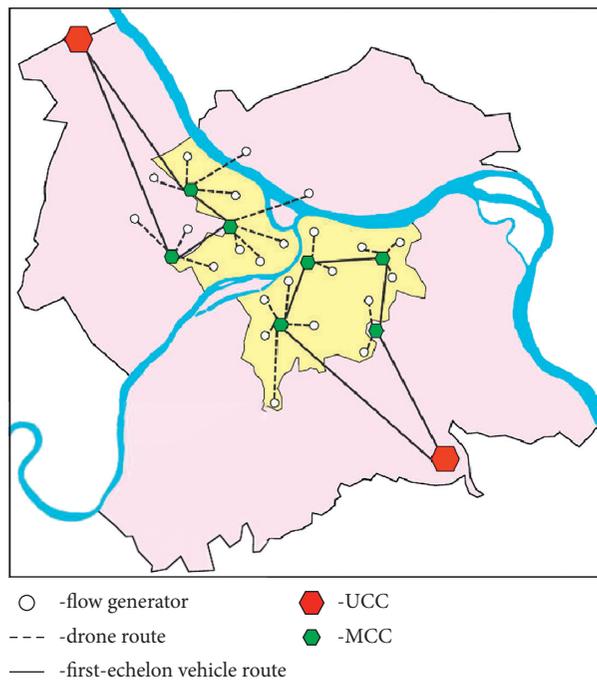


FIGURE 3: CL concept 3: two-echelon goods delivery with MCCs and drones.

