A Methodology for Planning City Logistics Concepts Based on City-Dry Port Micro-Consolidation Centres

Milovan Kovač, Snežana Tadić, Mladen Krstić* and Miloš Veljović

Logistics Department, Faculty of Transport and Traffic Engineering, University of Belgrade, Vojvode Stepe 305, 11000 Belgrade, Serbia; m.kovac@sf.bg.ac.rs (M.K.); s.tadic@sf.bg.ac.rs (S.T.); m.veljovic@sf.bg.ac.rs (M.V.)

* Correspondence: m.krstic@sf.bg.ac.rs

Abstract: The purpose of this study is to conceptualize a novel idea of potentially sustainable city logistics concepts—the development of urban consolidation centers (UCCs) on riverbanks and the establishment of city-dry port (DP) micro-consolidation centers (MCCs) as their displaced subsystems within the delivery zone. The concept enables the application of river transportation in delivering goods to the UCC, where the modal shift to electric delivery vehicles takes place for delivering goods to city-DP MCCs. In the final delivery phase (from city-DP MCCs to flow generators), smaller eco-vehicles are utilized. An innovative methodology for the planning and selection of the most sustainable concept variant is developed. The methodology combines mathematical programming and the axial-distance-based aggregated measurement (ADAM) multi-criteria decision-making (MCDM) method. The application of the defined approach is demonstrated in a case study inspired by Belgrade, Serbia. The theoretical contribution of this study is in demonstrating how a wide set of potentially viable city logistics concepts can be defined, starting from an initial idea (city-DP MCC). The practical contribution lies in developing a robust methodology that considers all relevant tactical and operational-level planning questions and takes into account qualitative and quantitative criteria in evaluating different concept variants.

Keywords: city logistics; concept; dry port; urban consolidation center; micro-consolidation; river transportation; sustainability; ADAM

MSC: 90B06; 90B50

1. Introduction

The unsustainable logistics effects in the last several decades [1] have intensified scientific efforts to solve logistics problems. These negative effects are most visible in urban areas, manifesting as air pollution, traffic congestion, noise, vibrations, violated traffic safety, time losses, inefficiency of logistics processes and activities, etc. [2,3]. To address and mitigate these unsustainable effects, significant emphasis has been set on the field of city logistics and the planning of sustainable concepts [4,5]. To be considered sustainable, a city logistics concept must take into account all the factors that describe the observed urban area [6], find a consensus between all the identified needs and available resources [7], stimulate stakeholders to participate and cooperate [8], and provide a compromise between their conflicting goals [9]. Applying an approach that considers all of the abovementioned is required to achieve economic, environmental, and social sustainability of logistics in urban areas.

The existing body of scientific literature offers various approaches to defining potentially sustainable city logistics concepts [10]. The feasibility of these concepts depends on economic, demographic, spatial, and other urban characteristics [6,11]. Nonetheless, certain elements can be identified as universally crucial in formulating sustainable city logistics concepts. Those elements are the development of adequate logistics center categories, the
application of intermodal transportation (including alternative transportation modes in general), and fostering cooperation among stakeholders and participants [12]. The initial step towards developing sustainable city logistics concepts involves establishing suitable logistics infrastructure in the form of different and diverse categories of logistics centers. Logistics centers, whose main function is supplying urban areas, could be classified into two main categories depending on their location and capacities. The first category refers to urban consolidation centers (UCCs), which offer larger capacities and are mostly on the outskirts of urban areas [13]. The second category refers to micro-consolidation centers (MCCs), which provide more localized coverage and are located within the delivery zone [14]. By channeling logistics flows through logistics centers, the system evolves into a multi-echelon system. Subsequently, establishing regular intermodal connections between the developed logistics centers, in conjunction with collaborative efforts among logistics service providers, can yield comprehensive solutions that foster economic, environmental, and social sustainability for all stakeholders [12]. Despite these considerations, only a limited number of articles have provided detailed elaboration and analysis of city logistics concepts that incorporate these elements. There is also a particular oversight regarding intermodal transportation within urban areas [15].

Numerous world metropolises have historically developed along navigable rivers. However, there are relatively few practical examples that incorporate river transportation in any phase of the delivery process [16]. Currently, some of the best practical examples of applying river transportation in city logistics include the Beer Boat in Utrecht, Mokum Maritiem and the DHL floating distribution center in Amsterdam, Vert Chez Vous and Franprix in Paris, Sainsbury’s in London, etc. [17,18]. Innovations in river transportation technologies are emerging, but there is still a lack of approaches and ideas for designing sustainable city logistics concepts that incorporate river transportation [19]. Furthermore, there is a lack of understanding and attempts to model the hinterland (urban distribution) part of chain realization in such concepts. The existing practical examples are limited to individual logistics providers and suppliers and are not sufficient to support large-scale logistics operations. Considering all this, the first research hypothesis states that it is possible to define potentially sustainable city logistics concepts that incorporate river transportation.

This study focuses on city logistics concepts that are based on UCCs situated on riverbanks and a distinctive category of MCCs serving as their subsystems within the delivery zone. The underlying idea is that a UCC located on the riverbank serves as the entry point for goods flows destined for the central city zone by applying river transportation. After that, the deliveries to flow generators would be executed in two phases through MCCs located in the delivery zone. Analogously with the existing literature in the domain of dry port (DP) terminals [20], which serve as physically dislocated subsystems of sea or river ports, in concepts that revolve around UCCs located on riverbanks, the MCCs would serve as city-dry ports (city-DPs). In other words, city-DP MCCs, as a subsystem of a UCC located at a riverbank, are equivalent to DP terminals in the framework of inland waterway (river) container terminals [21]—but in the context of an urban area. The second research hypothesis states that it is possible to develop a robust methodology that considers all relevant tactical and operational-level planning questions for planning such concepts and considers qualitative and quantitative criteria in evaluating different concept variants.

The main contribution of this study lies in providing a comprehensive exploration of city logistics concepts centered around the implementation of city-DP MCCs. The study presents an innovative methodology for planning such concepts. The methodology combines mathematical programming and a routing heuristic for tactical and operational planning of all considered concept variants. In this study, the concept variants differ in the riverbank location of the UCC. After the tactical and operational planning of every variant, the values of variants according to quantitative and qualitative criteria are determined. In the final step of the methodology, the concept variants are evaluated and ranked with a multi-criteria decision-making (MCDM) method, leading to the selection of the most sustainable option. The defined methodology is demonstrated in a case study inspired by
the city network of Belgrade, Serbia—a city located on the confluence of the Danube and Sava rivers. This concludes the final contribution to the scientific literature in the domain of planning sustainable city logistics concepts.

The next section presents a short literature review that covers the planning of complex city logistics concepts that refer to a multi-phase realization of logistics flows, or in other words, pass through different categories of logistics centers. Particular details of planning such concepts are brought into the context of planning city logistics concepts that revolve around the application of city-DP MCCs. The third section explains the idea in detail and further elaborates on individual concepts that are based on the application of city-DP MCCs. The section afterward describes the methodology for the planning of the analyzed concept. The methodology applies mathematical programming, a routing heuristic, the axial-distance-based aggregated measurement (ADAM) MCDM method [22], and takes several quantitative and qualitative criteria into consideration. The fifth section describes the case study and demonstrates the application of the defined methodology. The discussion of the approach, the developed methodology, the results in the context of the existing literature, and the limitations of this study are presented in Section 6. The last section contains concluding remarks, suggestions, and directions for future research.

