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Application of the MAMCA Method in the Evaluation of Delivery Flows within City Centers: A Case Study of Rijeka

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Abstract: The aim of this paper was to propose a model for the evaluation of the flow of goods delivered to urban centers based on a systematic approach, generating possible scenarios of delivery activities and selecting those criteria for evaluation that contributed to the development of delivery activities and their evaluation by individual stakeholders. The number of users of delivery services is increasing, which leads to an increase in the volume of goods in the city center, creating additional traffic congestion—so-called bottlenecks—which results in an increased noise level and the emission of harmful exhaust gases, increasing dissatisfaction with the quality of life of the city population. It is, therefore, necessary for decision-makers to make a decision that achieves the best consensus among stakeholders. A test was carried out in the city of Rijeka. Based on a review of the literature and the spatial planning of the city of Rijeka, this paper proposed the following possible scenarios for the delivery of goods within the city center: status quo, delivery from one consolidation center, delivery from two consolidation centers, delivery by environmentally friendly vehicles from one consolidation center and livability. The criteria were evaluated by relevant stakeholders to determine the weight of each criterion for the development of goods deliveries in the city center. This paper used a multi-actor multi-criteria analysis (MAMCA) based on the optimization and ranking of scenarios in accordance with the given objective, the research problem, the defined criteria and the interests of the stakeholders. The solution of the MAMCA analysis evaluated the scenario with two consolidation centers best in accordance with the specified optimization objective.

Keywords: city logistics; analytic hierarchy process; multi-actor multi-criteria analysis; delivery flows

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1. Introduction

The delivery of goods to a city center has a significant impact on the sustainable development of the city center. As the number of people moving into city centers increases, it becomes increasingly difficult to deliver the necessary goods needed in an appropriate way [1].

Carriers are faced with numerous problems when delivering goods to customers (traffic congestion, unavailable delivery points, etc.), resulting in delays in the delivery of goods. On one hand, the demand for the quantity of goods that gravitates to the city center is growing; on the other hand, customers expect that carriers will provide a better-quality transport service within the framework of just-in-time delivery [2]. This method of delivery without systematic planning results in the creation of an increasing number of bottlenecks; the noise level increases and the emission of harmful gases increases, which significantly affects the quality of life of the residents of the city center. This results in the inefficient use of delivery vehicles, which inadequately use their capacities, all for the reason of customer satisfaction in terms of delivery speed. For this reason, most carriers have their headquarters near the city center [3]. The entry of heavy goods delivery vehicles (HGVs) into city centers disturbs the quality of life of the city population; however, these same vehicles bring the goods they need. Within the city center, there are economic entities in the

city's business zone who want to receive goods on time, which results in a conflict with residents who want to have as little fluctuation of vehicles as possible on the roads next to residential buildings [1,4]. The task of urban policy-makers is to maintain a balance between these parties. On one hand, urban policy-makers must protect the interests of citizens; on the other hand, they must support the economic sector [5,6].

The aim of public administration is to improve the economic development of a city and to reduce traffic congestion. What is self-evident is the need to invest in information and communication technologies to improve the organization of the delivery of goods to city centers [7]. The supply chain is constantly developing, both through new technological solutions and through increasingly advanced information and communication technology [8,9]. City logistics strive to reduce delivery costs, increase delivery efficiency and reduce the harmful impact of vehicles on the environment. In order to evaluate the flow of goods deliveries using a multi-criteria analysis, a survey was carried out. The results were used to analyze a set of criteria that had been evaluated by the interest groups of the city logistics and the impact of the criteria on each defined delivery scenario [10]. Triantafyllou et al. [11] conducted a study in the UK and identified potential weaknesses, strengths and risks associated with the operation of consolidation centers whose goals were to reduce gas emissions and distribution costs. They concluded that carriers would have to invest in technological progress (e.g., in the use of vehicles without harmful gas emissions) and develop new logistics concepts that should be integrated into their operations. Verlinde et al. [12] pointed out the problem of the lifespan of consolidation centers. The construction of consolidation centers was dependent on government subsidies, but it was emphasized that the maximum use of the capacity of consolidation centers greatly reduced the number of trucks on city streets. Wasiak et al. [13] described the ecological solutions intended for the organization of logistics services in urban areas in their paper. The solutions were based on the use of a cross-docking system in combination with consolidation centers. In their work, they developed a logistics network using the SIMMAG 3D tool. After the implementation of the evaluation (case study: Warsaw, Poland), revenues increased by 8.1% and carbon monoxide emissions decreased by 16.7%. Qauk et al. [9] discussed the advantages and disadvantages of implementing electric delivery vehicles in a city center. The reductions in gas emissions and noise levels were emphasized as advantages, while the disadvantages lay in insufficient vehicle capacities and high investment costs. Allen et al. [14] provide an overview of the use of consolidation centers, which aim to reduce freight vehicle traffic, vehicle-related greenhouse gas emissions and local air pollution. They note that the problem lies in the high initial investment, which is only possible with government support. Taniguchi [15] presented urban logistics concepts for the sustainable development of city centers. Urban logistics can help to create more efficient and environmentally friendly urban freight transport systems. The application of innovative ICT (information and communication technology) and ITS (intelligent transport system) technologies and the synergy of public–private partnerships can have a significant impact on the implementation of city logistics policy measures. Foltynski [16] focused on electric urban freight mobility, considering the technical, legal and social factors relevant to small- and medium-sized cities [17]. He provides an overview of current developments and examples of European cities that have successfully introduced electric vehicles into their fleets. Tamagawa et al. [18] used the VRP–TW-F model. In the model, the customer determined the earliest and latest delivery time in which the order must be delivered. The results of the model showed that a ban on the entry of trucks into the city center directly affected the sustainability of the city area, leading to an acceptable environment for all interest groups, especially the local population, but also to a reduction in the delivery time of goods. Malindretos et al. [19] stated that delivery activities in cities should be more efficient and more environmentally sustainable. City logistics play a crucial role in meeting the increasing demand for resources in cities. Currently, one of the significant challenges is the coordination of freight transport within a city. Urban consolidation centers offer a great opportunity for synergy between different actors in supply chains to enable an envi-