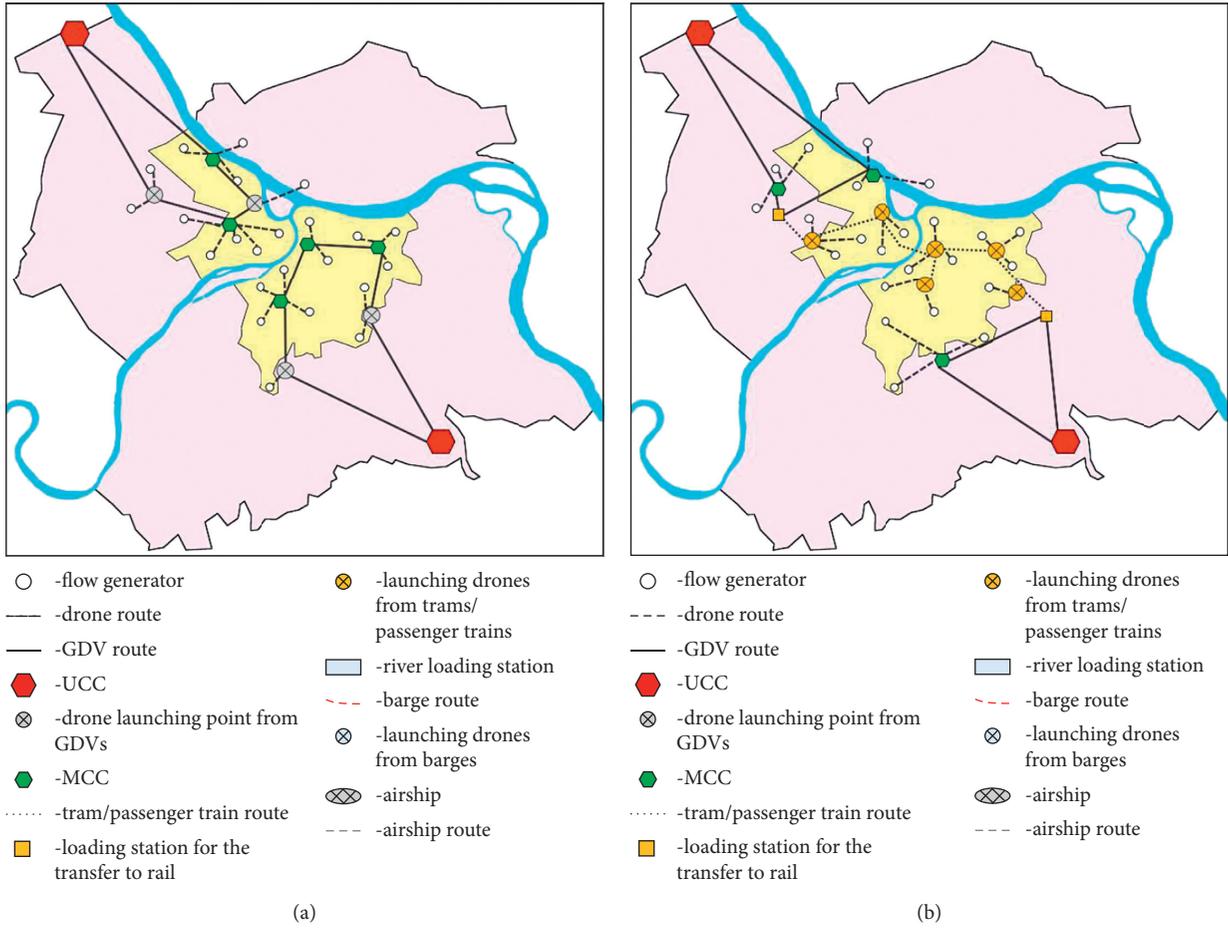


FIGURE 4: Continued.

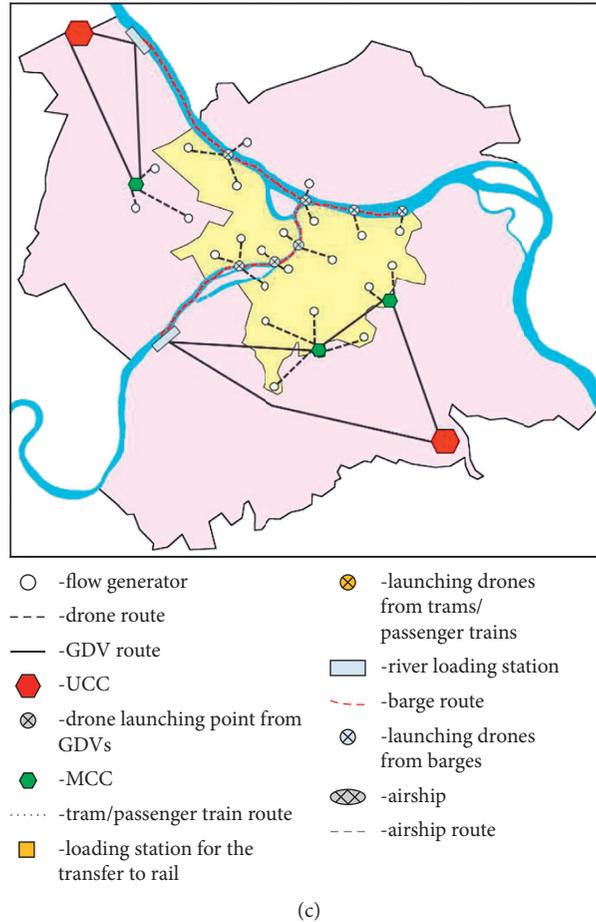


FIGURE 4: CL concept 4: hybrid delivery systems that combine mobile depots, MCCs, and drones. (a) GDV as mobile depots; (b) trams/ passenger trains as mobile depots; (c) barges as mobile depots.

(Figure 4(b)), and inland waterway (C4V3) (Figure 4(c)) transportation modes in the function of mobile depots for drone launching (the ideas of concepts C2V1, C2V2, and C2V4), for covering a portion of generators located in the zones of parking spots/rail infrastructure and inland waterways/canals. The rest of the generators, which are outside the service zone of mobile depots, are also served with drones, but from MCCs. The delivery of goods to MCCs is realized with GDVs. The advantage of concepts C4 is in developing fewer MCCs in comparison with the classical two-echelon system. MCCs are developed only in zones with a high concentration of generators (K4V1), while in the zones with lower volumes of demands only specialized parking slots are developed for GDVs. In C4V2 and C4V3, MCCs are developed in the zones that are outside the service areas of mobile depots (trams/trains and barges). The disadvantage of these concepts is greater system complexity in comparison to the concepts from other groups.