2. Literature Review

The global logistics sustainability challenge cannot be addressed through the same lens that has created the situation [23]. Current logistics networks are mostly fragmented, each dedicated to a specific organization [24]. Transportation resources are dedicated to specific logistics networks even if they share the infrastructure—roads, railways, or inland waterways [24]. This necessitates the replacement of the current logistics paradigm with a new paradigm that enables creative thinking [23]. The scientific literature recognizes the transformation of city logistics systems into multi-echelon systems as a direction for sustainable development [25,26].

Developing such systems entails identifying the locations of logistics centers that connect different levels within the system. The existing literature on this topic can be categorized into two groups. The first group consists of articles that simultaneously tackle tactical and operational decision-making when modeling multi-echelon systems (location routing)—locating logistics centers and vehicle routing [25,27,28]. A significant portion of research within this group focuses on two-echelon location routing problems (2E-LRP). These articles take into account quantitative indicators/objective functions/criteria, for example, Sluijk et al. 2023 [25], Abbassi et al. 2021 [27], and Darvish et al. 2019 [28]. The second group of articles is more focused on determining the number and locations of MCCs by considering qualitative criteria as well, for example, Aljohani and Thompson 2020 [29], Novotna et al. 2022 [30], and Bajec et al. 2023 [31].

A short review of recent literature on the topic of solving 2E-LRP (the research from the first group), the main characteristics of the research, applied methods, and the approach to solving the problem are presented in Table 1. Most articles consider cost minimization as the main objective function. Those costs, in most cases, refer to operational costs, satellite development, and satellite exploitation costs [28,32,33]. Some articles, besides costs, consider the minimization of external costs as well [34–36]. Objective functions that were less frequently considered in the literature are the minimization of service duration time [27], profit maximization [37], resource utilization rate maximization [38], demand coverage maximization [39], customer satisfaction maximization [40], risk minimization [41], etc. Articles that consider more than two objective functions are generally less frequent [39,40].

Articles from the first group take into consideration an important segment in modeling multi-echelon systems—vehicle routing. In this way, they are able to take into account quantitative indicators, which are the aftermath of tactical and operational decision making. On the other hand, simultaneous tactical and operational planning limits the ability to encompass a broader range of indicators/objective functions/criteria, typically favoring those with a quantitative nature.
Table 1. Recent literature in the domain of solving 2E-LRP.

<table>
<thead>
<tr>
<th>Literature</th>
<th>Distinct Feature</th>
<th>Objective Functions ¹</th>
<th>Solution Approach</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>[27]</td>
<td>Time makespan of distribution</td>
<td>min: Cost, min: DistrTime</td>
<td>Metaheuristic</td>
<td>Particle Swarm Optimization, Genetic Algorithm, Variable Neighborhood Search</td>
</tr>
<tr>
<td>[28]</td>
<td>Flexibility in network design and due dates of customer service</td>
<td>min: Cost</td>
<td>Heuristic</td>
<td>Variable Mixed-Integer Programming Neighborhood Descent, Enhanced Parallel Exact Method</td>
</tr>
<tr>
<td>[32]</td>
<td>Synchronization between echelons</td>
<td>min: Cost</td>
<td>Heuristic</td>
<td>Decomposition-based heuristic</td>
</tr>
<tr>
<td>[33]</td>
<td>Inventory routing</td>
<td>min: Cost</td>
<td>Metaheuristic</td>
<td>Tabu search, Genetic Algorithm</td>
</tr>
<tr>
<td>[34]</td>
<td>Heterogeneous fleet and satellites</td>
<td>min: Cost, min: ExtCost</td>
<td>Metaheuristic</td>
<td>Particle Swarm Optimization, Variable Neighborhood Search</td>
</tr>
<tr>
<td>[35]</td>
<td>Time windows and perishable products</td>
<td>min: Cost, min: ExtCost</td>
<td>Metaheuristic</td>
<td>Particle Swarm Optimization, Variable Neighborhood Search</td>
</tr>
<tr>
<td>[36]</td>
<td>Incorporation of company-owned and rented vehicles</td>
<td>min: Cost, min: ExtCost</td>
<td>Metaheuristic</td>
<td>Genetic Algorithm, Gray Wolf Optimizer</td>
</tr>
<tr>
<td>[37]</td>
<td>Profit and distance-dependent collection rate</td>
<td>max: Profit</td>
<td>Heuristic</td>
<td>Greedy heuristic approach</td>
</tr>
<tr>
<td>[38]</td>
<td>Underground logistics system planning as a 2E-LRP</td>
<td>min: Cost, max: UtilRate</td>
<td>Metaheuristic</td>
<td>Genetic Algorithm, Particle Swarm Optimization</td>
</tr>
<tr>
<td>[40]</td>
<td>Horizontal cooperation among service providers</td>
<td>min: Cost, min: ExtCost, max: CustSat</td>
<td>Metaheuristic</td>
<td>Immune algorithm, Genetic algorithm</td>
</tr>
<tr>
<td>[41]</td>
<td>Adaptation for cash logistics</td>
<td>min: Cost, min: Risk</td>
<td>Metaheuristic</td>
<td>Genetic Algorithm, Pareto Evolutionary Algorithm, Simulated Annealing</td>
</tr>
<tr>
<td>[42]</td>
<td>Multi-period variant of the 2E-LRP</td>
<td>min: Cost</td>
<td>Metaheuristic</td>
<td>Genetic Algorithm</td>
</tr>
<tr>
<td>[43]</td>
<td>Adaptation for a biomass logistics system</td>
<td>min: Cost</td>
<td>Metaheuristic</td>
<td>Tabu search, Variable Neighborhood Search</td>
</tr>
<tr>
<td>[44]</td>
<td>Linehaul transportation between distribution centers</td>
<td>min: ExtCost</td>
<td>Heuristic</td>
<td>Clarke-Wright algorithm, Local search</td>
</tr>
<tr>
<td>[45]</td>
<td>Autonomous mobile lockers as facilities</td>
<td>min: Cost</td>
<td>Heuristic</td>
<td>Clarke-Wright algorithm</td>
</tr>
<tr>
<td>[46]</td>
<td>Multi-product with pickup and delivery</td>
<td>min: Cost</td>
<td>Heuristic</td>
<td>Nearest Neighbor, Clustering approach</td>
</tr>
<tr>
<td>[47]</td>
<td>Stochastic demand and value-at-risk incorporation in the decision-making</td>
<td>min: Cost</td>
<td>Metaheuristic</td>
<td>Tabu search</td>
</tr>
<tr>
<td>[48]</td>
<td>Multi-period location lot-sizing</td>
<td>min: Cost</td>
<td>Metaheuristic</td>
<td>Genetic Algorithm, Local search</td>
</tr>
<tr>
<td>[49]</td>
<td>Lifecycle of green eco-packages considered</td>
<td>min: Cost</td>
<td>Metaheuristic</td>
<td>Gaussian mixture clustering, Clarke-Wright algorithm, Genetic Algorithm</td>
</tr>
<tr>
<td>[50]</td>
<td>GRASP complemented by a learning process and path relinking</td>
<td>min: Cost</td>
<td>Metaheuristic</td>
<td>Greedy Randomized Adaptive Search Procedure, Variable Neighborhood Descent</td>
</tr>
</tbody>
</table>

¹ DistrTime—distribution time; ExtCost—external costs; UtilRate—utilization rate of resources; DemCov—demand coverage; CustSat—customer satisfaction.