ronmentally friendly and efficient flow of goods into cities. Veličković et al. [20] concluded in their work that several small UCCs could provide better results than a central center, even in medium-sized cities, and that is necessary to include the external costs of freight transport into urban transport planning cost–benefit analyses in developing countries, especially in cases where planners are considering introducing UCCs in medium-sized cities. Janjević et al. [21] state that the main elements that influence the cost attractiveness of UCCs are the characteristics of the delivery operations (e.g., number of stops, average number of cargo units per stop or the type of actor who performs the delivery), the characteristics of the UCC (e.g., its location, the service price or the possibility of overnight deliveries) and the characteristics of the service area.

According to this review of the literature, it can be concluded that there are various ways of delivering goods to city centers. Urban consolidation centers built in the immediate vicinity of a city center are most often used to reduce transport costs and delivery times to the delivery point [17]. There is also an increasing tendency to reduce the number of conventional vehicles and to gradually start switching to environmentally friendly vehicles [22]. The management of complex systems such as the delivery of goods to city centers (city logistics) has complex goals, different scenarios, different preconditions, differently dimensioned evaluation criteria and different limitations, which results in the impossibility of their unequivocal solution [7,23]. In accordance with this knowledge, a multi-criteria decision-making procedure was used to evaluate the possible scenarios of goods deliveries to city centers and goods-delivery flows. Among the various optimization methods, this paper used a multi-participant multi-criteria analysis based on the analytic hierarchy process (AHP). The MAMCA research method can be used to solve the optimization problem [24–26]. Such an analysis enables a tripartite observation of the relationships and influences in the hierarchy from the point of view of possible users (stakeholders), possible evaluation criteria and possible scenarios for the development of goods deliveries to city centers [27,28]. The key difference, compared with previous research on urban centers and the use of MAMCA methods in decision-making, was the investigation of the criteria related to the organization of delivered activities. Therefore, an organizational group of criteria was formed in this paper, which is extremely important in the development of delivery models.

The aim of this paper was to propose a model to assess the flow of goods delivered to city centers based on a systematic approach. This included generating possible delivery scenarios, selecting evaluation criteria that contributed to the development of delivery activities and evaluating these activities by individual interest groups.

In the Section 1, we explain the importance of delivery activities within the city center and the purpose and aim of the research. In the Section 2, Research Methodology, the usage of the MAMCA method and its importance in the decision-making process are explained. The Section 3 demonstrates the application of the method in the selected city. The Section 4 focuses on the results of the empirical research. The article concludes with final remarks.

2. Research Methodology

When talking about the MAMCA method, the development methodology is expanded in such a way that the interdependence of all interest groups is considered [29]. The MAMCA method clearly expresses the goals of different interest groups, which leads to a better understanding of the goals of all interest groups in relation to the main goal [30,31]. This approach forces interest groups to think about what they really want and the reasons for those desires. By looking at the goals of the other side (other interest groups), an overall picture of the observed problem is obtained, from which an optimal solution can emerge in favor of all interest groups [32]. Within the framework of the MAMCA method, interest groups are individual groups that have an interest in any decision made, whether it is about finances, standards or the quality of life [33]. Interest groups focus on sustainable mobility and logistics. Regardless of the problem, vehicle manufacturers, network infrastructure managers, passenger-service operators, non-governmental organizations dealing with

environmental protection, etc., can be included in the discussion [31]. MAMCA is an iterative methodology consisting of the following seven steps. The first three steps are very important and influence each other. For this reason, the methodology should be iteratively implemented [28,34].