Solving the problems of CL is a difficult task in most cases. This is because a wide set of criteria must be defined in order to give a good insight into the characteristics of potential solutions, all the requirements of stakeholders, and the factors that cover different aspects of city characteristics [80]. The criteria should be used as indicators at what degree

the observed potential solutions could contribute to urban sustainability [81], but also as means for differentiation of potential solutions from a practical and technical point of view [82]. The existing literature in the field of CL considers a rich set of criteria belonging to different categories: technical, such as efficiency, reliability, flexibility, and customer coverage [82]; economic, such as costs (operational, implementation, and land acquisition) and required subsidies [83]; social, such as impacts on mobility and safety [15]; and environmental, such as air-pollution, energy conservation, and waste generation [84]. Different goals and complex interactions among stakeholders [85] make the selection of appropriate criteria a problem on its own.

In the following text, 10 criteria, used for evaluation of the observed drone-based CL concepts, are defined. The criteria are defined according to the existing literature in the field of CL [14, 67, 86] and the application of drones in goods delivery [24, 80, 87, 88], with the goal of concepts differentiation and their realistic evaluation.

Efficiency (Cr1) refers to the utility degree of vehicle capacities and the savings of energy and fuel. Requirement for additional infrastructure development (Cr2) describes the volume of required infrastructural investments for the development of appropriate logistics centers (MCCs, loading

stations). Operational complexity of delivery activities (Cr3) refers to the complexity of the planning and realization of goods flows. Concepts that require a greater degree of flows transformation are considered worse according to this criterion. External costs (Cr4) as a criterion describe to what degree does the observed concept contribute to the reduction of logistics negative environmental impact (air pollutant emissions, noise, and vibrations). The modal shift of transport work (Cr5) describes the stimulation for applying alternative transportation modes in goods delivery. Implementation possibility (Cr6) describes the practical feasibility of concept development as well as the readiness of CL stakeholders for its acceptance. Flexibility (Cr7) refers to the capability of the system for adapting to unexpected changes in demands, environment, etc. Reliability (Cr8) refers to the availability of goods and services in demanded (acceptable) time intervals, at the desired place, with quality preservation, secured from external impacts. Regulatory framework (Cr9) refers to the complexity of developing rules/licenses/regulations for drone (and airship) application in goods delivery for the observed concept. The concepts with MCCs are generally easier for regulation, because they have precisely defined drone service areas. Furthermore, in multiechelon concepts, drone-based delivery is easier to regulate by entrusting the delivery in the last phase to a specialized logistics provider. Freeing of public space (Cr10) describes how much does the implementation of the observed concept contributes to the freeing of public surfaces—roads, sidewalks, promenades, parks, etc.

The observed criteria importance is evaluated by four CL stakeholder groups: service providers, users, local administration, and residents. The goal of providers is an efficient realization of logistics activities and maximization of profits. Service users (senders and receivers of goods) demand flexible and reliable deliveries at acceptable price and short leading times. Local administration aims towards the economic and social development of cities, while the goal of residents is the availability of goods and services at every moment with the minimization of logistics negative environmental impacts [2].

The evaluation of criteria importance is based on the results of a series of meetings and questionnaires with representatives of all four CL stakeholder groups from the city of Belgrade. A total number of 131 participants expressed their opinions towards the importance of the defined criteria (37 experts from private logistics companies, 28 individuals involved in sending and receiving of goods, 9 representatives of local authorities, and 57 residents). Every participant was presented with the explanation of the 10 defined criteria and was asked to rank them by importance and, if possible, to describe their opinions towards individual criteria. Based on the most frequent answers and opinions per stakeholder group, the initial criteria importance evaluation matrix is formed.