Articles from the second group manage to simultaneously consider a wider set of criteria, including both qualitative and quantitative aspects. However, they tend to overlook
the combinatorial segment of the problem and the indicators, objective functions, or criteria that are influenced by tactical and operational planning. Some articles adopt a quantitative approach in solving the problems of locating MCCs [51–53], while others consider quantitative indicators/criteria and apply an MCDM method for location selection [29,30,54]. In contrast to most of the articles from the first group, the studies from this group often focus on case studies for specific urban areas. The literature review of articles from the second group is presented in Table 2.

Various different techniques have been used in solving city logistics problems—heuristics [32,53], metaheuristics [47–51], simulations [52], exact approaches [55,56], MCDM methods [29,30,54], and others. MCDM methods are very convenient for solving city logistics problems because they can encompass the goals of multiple stakeholders and wider criteria set when searching for the best or compromise solution. In this study, the recently introduced ADAM MCDM method [22] is applied to select the most sustainable city logistics concept based on city-DP MCCs.

Table 2. Recent literature in the domain of solving MCC location problems.

<table>
<thead>
<tr>
<th>Literature</th>
<th>Distinct Feature</th>
<th>Case Study</th>
<th>Objective Functions/ Criteria</th>
<th>Solution Approach</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>[29]</td>
<td>Utilizes map layers for decision criteria using ArcGIS</td>
<td>Melbourne</td>
<td>existing infrastructure, demographics, urban plans, access restrictions, implementation costs, effects on residents</td>
<td>GIS-MCDM</td>
<td>GIS, AHP, TOPSIS</td>
</tr>
<tr>
<td>[30]</td>
<td>Location selection for one MCC</td>
<td>Pardubice</td>
<td>distance from logistics centers, expansion capacities, resource availability, traveled distance, development costs</td>
<td>Hybrid MCDM</td>
<td>BWM, CRITIC, WASPAS</td>
</tr>
<tr>
<td>[31]</td>
<td>Location selection for one MCC by considering the goals of multiple stakeholders</td>
<td>Vienna</td>
<td>environmental, social, and spatial aspect</td>
<td>Hybrid AHP, DEA</td>
<td></td>
</tr>
<tr>
<td>[51]</td>
<td>Commercial density considered</td>
<td>Sevilla</td>
<td>operational costs</td>
<td>Metaheuristic</td>
<td>Genetic Algorithm</td>
</tr>
<tr>
<td>[52]</td>
<td>Mobile micro hubs</td>
<td>Hypothetical example</td>
<td>economic efficiency, time efficiency, environmental performances</td>
<td>Simulation-Analytical approach</td>
<td>Simulation-Analytical approach</td>
</tr>
<tr>
<td>[53]</td>
<td>Mathematical formulation and efficient heuristic for locating multiple MCCs</td>
<td>New York</td>
<td>operational costs, environmental costs,</td>
<td>Heuristic</td>
<td>Greedy heuristic</td>
</tr>
<tr>
<td>[54]</td>
<td>GIS-based data processing</td>
<td>Stuttgart</td>
<td>demand volume, urban planning, available infrastructure</td>
<td>Hybrid MCDM</td>
<td>AHP, PROMETHEE</td>
</tr>
<tr>
<td>[55]</td>
<td>Strategic last-mile network design problem through a three-echelon capacitated location-routing problem</td>
<td>Sao Paolo</td>
<td>development costs, operational costs</td>
<td>Hybrid</td>
<td>MILP, Continuous Approximation</td>
</tr>
<tr>
<td>[56]</td>
<td>Different settings and configurations of a location model</td>
<td>Barcelona</td>
<td>development costs, operational costs</td>
<td>Exact</td>
<td>MILP</td>
</tr>
</tbody>
</table>

In the existing literature focused on modeling two-echelon city logistics systems, no article has considered different concept variants based on the location of UCCs. The main
contribution of this study is in being the first to consider the development of a two-echelon city logistics system based on MCCs in the function of city-DP for a UCC situated on the riverbank. For modeling, and the selection of the most sustainable concept variant, this study introduces a methodology that combines mathematical programming, routing heuristics, and a multi-criterial approach for tactical and operational planning. For several different concept variants that differ in the location of the UCC, the problem of determining the number and location of city-DP MCCs is solved. Further on, the operational planning of the system is performed in order to determine the values of quantitative criteria (number of vehicle trips and traveled distance). The evaluation and ranking of concept variants are performed with the ADAM MCDM method, marking its first application in the domain of city logistics.

3. City Logistics Concepts Based on City-DP MCCs

The idea of hyperconnected city logistics systems with shared infrastructure and resources is the blueprint for achieving sustainable development in urban areas [57]. Developing multi-echelon city logistics concepts with different levels of flow consolidation that utilize alternative transportation technologies to traditional delivery trucks is a good way of achieving sustainability in all three sustainability aspects [58]. Economic sustainability can be achieved through greater efficiency of logistics activities, reduced costs, and providing a foundation for stimulating the economic growth of cities. Environmental sustainability can be achieved by reducing emissions of air pollutants, noise, and vibrations, while social sustainability can be achieved by better mobility and greater safety, fewer congestions, and more available public space for attractive content in urban areas [12]. Integrated planning of city logistics and the development of interconnected, multi-echelon concepts that utilize innovative technologies and alternative transportation modes can help realize these benefits. The idea of city logistics concepts based on city-DP MCCs presents a promising opportunity to achieve these sustainability goals.

It is possible to define a wide set of different city logistics concepts that are based on city-DP MCCs. Such concepts require the development of UCCs at riverbanks in order to be directly connected with the intermodal network through river transportation. City-DP MCCs are developed in the delivery zone, which transforms the system in its last-mile delivery leg into a two-echelon system. City-DP MCCs enable the modal shift towards smaller, light delivery vehicles (eco-friendly vehicles, bicycles, scooters, on-foot delivery, etc.). Between a UCC and city-DP MCCs, regular shuttle lines with larger transportation vehicles would be established. Considering the establishment of regular transportation links (shuttle lines) between UCCs and city-DP MCCs, and the fact that the UCC is located at the riverbank, the similarity with the DP concept in the framework of inland waterway container terminals [21] is obvious. Having this in mind, city-DP MCCs could be considered as UCC subsystems but within the urban hinterland. For these reasons, the authors consider the term city-DP for MCCs developed in such a manner appropriate. Inspired by [24,59–61], a large number of distinct city logistics concepts can be elaborated depending on the number of UCCs, the applied transportation modes and technologies in phases, and the carrier of logistics services in the final delivery phase. Some of the practically feasible city-DP MCCs concepts are shown in Table 3.