1. Defining the problem and scenario: This step aims to define the scope of the decision-making problem in such a way as to identify possible scenarios. Depending on the problem posed, alternatives can take different forms such as politics, technological solutions and the accommodation of a subject. Scenarios can be defined in advance in order to set the problem. Possible scenarios can be suggested based on a literature review or through interviews with interest groups. It is important to emphasize that before setting a scenario, the feasibility of the scenario should be checked in terms of legal, economic, social, environmental or technical problems. The above can be implemented through a risk analysis and the early involvement of interest groups in the topic itself. This way of development requires the involvement of the interest group at the beginning of the process, which means carrying out steps 2 and 3 before the scenarios are defined.
2. Analysis of interest groups: Understanding the interest groups is crucial in order to properly evaluate different scenarios. When identifying interest groups, it is necessary to determine the scope of the whole that is intended to be researched in order to determine the boundaries of the defined problem. With regard to issues of sustainability in the context of mobility and traffic, special attention must be paid to how the decision will affect certain interest groups. The most sensitive interest groups are undoubtedly the residents of the city center, who want a high-quality life with as few emissions of harmful gases, noise, vibrations, etc. The priorities may be different, but the same criteria are used for every interest group.
3. Defining criteria and assigning weight values: Defining the criteria is primarily based on determining the goals of the interest groups and the purpose of the considered scenarios. The criteria of all interest groups are considered. The decision made relating to the proposed scenario will also affect the goals of the interest groups. The selection of criteria is usually obtained through an interactive discussion with interest groups. A list of criteria is first provided to various interest groups based on a literature review. Then, each interest group has the opportunity to evaluate and confirm the predefined criteria.
4. Indicators and measurement methods: This step aims to evaluate the criteria with qualitative and quantitative indicators that measure the scope or ability of each alternative in fulfilling the criteria of each interest group. The indicators must be clear in order to understand their purpose. Based on the literature, the mutual effect of each criterion can be assessed. The advice of experts can provide a scientific basis and be the foundation for the implementation of the decision, which can be extremely important and helpful when accepting and implementing the proposed scenario. The assessment is carried out by an analyst and/or experts and is based on literature, empirical data collection and expert advice. It is desirable to cooperate with a multi-disciplinary team of experts.
5. Full analysis: This consists of a scenario evaluation using a multi-criteria analysis. Depending on the goal of the decision-making process, different participants such as analysts, experts and interest groups can provide data for scenario evaluations. Analysts can acquire the necessary expertise related to the problem so that the implementation is correct. It is also necessary to emphasize that cooperation with interdisciplinary experts is necessary in order to solve multi-dimensional problems. Interest groups can also evaluate alternatives themselves, where each interest group influences the decision according to its own strategic outcome.
6. Results and sensitivity analysis: Based on the results of the decision-making method, MAMCA recognizes the strengths and weaknesses of each option in relation to the problems of each interest group. MAMCA provides a comparison of interest groups

for different options while highlighting elements that have positive or negative effects. The MAMCA analysis provides a clear picture of which points of view do not agree and where an agreement could possibly be reached.

7. Implementation and recommendations: Based on the results of the MAMCA method, decision-makers can formulate further policies through strategies. Decision-makers, in the context of the organization of traffic in an inner city center, are the urban policy-makers who must look at the whole picture and take into account the opinion of all interest groups. There are two approaches for consideration. The first approach consists of considering public authority that represents the point of view of society. The urban policy-makers can choose the most appropriate option, considering the opinion of all interest groups. In this way, measures can be developed that reduce negative effects and cause fewer consequences for individual interest groups. In another approach, the decision-maker may choose the option that achieves the best consensus, faces fewer obstacles, or simply avoids the objection of interest groups.

This evaluation methodology specifically emphasizes the inclusion of various actors involved in a project, known as stakeholders. Similar to the traditional multi-criteria decision analysis (MCDA) method, it allows for the incorporation of both qualitative and quantitative criteria and their respective importance [35]. However, within the multi-actor multi-criteria analysis (MAMCA) method, these criteria represent the goals and objectives of multiple stakeholders. Consequently, stakeholders are integrated into the decision-making process [36].

During the procedure, new possibilities and new possible scenarios can potentially be identified; thus, the entire procedure must be repeated, especially the first three steps.

MAMCA is the "extended arm" of a multi-criteria analysis. The interaction between interest groups can become the basis for the discovery of innovative scenarios that suit all interest groups [37]. The goal of the MAMCA method is to select the best scenario for each interest group separately. Sometimes, there may be a scenario that is ranked at the very top by all interest groups [38].

The challenges and limitations of the MAMCA method are as follows [39]:

- Data availability: like any model, the accuracy of the outputs depends on the quality of the inputs, but high-precision data on impacts can be difficult or costly to find;
- Participation: engaging a representative sample of participants can be hard and participants may struggle to assign weights to impact factors;
- Exploring why: care must be taken not to blindly follow the outcome and instead unpick why certain solutions rank high or low;
- Conflict: MAMCA itself is not a conflict-solving tool and a willingness to cooperate is required.