5. The Application of the Developed Method

This section demonstrates the application of the spherical fuzzy MARCOS method for selecting the best drone-based CL concept. In the first phase, the SWAM operator is used

for determining spherical criteria weights. Criteria weights are determined according to their evaluation by the four stakeholder groups (Table 2). It is adopted that all stakeholder groups are equally important - $w_{Pro} = w_{Use} = w_{Adm} = w_{Res} = 0.25$, where w_{Pro} , w_{Use} , w_{Adm} , w_{Res} represent the relative importance of providers, users, administration, and residents as stakeholder groups, respectively.

After transforming the evaluations from Table 2 into corresponding spherical fuzzy values, the spherical weight coefficients of the criteria are determined by equation (1) (Table 3).

Drone-based CL concept evaluation according to the criteria is performed with linguistic terms from Table 1, which are then transformed into corresponding spherical fuzzy values (Table 4). The evaluations are made by the authors based on their long-term scientific and practical experience in the analysis and assessment of concepts and project development in the field of CL, through consultations with other experts in the field of CL.

The initial decision matrix is expanded into the format from equation (2) according to equations (3) and (4). Then, the expanded decision matrix is weighted by applying equations (5) and (6). Utility degrees of alternatives (K_i^+ and K_i^-) are determined with equations (7) and (8), after which the final drone-based CL concept scores are determined with equations (9)–(11). The observed drone-based CL concepts are ranked according to the parameter F_i (Table 5). In order to validate the results, the same problem has been solved with the two most commonly used and most significant distance based MCDM methods developed in spherical fuzzy environment—spherical fuzzy TOPSIS [79, 89] and spherical fuzzy VIKOR [90, 91]. According to the results, there are slight variations in alternatives ranking when using different spherical fuzzy MCDM methods, yet the same CL concept is the best-ranked in all three applied methods. This validates the solution proposed by the spherical fuzzy MARCOS method as a compromise and acceptable one.

According to the results obtained with the spherical fuzzy MARCOS method, the best-ranked drone-based CL concept is C3V2 ($F_i = 0.408$). This CL concept refers to the transformation of the logistics system into a two-echelon system with the implementation of MCCs, in which the first delivery phase to MCCs is realized with rail transportation mode, and the last delivery phase with drones. This CL concept is ranked as the best, because it efficiently rebalances the transport work by combining alternative transportation modes in goods delivery. The implementation of such a concept is practically feasible, and the effects of its application would reflect through the improvement of system efficiency and the reduction of logistics negative environmental impacts, and, at the same time, satisfying customer needs by providing a high-quality and reliable service. The second-ranked CL concept is C4V2 ($F_i = 0.395$), which refers to the combined application of rail transportation vehicles as mobile depots and the concept of MCCs outside their service area. The third-best CL concept is C3V1 ($F_i = 0.390$), which refers to the two-echelon delivery system through MCCs by applying GDVs in the first and drones in the last delivery

TABLE 2: Criteria importance evaluation by stakeholder groups.

Criterion	Providers	Users	Administration	Residents
Cr1	EX	EX	MG	G
Cr2	EG	M	EX	MG
Cr3	EG	G	EP	EP
Cr4	P	P	EG	EX
Cr5	P	EP	MG	MG
Cr6	EX	G	VG	MP
Cr7	MG	VG	P	P
Cr8	M	EG	P	VG
Cr9	MG	P	EX	M
Cr10	EP	P	G	VG

TABLE 3: Spherical criteria weight coefficients.

Criterion	μ_j^w	ϑ_j^w	ρ_j^w
Cr1	0.798	0.211	0.257
Cr2	0.738	0.278	0.285
Cr3	0.554	0.532	0.258
Cr4	0.706	0.336	0.176
Cr5	0.378	0.669	0.406
Cr6	0.716	0.303	0.268
Cr7	0.479	0.557	0.348
Cr8	0.616	0.412	0.286
Cr9	0.646	0.393	0.308
Cr10	0.501	0.557	0.303

TABLE 4: Drone-based CL concepts evaluation according to the criteria.