For the purpose of this study, the concept CL-city-DP-01 is considered. The concept refers to the development of a single UCC located on the riverbank serving the entire central urban area. In this concept, there is a regular road connection between the UCC and city-DP MCCs in the delivery zone and is realized with electric delivery vehicles with larger capacities. In the final delivery phase (from city-DP MCCs to flow generators), smaller eco-friendly delivery vehicles are utilized. A schematic representation of the concept is shown in Figure 1. Among all the concepts in Table 3, the CL-city-DP-01 concept is considered the most feasible for practical implementation. This is because it requires the development of only one UCC, does not rely on the development of additional rail infrastructure, is more
operationally flexible, and the logistics providers are responsible for performing all the logistics activities required.

Table 3. Theoretical elaboration of different city-DP MCCs concepts of city logistics.

<table>
<thead>
<tr>
<th>City Logistics Concept</th>
<th>Number of UCCs</th>
<th>Transportation UCC—City-DP MCCs</th>
<th>Transportation—Last Phase</th>
<th>Service Provider</th>
</tr>
</thead>
<tbody>
<tr>
<td>CL-city-DP-01</td>
<td>1</td>
<td>road (electric vehicles)</td>
<td>electric vehicles/autonomous vehicles/bicycles/on foot/etc.</td>
<td>logistics service provider</td>
</tr>
<tr>
<td>CL-city-DP-02</td>
<td>1</td>
<td>road (electric vehicles)</td>
<td>passenger vehicles/bicycles/scooters/on foot/etc.</td>
<td>crowdsourcing agents</td>
</tr>
<tr>
<td>CL-city-DP-03</td>
<td>1</td>
<td>road (electric vehicles)</td>
<td>electric vehicles/autonomous vehicles/bicycles/on foot/etc.</td>
<td>logistics service provider</td>
</tr>
<tr>
<td>CL-city-DP-04</td>
<td>1</td>
<td>rail</td>
<td>electric vehicles/autonomous vehicles/bicycles/on foot/etc.</td>
<td>logistics service provider</td>
</tr>
<tr>
<td>CL-city-DP-05</td>
<td>1</td>
<td>rail</td>
<td>passenger vehicles/bicycles/scooters/on foot/etc.</td>
<td>crowdsourcing agents</td>
</tr>
<tr>
<td>CL-city-DP-06</td>
<td>1</td>
<td>rail</td>
<td>electric vehicles/autonomous vehicles/bicycles/on foot/etc.</td>
<td>combined logistics service provider &amp; crowdsourcing agents</td>
</tr>
<tr>
<td>CL-city-DP-07</td>
<td>multiple</td>
<td>road (electric vehicles)</td>
<td>electric vehicles/autonomous vehicles/bicycles/on foot/etc.</td>
<td>logistics service provider</td>
</tr>
<tr>
<td>CL-city-DP-08</td>
<td>multiple</td>
<td>road (electric vehicles)</td>
<td>passenger vehicles/bicycles/scooters/on foot/etc.</td>
<td>crowdsourcing agents</td>
</tr>
<tr>
<td>CL-city-DP-09</td>
<td>multiple</td>
<td>road (electric vehicles)</td>
<td>electric vehicles/autonomous vehicles/bicycles/on foot/etc.</td>
<td>combined logistics service provider and crowdsourcing agents</td>
</tr>
<tr>
<td>CL-city-DP-10</td>
<td>multiple</td>
<td>rail</td>
<td>electric vehicles/autonomous vehicles/bicycles/on foot/etc.</td>
<td>logistics service provider</td>
</tr>
<tr>
<td>CL-city-DP-11</td>
<td>multiple</td>
<td>rail</td>
<td>passenger vehicles/bicycles/scooters/on foot/etc.</td>
<td>crowdsourcing agents</td>
</tr>
<tr>
<td>CL-city-DP-12</td>
<td>multiple</td>
<td>rail</td>
<td>electric vehicles/autonomous vehicles/bicycles/on foot/etc.</td>
<td>combined logistics service provider and crowdsourcing agents</td>
</tr>
</tbody>
</table>
4. Methodology for Selecting the Most Sustainable City-DP MCC Concept Variant

The main difficulty of evaluating city logistics concepts lies in the modeling work that precedes the evaluation. To evaluate the sustainability of a concept, the structure and configuration of the system have to be determined through tactical planning. Tactical planning provides practitioners with the values of some criteria considered for the evaluation (such as the number of facilities required for development, the average distance between those facilities and flow generators, etc.) but not all of them. Some of the evaluation criteria values can be determined only after the operational planning is performed (such as traveled distance, number of vehicle trips, delivery duration, etc.). Since tactical and operational decision-making are affecting each other, this poses a difficult task for itself. When the modeling phase is performed, then it is possible to determine the values of all relevant criteria and apply an evaluation tool for assessing the sustainability of the concept (or concepts). This means that developing methodologies that cover tactical and operational planning and incorporate evaluation methods (such as MCDM methods or simulation models) is required for the appropriate evaluation of city logistics concepts.

In this study, identifying the most sustainable concept variant is performed through two steps. Every concept variant is defined by a different UCC location, while the locations of city-DP MCCs are determined consequently. After identifying potential UCC and city-DP MCC locations, for every concept variant, the problem of determining the number and location of city-DP MCCs is solved, which is followed by the operational planning (vehicle routing) in both system echelons. In this way, the values according to quantitative criteria for all concept variants are determined. The values of concept variants according to qualitative criteria and the weight coefficients of all criteria are determined according to expert opinions, existing scientific literature, and the experience of authors in the field of city logistics. In the final step, the ADAM MCDM method is applied for evaluating
and ranking all concept variants and selecting the most sustainable. The algorithmic steps of the methodology are presented in Figure 2. The location model and ADAM MCDM method are explained in the following subsections.