Jardas et al. [40], based on a literature review, defined four interest groups and criteria related to delivery activities within the city center. The MAMCA method was performed on the same criteria in this paper. To create a model to evaluate the flows of goods in city centers to improve sustainable logistics, it is necessary to have the following elements in the system:

1. **General Goal:** the optimal flow of goods deliveries to city centers.
2. **Interest Groups:**

- delivery recipients;
- urban policy-makers;
- residents;
- carriers.

3. **Research Criteria:**

a. *Technical–technological criteria*

- The use of existing/new technologies;
- The condition and quality of the infrastructure;
- Traffic congestion;

– Unloading/loading equipment.

b. *Economic–financial criteria*

– Transport infra- and superstructure maintenance costs;
– Transport time to the delivery point;
– Transport time from the delivery point to the delivery recipient;
– Investment in new technological solutions;
– Shipping cost.

c. *Social criteria*

– Delivery recipient's satisfaction;
– Greenhouse gas emissions;
– Noise level;
– Consequences of traffic accidents;
– Safety;
– Carrier satisfaction.

d. *Organizational criteria*

– Possibility of access to the delivery point;
– Distance from the delivery point to the delivery recipient;
– Customer coverage.

4. Possible Scenarios Of The Delivery Of Goods

– Scenario 1;
– Scenario 2;
– Scenario n (...).

The criteria for optimal delivery can be applied when surveying any city. Each city has its own history, structure and unique characteristics, leading to variations in delivery models from one scenario to another.

3. Application of the MAMCA Method in the Evaluation of Delivery Flows within the City Center of Rijeka

The methodology of implementing the MAMCA method was implemented in the city center of the city of Rijeka. For comprehensive research on defining the optimal flow of goods deliveries to city centers, it is necessary to make an analysis in which all interest groups of the city center evaluate the impact of all criteria that influence delivery activities in city centers [30,32].

According to their own opinion, the respondents compared the criteria with each other in order to obtain the weight of individual criteria within the logical group of criteria. The observed area is shown in Figure 1. The red points are the following locations:

– R6: Krešimirova street;
– R38: Vukovarska street;
– R40-41: Street 1, Maja;
– R46-47: Laginjina street;
– R24-25: Street Franje Račkog;
– R20-21: Strossmayerova and Križanićeva streets;
– R89: road D404.

Delivery scenarios were defined by the authors based on the literature review explained in the Introduction of this paper. Considering the area of the city of Rijeka, two scenarios with consolidation centers were defined, one that referred to one consolidation center (Figure 2) and one that referred to two consolidation centers (Figure 3).

A delivery scenario with one consolidation center was also identified in which the fleet consisted of environmentally friendly vehicles, as well as a scenario in which one part of the city center was transformed into a pedestrian zone (black line represents pedestrian part of the main street Riva), which is why the scenario was called the livability model (Figure 4).

Figure 1. Entries in the city center of Rijeka. Source: Rijeka Plus d.d (https://www.rijeka-plus.hr/promet/prometno-opterecenje/, accessed on 3 August 2024).

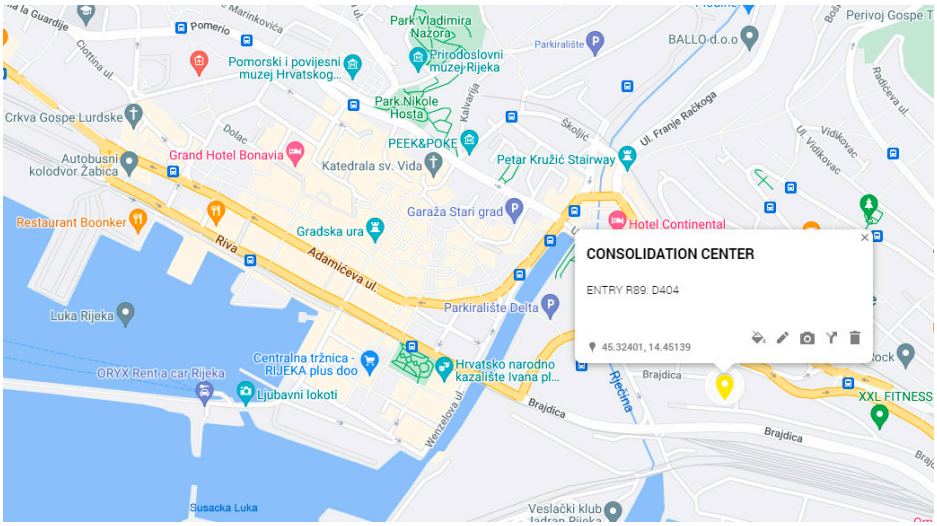


Figure 2. Consolidation center, entry R89: D404. Source: authors and Google maps (screenshot).