CL concept	Cr1	Cr2	Cr3	Cr4	Cr5	Cr6	Cr7	Cr8	Cr9	Cr10
C1	EP	EX	EP	VP	EP	EX	VG	G	EP	EP
C2V1	VP	EG	VP	P	P	EG	EX	MG	MG	VP
C2V2	MG	G	M	MG	EG	VG	MG	G	M	MG
C2V3	P	MP	MP	M	G	VP	MG	VP	VP	EX
C2V4	M	G	G	VG	VG	MG	MP	M	MP	G
C3V1	MG	G	MP	MP	MP	VG	EG	VG	EX	MG
C3V2	EG	MG	EX	EG	EX	G	M	EX	EX	VG
C3V3	EX	EP	EG	EX	EG	EP	VP	EG	EX	EG
C3V4	G	P	M	G	VG	P	MG	P	VG	EG
C4V1	MG	VG	P	MP	VP	G	EX	G	VG	M
C4V2	VG	G	MG	MG	VG	M	G	VG	G	G
C4V3	G	M	VG	G	G	M	MG	MG	MG	MG

phase. The three best-ranked CL concepts show that the application of drones in goods delivery has the best effects when combined with the concept of flow micro-consolidation, and that those effects are even better when combined with alternative transportation modes. The three worst-ranked concepts are C1, C2V3, and C2V1. The concepts C1 (ground vehicle-drone tandem) and C2V1 (GDVs as mobile depots) are poorly ranked, because they still predominantly rely upon road transportation. The concept C2V3 (airships as mobile depots) is poorly ranked, because it is complex for implementation, and its efficiency is generally questionable and unexplored.

A sensitivity analysis was performed to examine the stability of the obtained solution. The sensitivity analysis is performed under different setups of criteria importance

through four different scenarios. In the scenarios (Sc. 1, Sc. 2, Sc. 3, and Sc. 4), the criteria importance is evaluated only according to individual stakeholder groups—Sc. 1 for providers, Sc. 2 for users, Sc. 3 for administration, and Sc. 4 for residents. The obtained criteria weights for these four scenarios are presented in Table 6.

For every scenario, the drone-based CL concepts are evaluated using the developed model. The results of the sensitivity analysis show that there are minor changes in rankings compared with the initial setup that considers all stakeholder groups and their opinions regarding criteria importance—Sc. 0 (Table 7). CL concept C3V2 is still the best ranked in all scenarios. C4V2 remained as the second-best concept in two scenarios (Sc. 1 and Sc. 3), while C3V1 was second-ranked in Sc. 2 and Sc. 4. C1 and C2V3 remained

TABLE 5: Final drone-based CL concept scores and their ranking.

CL concept	K_i^+	K_i^-	F_i	Rank	Rank according to spherical fuzzy TOPSIS	Rank according to spherical fuzzy VIKOR
C1	0.647	0.310	0.268	12	11	12
C2V1	0.618	0.473	0.356	10	10	9
C2V2	0.589	0.573	0.387	4	4	4
C2V3	0.643	0.426	0.337	11	12	11
C2V4	0.601	0.553	0.384	6	7	5
C3V1	0.595	0.576	0.390	3	3	6
C3V2	0.584	0.645	0.408	1	1	1
C3V3	0.621	0.504	0.370	9	8	10
C3V4	0.616	0.525	0.377	8	9	8
C4V1	0.600	0.541	0.379	7	6	7
C4V2	0.590	0.595	0.395	2	2	3
C4V3	0.591	0.564	0.385	5	5	2

TABLE 6: Criteria weights used in the sensitivity analysis scenarios.