**Figure 2. Methodology of the study.**

### 4.1. Location Model

Determining the minimal number of city-DP MCCs to cover the whole delivery zone is performed with a simple location model of linear programming inspired by the model from [56]. Let \( I \) be the set of all flow generators, and let \( K \) be the set of all potential city-DP MCC locations. According to the main definition of MCCs, due to limited capacities, the coverage area of a city-DP MCC is local [14]. It is assumed that every located city-DP MCC has its coverage area defined by the maximal allowed distance \( d_{CL-DP}^{max} \). On the other hand, UCCs are logistics centers with larger capacities, so it is assumed that their coverage area is larger when compared to MCCs. It is assumed that some flow generators can be serviced from the UCC as well. The UCC coverage area is determined by \( d_{UCC}^{max} \). Let the binary variable \( \mu_{ij} \) be equal to 1 if the flow generator \( i \) is assigned to the city-DP MCC \( j \), 0 if otherwise. In the case where the generator \( i \) is directly assigned to the UCC, the binary variable \( \mu_{i} \) equals 1, 0 if otherwise. Let the binary variable \( Y_j \) be equal to 1 if a city-DP MCC is located in \( j \), 0 if otherwise. Considering the defined decision variables, the location model could be formulated as follows:

\[
\min \sum_{j \in K} Y_j
\]

with constraints:

\[
\mu_i + \sum_{j \in K} \mu_{ij} = 1 \quad \forall i \in I
\]

\[
\mu_{ij} \cdot d_{ij} \leq d_{CL-DP}^{max} \quad \forall i \in I, \forall j \in K
\]

\[
\mu_{i} \cdot d_{ij} \leq d_{UCC}^{max} \quad \forall i \in I, j = UCC
\]
\[ Y_j \geq \mu_{ij} \quad \forall i \in I, \forall j \in K \]  

(5)

The objective Function (1) minimizes the number of developed city-DP MCCs. Constraint (2) ensures that every flow generator will be assigned to a city-DP MCC or the UCC terminal. Constraints (3) and (4) ensure that generators are assigned by respecting the coverage areas of MCCs and the UCC. \( d_{ij} \) represents the distance between \( i \) and \( j \). In the case when there are generators that could not be assigned to any city-DP MCC or the UCC and respect Constraints (3) and (4), it is assumed that those flow generators would be serviced by the delivery vehicles in the first echelon, directly from the UCC during their trips to city-DP MCCs. Equation (5) keeps track of the locations where city-DP MCCs are developed.

For the input values of the model (the set of all generators, the set of all potential city-DP MCC locations and their maximal coverage area, and the location and maximal coverage area of the observed UCC), the output result is the set of locations where MCCs are to be developed to cover the observed flow generators. Generators are assigned to the closest opened city-DP MCC. Afterward, for both system echelons, vehicle routing is performed. Solving routing problems with a larger number of delivery locations has been proven rather difficult and computationally expensive; therefore, a heuristic approach is selected—in this case, the nearest neighbor heuristic [62]. This heuristic is selected because it provides reasonable solutions for very short computational times when compared with other routing heuristics. During the routing of vehicles, their capacity constraints are considered—\( Q_{\text{max}} \) for the larger vehicles in the first echelon (vehicles that supply the city-DP MCCs from the UCC) and \( Q'_{\text{max}} \) for the vehicles in the second echelon (vehicles that perform the final delivery phase).

4.2. ADAM MCDM Method

The ADAM MCDM method is unique in the scientific literature because it is based on determining the volumes of complex polyhedra (which represent the aggregated evaluation of alternatives according to the criteria) and the ranking of alternatives according to those volumes [22]. The method is relatively fresh in the literature but is proven stable and yields consistent solutions when compared with other, more popular MCDM methods [22,63].

The main idea of the ADAM MCDM method is to define complex polyhedra whose volumes represent the aggregated evaluation of alternatives. The outer rims of the polyhedra are composed of sides that are defined by the coordinate origin, referent, and weighted referent points (vertices) of two consequent criteria [22]. The algorithmic steps of the ADAM MCDM method are described in the following text.

**Step 1.** Define the decision matrix \( E \), composed of the evaluations of alternatives according to criteria. For the purposes of explaining the steps of the ADAM MCDM method, the term “alternative” refers to a city-DP-MCC concept variant. Let \( e_{ij} \) represent the evaluation of alternative \( i \) according to the criterion \( j \):

\[
E = [e_{ij}]_{m \times n}  
\]  

(6)

where \( m \) represents the overall number of alternatives and \( n \) represents the overall number of criteria.

**Step 2.** Define the sorted decision matrix \( S \). The matrix \( S \) is composed of elements \( s_{ij} \), which represent the sorted evaluations \( e_{ij} \) in descending order according to the criteria weight coefficients:

\[
S = [s_{ij}]_{m \times n}  
\]  

(7)

**Step 3.** Define the normalized decision matrix \( N \) whose elements \( n_{ij} \) are calculated as follows:
where $B$ represents the set of all benefit criteria, while $C$ represents the set of all cost criteria.

**Step 4.** Determine the coordinates $(x, y, z)$ of reference points ($R_{ij}$) and weighted reference points ($P_{ij}$) that define the complex polyhedra of alternatives according to:

$$n_{ij} = \begin{cases} 
  \frac{s_{ij}}{\max s_{ij}}, & \text{for } j \in B \\
  \frac{s_{ij}}{\min s_{ij}}, & \text{for } j \in C 
\end{cases} \quad (8)$$

where $\alpha_j$ is the angle that determines the direction of the vector that defines the value of the alternative. This angle is determined in the following way:

$$\alpha_j = (j - 1) \frac{90^\circ}{n - 1}, \ \forall j = 1, \ldots, n, \quad (12)$$

**Step 5.** Find the volumes of complex polyhedra $V^C_i$ as the sum of the volumes of the pyramids of which it is composed using the following equation:

$$V^C_i = \sum_{k=1}^{n-1} V_k, \ \forall i = 1, \ldots, m \quad (13)$$

The value $V_k$ represents the volume of the pyramid $k$ that can be calculated as:

$$V_k = \frac{1}{3} B_k \times h_k, \ \forall k = 1, \ldots, n - 1, \quad (14)$$

where $B_k$ represents the surface of the base of the pyramid. This surface is defined by the reference and weighted reference points of two consecutive criteria. The surface is calculated as:

$$B_k = c_k \times a_k + \frac{a_k \times (b_k - c_k)}{2}, \quad (15)$$

where $a_k$ is the Euclidean distance between the reference points of two consecutive criteria. The value $a_k$ is obtained according to the equation:

$$a_k = \sqrt{(x_{j+1} - x_j)^2 + (y_{j+1} - y_j)^2}, \quad (16)$$

Values $b_k$ and $c_k$ refer to the magnitudes of the vectors corresponding to the weights of two consecutive criteria, that is:

$$b_k = z_j, \quad (17)$$

$$c_k = z_{j+1} \quad (18)$$

and $h$ is the height of the pyramid from the defined base to the top of the pyramid located in the coordinate origin ($O$). $h$ is determined with the following equation:

$$h_k = \frac{2\sqrt{s_k(s_k - a_k)(s_k - d_k)(s_k - e_k)}}{a_k}, \quad (19)$$
where $s_k$ is the semi-circumference of the triangle. It is defined by the $x$ and $y$ coordinates of two consecutive criteria and the coordinate origin and is determined as:

$$s_k = \frac{a_k + d_k + e_k}{2},$$

(20)

where $d_k$ and $e_k$ are the Euclidean distances of the reference points of two consecutive criteria from the coordinate origin. Those are calculated as:

$$d_k = \sqrt{x_j^2 + y_j^2},$$

(21)

$$e_k = \sqrt{x_{j+1}^2 + y_{j+1}^2}$$

(22)

**Step 6.** The alternatives are ranked according to the volumes of complex polyhedra $V_i^C$ ($i = 1, \ldots, m$) in descending order. The best alternative is the one with the highest volume value.