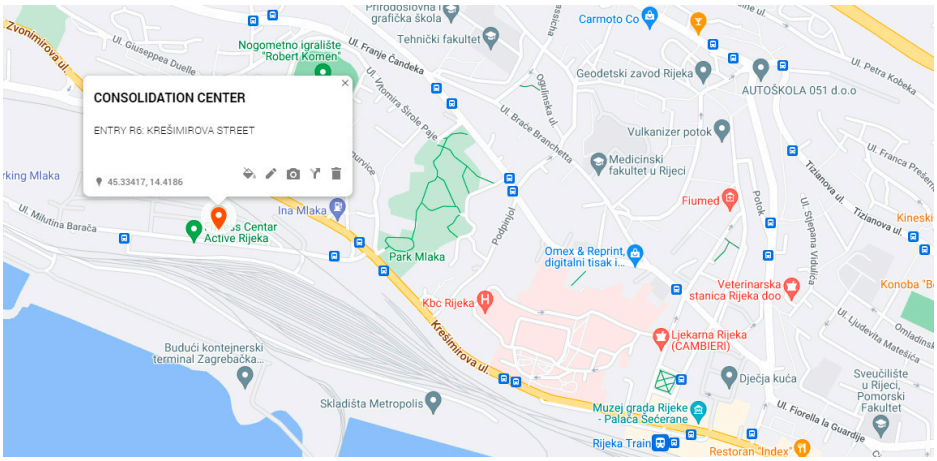


Figure 3. Consolidation center, entry R6: Krešimirova street. Source: authors and Google maps (screenshot).

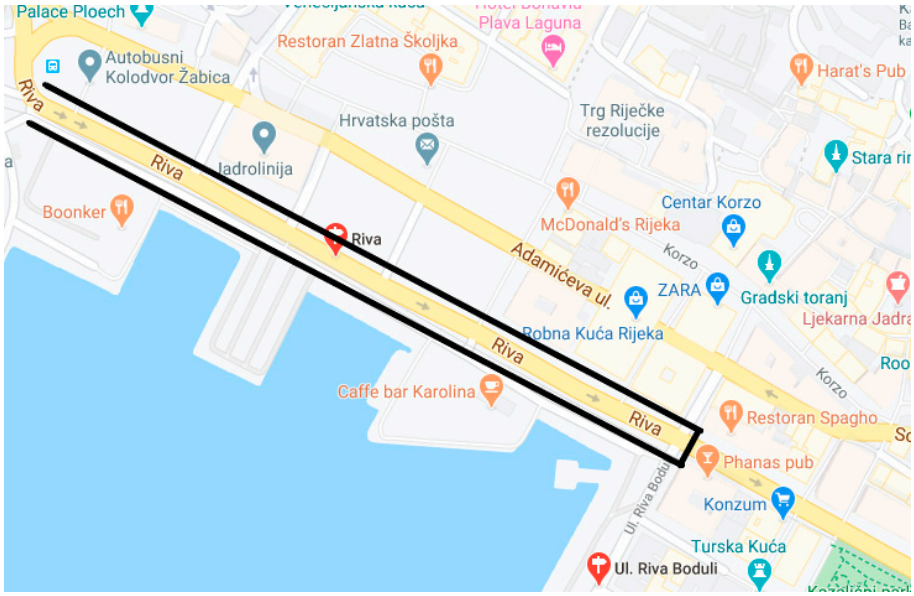


Figure 4. Pedestrian street, Riva street. Source: authors and Google maps (screenshot).

After defining all the elements of the model (the goal, the evaluation criteria, the interests of interest groups and possible scenarios for the development of delivery activities in the function of sustainable development) as well as the methodology of the multi-actor multi-criteria analysis, it was necessary to develop a software solution, as illustrated in Figure 5 (the interaction between interest groups and criteria is shown by colored lines).