Criterion	Sc. 1			Sc. 2			Sc. 3			Sc. 4		
	μ_j^w	ϑ_j^w	ρ_j^w									
Cr1	0.982	0.010	0.061	0.000	1.000	0.000	0.500	0.500	0.500	0.600	0.400	0.400
Cr2	0.800	0.200	0.200	0.400	0.600	0.400	0.900	0.100	0.100	0.500	0.500	0.500
Cr3	0.800	0.200	0.200	0.600	0.400	0.400	0.000	1.000	0.000	0.000	1.000	0.000
Cr4	0.280	0.640	0.274	0.000	1.000	0.000	0.800	0.200	0.200	0.900	0.100	0.100
Cr5	0.200	0.800	0.200	0.000	1.000	0.000	0.661	0.250	0.559	0.000	1.000	0.000
Cr6	0.900	0.100	0.100	0.600	0.400	0.400	0.700	0.300	0.300	0.300	0.700	0.300
Cr7	0.500	0.500	0.500	0.700	0.300	0.300	0.280	0.640	0.274	0.000	1.000	0.000
Cr8	0.400	0.600	0.400	0.800	0.200	0.200	0.200	0.800	0.200	0.700	0.300	0.300
Cr9	0.500	0.500	0.500	0.200	0.800	0.200	0.900	0.100	0.100	0.400	0.600	0.400
Cr10	0.000	1.000	0.000	0.200	0.800	0.200	0.600	0.400	0.400	0.700	0.300	0.300

TABLE 7: Drone-based CL concepts ranking in sensitivity analysis scenarios.

CL concept	Sc. 0		Sc. 1		Sc. 2		Sc. 3		Sc. 4	
	F_i	Rank								
C1	0.268	12	0.255	12	0.209	12	0.255	12	0.189	12
C2V1	0.356	10	0.318	9	0.243	8	0.332	9	0.244	10
C2V2	0.387	4	0.337	4	0.249	5	0.351	4	0.266	5
C2V3	0.337	11	0.281	11	0.210	11	0.312	11	0.229	11
C2V4	0.384	6	0.334	6	0.244	7	0.345	6	0.261	6
C3V1	0.390	3	0.339	3	0.258	2	0.355	3	0.273	2
C3V2	0.408	1	0.353	1	0.261	1	0.363	1	0.280	1
C3V3	0.370	9	0.314	10	0.213	10	0.329	10	0.255	9
C3V4	0.377	8	0.322	8	0.230	9	0.344	8	0.259	8
C4V1	0.379	7	0.331	7	0.253	3	0.347	5	0.269	4
C4V2	0.395	2	0.342	2	0.253	4	0.356	2	0.272	3
C4V3	0.385	5	0.336	5	0.245	6	0.345	7	0.261	7

the worst-ranked concepts in all scenarios. In general, there are no significant ranking changes in the scenarios (Figure 5). Such results indicate that the developed model behaves with stability; therefore, the obtained solution (Sc. 0) can be accepted as final.

The obtained results in this article are the consequence of a generalized perception of drone-based CL concepts. Future research should focus on developing concrete planning and evaluation models for every individual concept, especially for those that are poorly covered in the literature (C2V3, C2V4, C3V2, C3V3, C3V4, C4V1, C4V2, and C4V3).

Furthermore, future research could define new CL concepts based generally on the application of new technologies, especially those of industry 4.0. The results obtained in this article could help decision-makers in the field of CL provide a framework for defining and evaluating complex CL concepts.

Practical implications of this article are twofold. Firstly, this article gives an insight about the role and potential of drone application in different CL concepts. Future policy makers and planners in CL can use this article as guidance for defining potential development directions of CL in urban

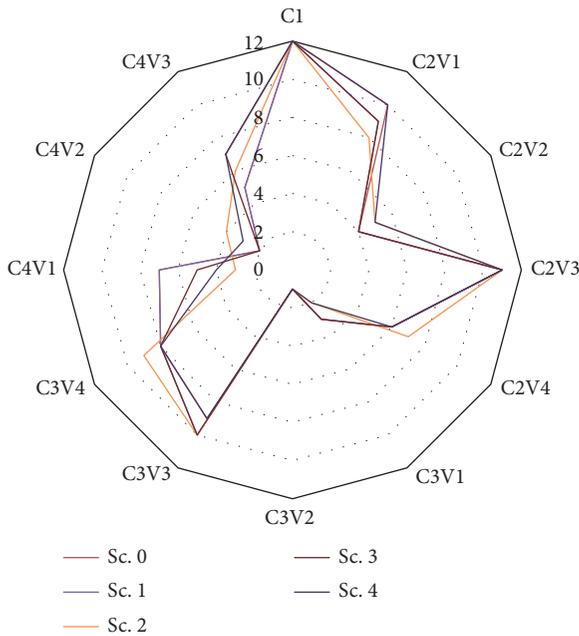


FIGURE 5: Sensitivity analysis.