5. **Case Study and the Application of the Developed Methodology**

For urban areas developed on riverbanks, during the modeling of concepts that utilize the river transportation mode, it is necessary to determine at what locations the modal shift to ground transportation modes (rail or road) takes place. In the context of the observed city logistics concept that relies on UCCs at riverbanks, their location determines the configuration of the whole system. When modeling such systems, it is necessary to examine different variants depending on the number and location of UCCs and (city-DP) MCCs.

To illustrate the aforementioned, a smaller case study inspired by the city network of Belgrade, Serbia, is generated. Five hundred flow generators are distributed within four city zones that differ in the generator structure (Figure 3). Five different types of flow generators that differ in delivery size are defined (Table 4). Generator types and the probability distribution of delivery size per type are determined according to real-life data from several logistics companies in Belgrade. The distribution of generators per zones is shown in Table 5.

<table>
<thead>
<tr>
<th>Generator Type</th>
<th>Delivery Size (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1</td>
<td>U-[0.5, 1.0]</td>
</tr>
<tr>
<td>Type 2</td>
<td>U-[1.0, 5.0]</td>
</tr>
<tr>
<td>Type 3</td>
<td>U-[5.0, 10.0]</td>
</tr>
<tr>
<td>Type 4</td>
<td>U-[10.0, 20.0]</td>
</tr>
<tr>
<td>Type 5</td>
<td>U-[20.0, 50.0]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Generator Type</th>
<th>Distribution of Generators</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Type 1</td>
</tr>
<tr>
<td>Zone 1</td>
<td>0%</td>
</tr>
<tr>
<td>Zone 2</td>
<td>5%</td>
</tr>
<tr>
<td>Zone 3</td>
<td>25%</td>
</tr>
<tr>
<td>Zone 4</td>
<td>35%</td>
</tr>
</tbody>
</table>

Seven potential UCC locations and 25 potential city-DP MCC locations are defined. Depending on the location of the UCC, seven potential concept variants could be defined. To determine the most sustainable concept variant, it is necessary to evaluate them according to qualitative and quantitative criteria. According to the existing literature in the field (shown in the review in Tables 1 and 2), in order to have a meaningful differentiation
between variants of the same city logistics concept, six different evaluation criteria are selected for evaluating the concept variants:

- \( C_1 \) — the number of city-DP MCCs required for development;
- \( C_2 \) — the number of delivery vehicle trips;
- \( C_3 \) — traveled distance by delivery vehicles;
- \( C_4 \) — expansion capacities and land ownership;
- \( C_5 \) — delivery reliability and flexibility;
- \( C_6 \) — availability of traffic infrastructure.

Figure 3. Generated instance inspired by a part of the city network of Belgrade, Serbia.
For every potential UCC location, the location problem defined in Formulations (1)–(5) is solved. The coverage radii of UCCs and city-DP MCCs were set to $d_{\text{CL-DP}} \text{max} = 3.5 \text{ km}$ and $d_{\text{UCC}} \text{max} = 5 \text{ km}$. After that, for the obtained system structure, the routing of delivery vehicles in both echelons was performed. For the capacity of vehicles, the following values were adopted: $Q_{\text{max}}^{I} = 1500 \text{ kg}$ and $Q_{\text{max}}^{II} = 250 \text{ kg}$. Consequently, the number of delivery trips and the traveled distance by delivery vehicles was determined. Since the application of smaller delivery vehicles from the second echelon is economically, environmentally, and socially more acceptable when compared to the application of larger vehicles from the first echelon, during the calculation of criteria $C_2$ and $C_3$ values, the value for the smaller (second echelon) vehicles is weighted by the coefficient $\beta$. Having this in mind, the values of concept variants ($e_{12}$ and $e_{13}$) according to criteria $C_2$ and $C_3$ are calculated in the following way:

$$e_{12} = n_{I}^{\text{trips}} + \beta \cdot n_{II}^{\text{trips}}$$

$$e_{13} = d_{I}^{\text{route}} + \beta \cdot d_{II}^{\text{route}}$$

where $n_{I}^{\text{trips}}$ and $n_{II}^{\text{trips}}$ refer to the number of delivery trips, while $d_{I}^{\text{route}}$ and $d_{II}^{\text{route}}$ refer to the traveled distance of vehicles in the first and second echelon, respectively. For the coefficient $\beta$, the value 0.75 was adopted. An alternative approach to this is to consider the number of vehicle trips and their traveled distance in every echelon as separate criteria. The first three criteria are minimizing in their nature. The remaining three criteria are qualitative; therefore, the evaluation of concept variants according to them will be conducted in correspondence with expert evaluations and will be represented with values between 1 and 9. These three criteria are maximizing in their nature. The evaluation of concept variants according to all criteria is presented in Table 6.

### Table 6. Concept variants evaluation according to the criteria.

<table>
<thead>
<tr>
<th>Concept Variant</th>
<th>UCC Location</th>
<th>$C_1$</th>
<th>$C_2$</th>
<th>$C_3$</th>
<th>$C_4$</th>
<th>$C_5$</th>
<th>$C_6$</th>
</tr>
</thead>
<tbody>
<tr>
<td>city-DP-V_1</td>
<td>UCC 1</td>
<td>12</td>
<td>32</td>
<td>792</td>
<td>6</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>city-DP-V_2</td>
<td>UCC 2</td>
<td>11</td>
<td>33</td>
<td>617</td>
<td>2</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>city-DP-V_3</td>
<td>UCC 3</td>
<td>10</td>
<td>31</td>
<td>584</td>
<td>4</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>city-DP-V_4</td>
<td>UCC 4</td>
<td>11</td>
<td>31</td>
<td>622</td>
<td>5</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>city-DP-V_5</td>
<td>UCC 5</td>
<td>11</td>
<td>32</td>
<td>588</td>
<td>1</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>city-DP-V_6</td>
<td>UCC 6</td>
<td>12</td>
<td>32</td>
<td>632</td>
<td>7</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>city-DP-V_7</td>
<td>UCC 7</td>
<td>12</td>
<td>32</td>
<td>693</td>
<td>8</td>
<td>3</td>
<td>6</td>
</tr>
</tbody>
</table>

According to the existing literature that performed the prioritization of criteria before solving city logistics-related problems [12,64,65], the following criteria weights are adopted: $w_1 = 0.161$, $w_2 = 0.116$, $w_3 = 0.202$, $w_4 = 0.243$, $w_5 = 0.151$, $w_6 = 0.127$. Articles [12,64,65] performed the criteria evaluation according to the opinions and goals of stakeholders in Belgrade (and Serbia in general); therefore, they could be considered relevant for this study as well. The adopted criteria weights compose the initial concept variants evaluation scenario (Sc. 0). The described methodology was developed and applied in Python 3.9.5 programming language on a computer with the following characteristics: Intel® Core™ i7-8750H CPU @ 2.20GHz, 8 GB RAM. The city network of Belgrade was downloaded using the OSMnx Python library [66]. The full locations dataset is available at [https://docs.google.com/input_data_BG_case_study](https://docs.google.com/input_data_BG_case_study), accessed on 1 June 2023. The location model was solved with Gurobi 9.5.1 optimizer [67], while the ADAM MCDM software was utilized [68].