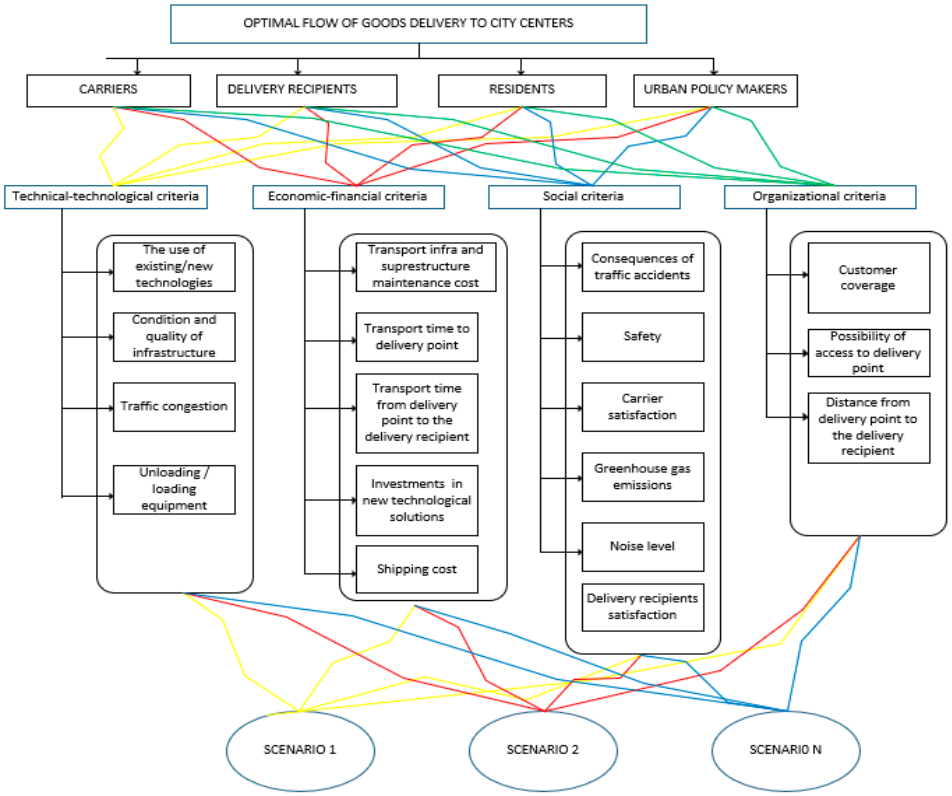


Figure 5. Model of evaluation of delivery activities within city centers. Source: authors.

4. Research Results

In order to determine the importance of each criterion for the optimal flow of goods deliveries to city centers, a questionnaire was conducted. The survey questionnaire was distributed to 650 email addresses, resulting in a total of 239 completed responses. The survey participants included carriers, recipients of deliveries, representatives of residents and urban policy-makers focused on urban issues. Within the "urban policy-makers" stakeholder group, various departments related to transportation, public authorities and urban planners participated in the survey. The "delivery recipients" group comprised stakeholders who received delivery services in the city center such as cafes, shops and restaurants. The "resident representatives" group included individuals representing buildings in the city center, with one representative typically representing about 20 tenants. Respondents were carefully selected based on their relevance to the research topic, specifically focusing on those who had a direct interaction with delivery services. The data were collected in the first quarter of 2022.

The research was conducted for the purpose of defining the criteria and their importance (weighting factors) as well as the impact of the criteria on the proposed scenarios of goods-delivery flows to city centers with the help of the multi-actor multi-criteria analysis (MAMCA). Below are the results for each interest group separately (Table 1) and the combined results of all interest groups. The research was conducted using a MAMCA decision-making tool [41].

The organizational and technical–technological groups of criteria were the most important from the perspective of economic entities. They believed that the good organization of delivery activities and investment in new technological solutions were a prerequisite when improving social criteria such as the noise level, transport time to the delivery point and emission of harmful gases.

Urban policy-makers pointed out two criteria that required special attention to improve delivery activities. These were the economic–financial criterion of investment in new technological solutions and the technical–technological criterion of the application of existing/new technologies. They believed that the successful implementation of the most important criteria would significantly increase the quality of the social criteria that were rated as the least important criteria.

The residents considered the group of organizational criteria as the most important criteria, followed by the group of technical and technological criteria. Within the mentioned groups of criteria, the economic–financial criterion of investment in new technological solutions was inserted. This criterion was considered by the residents to be the link between the organizational and technical–technological groups of criteria.

Carriers believed that the most attention should be paid to the organizational and technical–technological criteria. However, they were of the opinion that investment in new technological solutions and their application could be problematic because they believed that this would increase the unloading time and slow down the delivery service. They noted that fiscalization had produced this result through the loss of time when issuing invoices.

The analysis of the results concluded that all interest groups believed that the organizational and technical–technological groups of criteria were the most important when creating a model of the flow of goods deliveries to the city center, which proved that for the evaluation of the model of the flow of goods deliveries it was necessary to recognize the motives and interests of the interest groups in relation to the delivery activities. The average values of the obtained results—that is, the average importance of the criteria—are shown in Table 2. After entering the parity for all criteria of all interest groups, it was necessary to determine the influence or importance of each criterion for each of the proposed scenarios. The method of entering the impact of each criterion for the proposed scenario of delivery activities is shown in Figure 6 and was obtained using the MAMCA software tool. The impact of each criterion on the proposed scenario was evaluated by all interest groups.

Table 1. The results of the criteria for all interest groups.