areas. Furthermore, the approach presented in this article can inspire policy makers and planners to define new CL concepts based on other emerging technologies combined with known CL initiatives, measures, and solutions. Secondly, the approach presented in this article can help decision-makers in CL address CL problems adequately—by considering the interests of all stakeholder groups and incorporating their goals and demands into a comprehensive decision-making framework. This article represents the first attempt in the existing literature of developing the MARCOS method in the spherical fuzzy environment. Its application is universal, so future research could use the newly developed method for solving other problems from this, and also other research fields. The topic of spherical fuzzy sets is relatively new in the literature, at a developing phase, so future research could focus on other approaches in developing this, and other MCDM methods, in the spherical fuzzy environment.

According to the previously discussed issues, it can be concluded that all established hypothesis are confirmed. It is indeed possible to define practically feasible drone-based CL concepts. A comprehensive set of criteria used for the evaluation of drone-based CL concepts can be established in such way to include the opinions and goals of all stakeholders. It is confirmed that the most feasible drone-based CL concepts refer to multiechelon systems that include different types of logistics centers and alternative transportation modes. It is also confirmed that it is possible to develop an adequate MCDM method in the spherical fuzzy environment for evaluating the observed CL concepts and that the developed spherical fuzzy MARCOS method has proven reliable and competent in solving this kind of problems.

6. Conclusion

The problem of selecting the best drone-based CL concept is solved in this article. A wide set of potential drone-based CL concepts and a set of relevant criteria used for their evaluation are defined, which represent the main contribution of this article. For evaluating and ranking CL concepts, the MARCOS MCDM method is developed in the spherical fuzzy environment, which represents another contribution of the article.

The results obtained by the spherical fuzzy MARCOS method indicate that a potentially best drone-based CL concept ($F_i = 0.408$) is the one that transforms the system into a two-echelon system through the implementation of MCCs, where the delivery of goods to MCCs is realized with rail transportation mode and the last delivery phase with drones. The effects of the development of such CL concepts comply with the demands of sustainability, and they are, namely, greater system efficiency and the reduction of logistics negative environmental impact, which are the consequences of the modal shift towards alternative transportation modes. The second-ranked CL concept ($F_i = 0.395$) refers to the combined application of rail transportation vehicles as mobile depots and the concept of MCCs outside their service area, while the third-best CL concept ($F_i = 0.390$) refers to the two-echelon delivery system through MCCs by applying GDVs in the first and drones in the last delivery phase. These results indicate that the development of MCCs can contribute to the sustainability of complex drone-based CL solutions.

All hypotheses established in this article have been confirmed, but some other issues emerged, which require further investigation. The direction of future research could be in a more detailed quantitative and qualitative analysis of the observed CL concepts. The literature lacks analytical models that could examine in more detail the implementation effects of the observed, as well as generally more complex CL concepts. An especially interesting direction for future research would be in defining and analysing new CL concepts as the combination of the observed ones with the technologies of industry 4.0 and other CL initiatives.

The developed method is universally applicable, so a direction for future research could be in its application for solving other MCDM problems from this, and other fields. It would be interesting to examine and compare the performances of the MARCOS method developed in different environments—fuzzy, grey, spherical, interval-valued, intuitionistic, etc. The literature is growing with research that focuses on the spherical fuzzy sets and different operators and functions for those sets, so future research could follow other approaches in developing the MARCOS method in the spherical fuzzy environment. In the end, future research could focus on developing new, hybrid models based on MCDM methods in the spherical fuzzy environment.

Data Availability

All data associated with this paper can be found within the paper.

Conflicts of Interest

No potential conflicts of interest/competing interests were reported by the authors.

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