By applying the ADAM method through steps (6)–(22), the observed concept variants were evaluated and ranked. After forming the initial decision matrix $E$, by applying steps (7) and (8), the sorted decision matrix $S$ and the normalized decision matrix $N$ were formed, respectively. By applying Equations (9)–(12), the coordinates of reference points $(R_{ij})$ and weighted reference points $(P_{ij})$ were determined. Complex polyhedra volumes of concept variants (alternatives) were calculated with Equations (13)–(22). The variants were ranked
Table 7. Output results for Sc. 0.

<table>
<thead>
<tr>
<th>Concept Variant</th>
<th>UCC Location</th>
<th>( V_i )</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>city-DP-V₁</td>
<td>UCC 1</td>
<td>0.043</td>
<td>6</td>
</tr>
<tr>
<td>city-DP-V₂</td>
<td>UCC 2</td>
<td>0.045</td>
<td>5</td>
</tr>
<tr>
<td>city-DP-V₃</td>
<td>UCC 3</td>
<td>0.067</td>
<td>1</td>
</tr>
<tr>
<td>city-DP-V₄</td>
<td>UCC 4</td>
<td>0.053</td>
<td>2</td>
</tr>
<tr>
<td>city-DP-V₅</td>
<td>UCC 5</td>
<td>0.040</td>
<td>7</td>
</tr>
<tr>
<td>city-DP-V₆</td>
<td>UCC 6</td>
<td>0.050</td>
<td>3</td>
</tr>
<tr>
<td>city-DP-V₇</td>
<td>UCC 7</td>
<td>0.049</td>
<td>4</td>
</tr>
</tbody>
</table>

The determined complex polyhedra of concept variants used for their ranking are shown in Figure 4.

![Complex polyhedra of city-DP MCC concept variants.](image)

The stability of the obtained results was examined through a sensitivity analysis. Aside from the initial scenario (Sc. 0), the analysis considered 13 other scenarios that differed in the criteria weight coefficients. In the first scenario (Sc. 1), all criteria were considered equally important (\( w_j = 0.167 \)). In the next six scenarios (Sc. 2–7), each individual criterion was left out of the evaluation. In the last six criteria (Sc. 8–13), the weight coefficient of every individual criterion was doubled. Sensitivity analysis results are presented in Table 8 and Figure 5. In some scenarios, the results differed when compared to the initial scenario, but this is expected since criteria prioritization plays a pivotal role in solving city logistics problems. After calculating the average rank of concept variants for all scenarios and ranking them according to descending values, the variant city-DP-V₅ emerged as the first-ranked again. Such a result confirms that UCC3 is the best location for the UCC in a concept based on city-DP MCCs. The second-best concept variant was city-DP-V₇. This concept variant had slightly worse results than the first-ranked and represented a decent alternative.
Table 8. The rankings of concept variants in sensitivity analysis scenarios.

<table>
<thead>
<tr>
<th>Concept Variant</th>
<th>Sc. 0</th>
<th>Sc. 1</th>
<th>Sc. 2</th>
<th>Sc. 3</th>
<th>Sc. 4</th>
<th>Sc. 5</th>
<th>Sc. 6</th>
<th>Sc. 7</th>
<th>Sc. 8</th>
<th>Sc. 9</th>
<th>Sc. 10</th>
<th>Sc. 11</th>
<th>Sc. 12</th>
<th>Sc. 13</th>
<th>Average Rank</th>
<th>Final Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>city-DP-V1</td>
<td>6</td>
<td>2</td>
<td>5</td>
<td>2</td>
<td>5</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>2</td>
<td>5</td>
<td>2</td>
<td>3.57</td>
<td>4</td>
</tr>
<tr>
<td>city-DP-V2</td>
<td>5</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>5.93</td>
<td>6</td>
</tr>
<tr>
<td>city-DP-V3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>4</td>
<td>1.93</td>
<td>1</td>
</tr>
<tr>
<td>city-DP-V4</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>3.86</td>
<td>5</td>
</tr>
<tr>
<td>city-DP-V5</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7.00</td>
<td>7</td>
</tr>
<tr>
<td>city-DP-V6</td>
<td>3</td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3.50</td>
<td>3</td>
</tr>
<tr>
<td>city-DP-V7</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2.21</td>
<td>2</td>
</tr>
</tbody>
</table>

Figure 5. The rankings of concept variants in sensitivity analysis scenarios.

Other different MCDM methods could be used in the second phase of the methodology as well. The final step of proving the stability and consistency results of the ADAM MCDM method is to compare them with the results obtained with widely accepted MCDM methods in the literature. The results for Sc. 0 were compared with the results obtained from four popular MCDM methods—EDAS [69], MARCOS [70], MABAC [71], and TOPSIS [72] (Table 9). The results show some minor ranking differences, but the first-ranked concept variant in all cases was city-DP-V3. This proves again that ADAM MCDM is a reliable tool.

Table 9. Comparing output results with other MCDM methods for Sc. 0.

<table>
<thead>
<tr>
<th>Concept Variant</th>
<th>UCC Location</th>
<th>ADAM Rank</th>
<th>EDAS Rank</th>
<th>MARCOS Rank</th>
<th>MABAC Rank</th>
<th>TOPSIS Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>city-DP-V1</td>
<td>UCC 1</td>
<td>6</td>
<td>4</td>
<td>5</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>city-DP-V2</td>
<td>UCC 2</td>
<td>5</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>city-DP-V3</td>
<td>UCC 3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>city-DP-V4</td>
<td>UCC 4</td>
<td>2</td>
<td>5</td>
<td>4</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>city-DP-V5</td>
<td>UCC 5</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>city-DP-V6</td>
<td>UCC 6</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>city-DP-V7</td>
<td>UCC 7</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>
6. Discussion

The novelty in this study is in defining a new development direction of potentially sustainable city logistics concepts for urban areas located at riverbanks of sailable rivers. The key novelty lies in proposing the establishment of a distinct category of logistics centers—city-DP MCCs as subsystems of UCCs located at riverbanks. The existing literature overlooks the potential of river transportation for delivering goods into the central urban areas. By overlooking this potential, a whole range of potentially feasible city logistics concepts that rely on river transportation is neglected. Noteworthy examples of defining city logistics concepts that integrate river transportation can be found in the works of Tadić et al. [6], Krstić et al. [64], and Kovač et al. [73]. The conceptualization and elaboration of city logistics concepts in this study are inspired by [59] and align with the emerging trend of planning interconnected city logistics systems [74,75]. This proves the first hypothesis, which states that it is possible to define potentially sustainable city logistics concepts that incorporate river transportation.

The developed methodology is universally applicable for selecting sustainable two-echelon concept variants. The methodology covers some of the most significant questions when planning complex concepts—the location of the UCC, the number and locations of MCCs (city-DP MCCs), as well as operational planning. This enabled the sustainability evaluation of concept variants through a set of qualitative and quantitative criteria. The selected criteria are not novel and are adopted from the existing scientific literature [12,64,65]. This proved the second research hypothesis, which stated that it is possible to develop a robust methodology for planning such concepts by considering all relevant tactical and operational level planning questions and qualitative and quantitative criteria in evaluating different concept variants.