Criteria Name	Criteria Group	Urban Policy-Makers	Delivery Recipients	Residents	Carriers
Investment in new technological solutions	Economic–financial criteria	14.66%	7.06%	7.20%	4.02%
Shipping cost	Economic–financial criteria	3.55%	3.99%	3.69%	3.78%
Transport infra- and superstructure maintenance costs	Economic–financial criteria	5.63%	4.15%	4.18%	3.92%
Transport time from the delivery point to the delivery recipient	Economic–financial criteria	5.80%	3.90%	3.97%	4.40%
Transport time to the delivery point	Economic–financial criteria	4.84%	2.96%	3.38%	4.91%
Customer coverage	Organizational criteria	7.60%	12.36%	10.65%	10.80%
Distance from the delivery point to the delivery recipient	Organizational criteria	2.14%	10.84%	9.49%	9.77%
Possibility of access to the delivery point	Organizational criteria	5.87%	11.68%	9.87%	15.03%
Carrier satisfaction	Social criteria	2.51%	3.61%	4.04%	2.95%
Consequences of traffic accidents	Social criteria	2.17%	3.51%	4.16%	4.36%
Delivery recipient's satisfaction	Social criteria	4.92%	3.59%	2.04%	3.48%
Greenhouse gas emissions	Social criteria	2.76%	3.38%	4.09%	2.80%
Noise level	Social criteria	1.66%	2.69%	3.40%	2.14%
Safety	Social criteria	3.74%	4.47%	5.11%	3.73%
Condition and quality of the infrastructure	Technical–technological criteria	8.71%	5.96%	6.67%	5.97%
The use of existing/new technologies	Technical–technological criteria	11.24%	4.87%	6.09%	5.93%
Traffic congestion	Technical–technological criteria	6.25%	6.04%	7.01%	6.86%
Unloading/loading equipment	Technical–technological criteria	5.97%	4.96%	4.96%	5.16%

Source: Authors, according to the results from the MAMCA software tool (https://mamca.vub.be/, accessed on 3 August 2024).

Table 2. Average weight of criteria by all interest groups.

Criteria	Weight Factors
Customer coverage	11.57%
Possibility of access to the delivery point	10.06%
Investment in new technological solutions	8.88%
Distance from the delivery point to the delivery recipient	7.39%
The use of existing/new technologies	7.01%
Condition and quality of the infrastructure	6.96%
Traffic congestion	6.45%
Unloading/loading equipment	5.25%
Transport infra- and superstructure maintenance costs	4.48%
Safety	4.37%
Transport time from the delivery point to the delivery recipient	4.35%
Shipping cost	3.74%
Delivery recipient's satisfaction	3.63%
Transport time to the delivery point	3.54%
Greenhouse gas emissions	3.34%
Carrier satisfaction	3.31%
Consequences of traffic accidents	3.18%
Noise level	2.50%

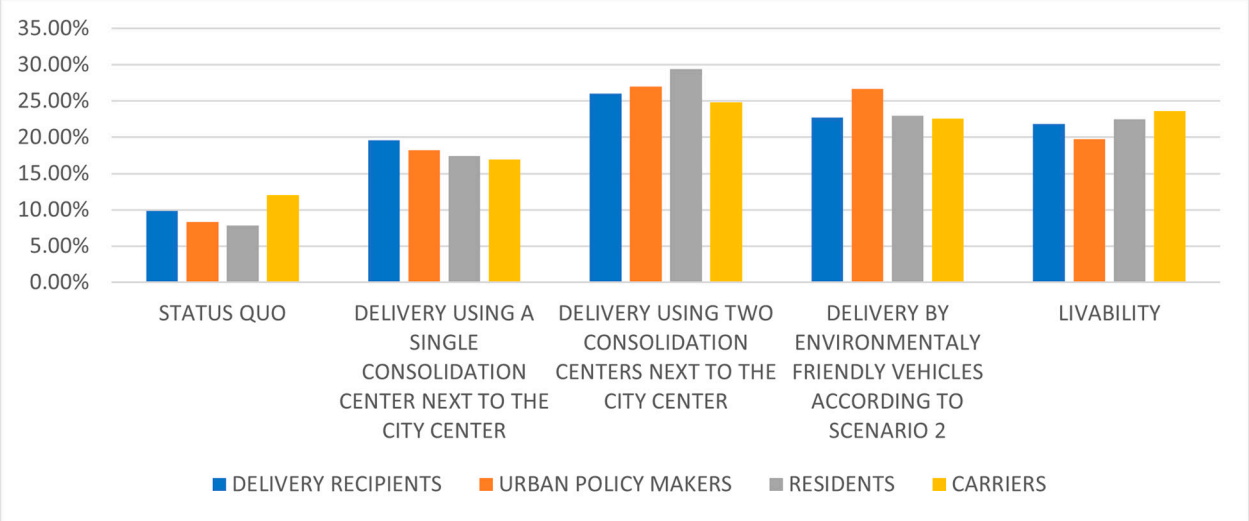
Application of existing / new technologies

Figure 6. The influence of the criteria on the proposed scenarios for the delivery of goods to city centers.

Graph 1 shows that the interest groups preferred the scenario of goods deliveries from two consolidation centers next to the city center. The worst-rated scenario was the status quo scenario, especially from the residents and urban policy-makers interest groups.

As the best scenario, all interest groups chose the delivery of goods from two consolidation centers right next to the city center (Table 3). The urban policy-makers as well as the residents emphasized the criteria of reducing the noise level and reducing the emission of harmful gases in the evaluation. They believed that the delivery of goods by environmentally friendly vehicles according to scenario 2 would create greater traffic congestion compared with the delivery of goods by smaller delivery vehicles because transporters would have to wait for a certain time until the vehicle was charged at a charging station due to a smaller kilometer capacity range. Another problem was the transmission capacity in comparison to current conventional vehicles. They were also of the opinion that the cost of delivery as well as the maintenance of vehicles would be rather more expensive than the current form of delivery due to the high initial investment required, one that carriers are currently not ready for and are hoping for necessary subsidies in order to even consider the mentioned scenario. Interestingly, the organizational criteria, which proved to be the most important when evaluating the importance of the criteria, increased the least when

comparing the scenarios. The results showed that during the evaluation of the scenarios by all interest groups, the social and the economic–financial criteria increased. Through discussions with the respondents, it was emphasized that the basis of all scenarios was the investment in new technologies to be able to connect the key actors of delivery activities, the recipients and carriers.



Graph 1. Presentation of scenario ratings among interest groups. Source: authors and the MAMCA software tool.

Table 3. Presentation of the best scenarios from all interest groups.

Scenario	Scenario Values
Status quo	9.51%
Delivery using a single consolidation center next to the city center	18.03%
Delivery using two consolidation centers next to the city center	26.80%
Delivery by environmentally friendly vehicles according to scenario 2	23.73%
Livability	21.94%

Source: authors and the MAMCA software tool (https://mamca.vub.be/, accessed on 3 August 2024).

The following should also be emphasized:

- The delivery of goods by environmentally friendly vehicles could only be considered with the construction of a consolidation center (or several); the reason for this was the current too great a distance between the distribution centers and the city center;
- In relation to the delivery of goods by environmentally friendly vehicles according to scenario 2, the criteria that favored the delivery of goods from two consolidation centers were the transport time to the delivery point, carrier satisfaction, delivery recipient's satisfaction and safety.

5. Conclusions

City logistics must ensure a reliable supply of goods on one hand while on the other hand they must improve people's quality of life, which results in sustainable urbanization. In order to obtain an answer to the questions of what to do for the sustainable development of a city center and how to do it, it is necessary to take into account the examples of cities that have improved their delivery service and also to involve all interest groups in order to be able to identify the problems of delivery activities and find a solution. This is necessary in order to identify different models of delivery activities, which allows them to be proposed for the observed area of urban delivery. For the successful implementation of any scenario

of the delivery of goods within a city center, it is necessary to look at and analyze the views of all interest groups in order to make a decision to everyone's satisfaction. For this reason, MAMCA (multi-actor multi-criteria analysis) was used in the paper, which has the purpose of solving problems that involve all interest groups from the beginning to the end of the entire decision-making process. The method considers several scenarios in which any change in the evaluation of a criterion can affect other criteria to which that criterion is correlated. Interest groups using the multi-actor multi-criteria method chose the delivery of goods from two consolidation centers right next to the city center as the best scenario. The urban policy-makers as well as the local population highlighted the criteria of reducing the noise level and greenhouse gas emissions. Carriers believed that the delivery of goods by environmentally friendly vehicles from one consolidation center would create greater traffic congestion compared with the delivery of goods by smaller delivery vehicles because it would be necessary to wait until the vehicle is charged at a charging station due to the smaller kilometer capacity range. The transmission capacity in relation to current conventional vehicles also appeared to be a problem. The participants were also aware that environmentally friendly vehicles are the future and they believed that the aforementioned shortcomings would be eliminated. The results showed that through the evaluation of the scenarios by the interest groups, the social and economic–financial criteria grew. Through the discussion with the respondents, it was emphasized that the foundation of these scenarios was an established organizational structure and investment in new technologies in order to be able to connect the key actors of delivery activities, delivery recipients and carriers. The exchange of information within the organization of delivery activities is the basis for an effective process as well as the basis for process improvement. The organization of delivery activities must be efficient, which means that it must be fast, effective and timely.

This also ensures the availability of products and quick responses to changes in demand, which results in fewer disruptions to deliveries and, ultimately, damage that may occur in business. Joint planning and the exchange of information are necessary to harmonize operations—that is, the capacities of carriers in relation to the demand of delivery recipients—and can lead to the creation of innovative solutions and a new way of providing services. It should certainly be emphasized that urban centers are experiencing exceptional development. As a result, there will undoubtedly be a need for new criteria, potentially even a new group of criteria, and, consequently, for further research.

For future research, it will be necessary to produce a simulation in real-time for all scenarios to be able to determine bottlenecks, emissions of harmful gases, etc., and furthermore, to make a comparison of the results obtained by the simulation in relation to the implemented MAMCA method with special reference to the technical and organizational groups of criteria.

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