The limitation of the methodology is in considering only concept variants that refer to the development of only one UCC. This leaves some space for developing more robust methodologies that would focus on a more detailed structure modeling—examining different variants according to the number and location of UCCs. When compared with other methodologies and frameworks for planning/evaluating city logistics, there are several aspects that could be included in the future improvement of this methodology to make it more robust. The first one includes the ex ante and ex post assessment of city logistics concepts throughout their main lifecycle stages, as in [76]. Another improvement could include a better assessment of the current situation in an observed urban area and providing a better insight into the main impact areas that a concept would have, as it is proposed in [77]. Study [78] proposes that dynamic aspects of city logistics should be included as well to have a more realistic observation of the behavior of city logistics concepts. The framework proposed in [79] shows that incorporating agent-based modeling can help in understanding the interactions between heterogeneous stakeholders of the system, which is another potential aspect of improving this methodology. Considering real-world data is essential in designing sustainable city logistics solutions; therefore, another improvement of the methodology would be to provide it with the capability of ingesting more real-world data. A good example of this is the methodology proposed in [80].

The adopted set of criteria should not be considered final, and other qualitative and quantitative criteria should be considered—air pollution, operational costs, system efficiency, workload balance, time losses, etc. Other MCDM methods could be used as a replacement for the ADAM method in the second phase of the methodology.

This study did not focus on selecting the most appropriate concept from the initial set of feasible concepts (Table 3) that revolve around the idea of city-DP MCCs as subsystems of UCCs at riverbanks. The analyzed case study is artificially generated according to the city network of Belgrade, Serbia. The planning of such systems, in reality, would require the availability of real-life data regarding the characteristics of generators, flows, and potential development locations of UCCs and MCCs. Considering the state and complexity of logistics, and the lack of attempts to solve city logistics problems in Belgrade, a more in-depth analysis of potential development directions for city logistics concepts is required.
Another issue worth mentioning is the absence of collaboration among stakeholders in Belgrade, which must be resolved to make the development of complex city logistics concepts even possible.

However, the approach and methodology are practically applicable and could help decision makers and policy creators in the field of city logistics. This study demonstrated one way of defining a wider set of practically feasible city logistics concepts by beginning from one initial idea. Afterward, the study demonstrated how to select the most sustainable variant of an observed city logistics concept. The methodology and the results of this study should primarily inspire stakeholders in the field of city logistics to engage in solving sustainability problems that society is facing right now.

7. Conclusions

Solving sustainability problems in city logistics requires defining, analyzing, and developing sustainable city logistics concepts. To contribute to achieving economic, environmental, and social sustainability, the systems are required to be transformed into multi-echelon systems by developing different categories of logistics centers. Moreover, instead of relying solely on road transportation, alternative modes of transportation should be utilized, with a particular emphasis on promoting intermodal transportation. Cities situated along riverbanks have a unique opportunity to integrate river transportation into their city logistics systems. Combining different categories of logistics centers and different transportation modes results in a wide set of potentially sustainable city logistics concepts. From this pool of potentially sustainable and feasible concepts, it is necessary to identify variants that contribute to sustainability the most.

This study introduced a novel idea for city logistics concepts that rely on the development of different categories of logistics centers (UCCs and city-DP MCCs) and the application of intermodal transportation/alternative transportation modes in such a system. From a set of practically feasible concepts that are based on the idea of city-DP MCCs as subsystems of UCCs located at riverbanks, one concept is selected and further elaborated. A generic approach that combines mathematical programming, a routing heuristic, and an MCDM method is developed for modeling such a concept and selecting its most sustainable variant. The application of the defined methodology is demonstrated in a generated case study. The case study is inspired by the city network of Belgrade, Serbia.

Aside from elaborating on the city-DP MCC concept idea, the contribution of this study is in demonstrating how to define a wider set of potentially feasible city logistics concepts starting from an initial idea. Another contribution is in showing how to identify the most sustainable variant of a chosen concept by considering qualitative and quantitative criteria.

Future research on this topic could go into more detailed decision making on all levels (strategic, tactical, and operational) and include different stakeholder groups in that process. On the strategic level, future studies could further elaborate other city-DP MCC concepts and focus on selecting the most appropriate starting concept for a given case study first. It is necessary to further investigate the compatibility of different types of goods and delivery sizes with such system structures. How the consolidation level (delivery size) affects the shaping of such concepts should be investigated as well. On the tactical and operational levels, the direction of future research could be to consider a wider set of criteria when modeling such concepts. Other hybrid and integrated methods and models should be developed to simultaneously tackle the problems of tactical and operational decision making through the lens of a wider criteria set. Other aspects of the methodology could be upgraded according to the existing frameworks in the literature. Some of those are the assessment of city logistics concepts throughout their main lifecycle stages, considering real-life dynamics, adding real-world data into the framework, incorporating agent-based modeling and simulation to better account for complex interactions among stakeholders and participants, etc.
Author Contributions: Conceptualization, M.K. (Milovan Kovač) and S.T.; methodology, M.K. (Milovan Kovač), S.T. and M.K. (Mladen Krstić); software, M.K. (Milovan Kovač); validation, M.K. (Milovan Kovač), S.T. and M.V.; formal analysis, M.K. (Milovan Kovač); writing—original draft preparation, M.K. (Milovan Kovač); writing—review and editing, S.T. and M.K. (Mladen Krstić); visualization, M.K. (Milovan Kovač) and M.V.; supervision, S.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Location data used in this study is available at the following link: https://docs.google.com/input_data_BG_case_study (accessed on 1 June 2023) and could also be retrieved by contacting the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

References

2. Bosona, T. Urban freight last mile logistics—Challenges and opportunities to improve sustainability: A literature review. Sustainability 2020, 12, 8769. [CrossRef]
8. Katsela, K.; Browne, M. Importance of the stakeholders’ interaction: Comparative, longitudinal study of two city logistics initiatives. Sustainability 2019, 11, 5844. [CrossRef]
13. Raicu, S.; Costescu, D.; Burcic, S. Distribution system with flow consolidation at the boundary of urban congested areas. Sustainability 2020, 12, 990. [CrossRef]
15. He, Z.; Haasis, H.D. Integration of urban freight innovations: Sustainable inner-urban intermodal transportation in the retail/postal industry. Sustainability 2019, 11, 1749. [CrossRef]


56. Savall-Manyo, M.; Ribas, I. Location of micro-urban consolidation centres for the superblocks in Barcelona. IFAC PapersOnLine 2022, 55, 145–150. [CrossRef]
75. Maslarić, M.; Nikolić, S.; Mrčetić, D. Logistics response to the Industry 4.0: The Physical Internet. Open Eng. 2016, 6, 511–517. [CrossRef]
77. Xenou, E.; Madas, M.; Ayandopoulos, G. Developing a smart city logistics assessment framework (SCLAIF): A conceptual tool for identifying the level of smartness of a city logistics system. Sustainability 2022, 14, 6039. [CrossRef]

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.