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# A GIS-based multi-criteria decision-making approach for location selection of urban micro-consolidation centers under sustainability

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**Abstract**

With the rise of e-commerce, urban micro-consolidation centers (UMCs) have emerged as vital solutions for efficient last-mile logistics (LML). However, selecting appropriate locations for UMCs presents challenges in urban freight distribution, particularly concerning its impact on logistics activities and city stakeholders. This paper aims to introduce an evaluation system that facilitates logistics activities while considering economic, social, and environmental sustainability in the UMC location selection process for LML. To address this issue, a three-step solution approach has been developed. First, the criteria influencing UMC location decisions are identified based on sustainability dimensions, utilizing expert opinions and literature. Second, the importance of these criteria indicators is prioritized using the Analytical Hierarchy Process (AHP), while spatial analysis of the indicators is conducted using Geographic Information Systems (GIS). In this phase, the two methods are integrated through weighted overlay analysis within GIS to create a suitability map for potential locations. Finally, the possible sites are ranked using the Technique for Preference Ranking Similarity to the Ideal Solution (TOPSIS) for the Izmir region in Turkey, followed by a sensitivity analysis. The findings reveal that accessibility in the economic, traffic density in the social, and land topography in the environmental dimensions are crucial when selecting UMC locations for sustainability. Notably, the Çiğli district has been identified as the top priority for establishing a UMC, followed by the Bayraklı and Buca districts in İzmir, Turkey. As no such center currently exists in the region studied, these insights are expected to assist the industry and local authorities in future initiatives.

## 1. Introduction

Today, even for people who have not experienced online shopping before, purchasing tendencies are shifting to online platforms, and the e-commerce freight flow is booming globally. By the COVID-19 epidemic, it is known that 82% of all consumers globally shop online in the first quarter of 2020, and it is estimated that approximately 41% of the global retail share will be captured via e-commerce in 2027 (Boston Consulting Group, 2023). Although the growth of the e-commerce market promises economic opportunities for countries, the increasing freight flow is expected to boost the intensity experienced in urban distribution operations and the problems caused by the logistics sector. According to The Future of the Last-Mile Ecosystem report by the World Economic Forum (2020), it is predicted that urban freight flow both in freight volume and freight traffic will increase by 78%, the number of delivery vehicles by 36%, the emission rate by 32%, and the traffic congestion by 11 minutes globally in 2030.

Last-mile logistics (LML), which means delivery from the final distribution center to the ultimate customer, is characterized not only as the most crucial part of the supply chain but also the most inefficient and costly part (Bertolini, De Matteis, Nava, 2024). According to Capgemini Research Institute (2019), the last-mile constitutes 41% of the total supply chain cost considering the variability of the factors in the process. Increasingly demanding customer expectations in delivery times such as same-day, instant, and late-night and delivery options such as picking up from points or waiting for home delivery create challenges for operating LML. Operational inefficiencies are considerably high, as the LML features multi-location distribution in droplets (Sawik, 2024) and vehicles with less truckload (LTL) capacity during distribution (Ersoy and Çetiner, 2022). Further, LML is a process that creates significant external costs for society in social and environmental aspects. In urban areas, the effect of the number of commercial vehicles on road transport on the total global greenhouse gases (GHG) is measured by 25% (International Energy Agency, 2021). The relationship of last-mile operations with issues such as traffic safety, noise, land use, and security also closely affect the liveability level of the urban.

Based on today's expectations, transforming the LML into a more sustainable one is becoming more important. At this point, one of the promising concepts is the urban micro-consolidation center (UMC) (Arrieta-Prieto, Ismael, Rivera-Gonzalez, Mitchell, 2021; Rudolph, Nsamzinshuti, Bonsu, Ndiaye, Rigo, 2022; Bertolini et al., 2024). UMC is a small transshipment facility close to the distribution area, allowing the LML to be carried out effectively. In this micro facility, all loads coming from the city consolidation center or logistics centers are dropped off from large vehicles (e.g., trucks and vans), reconsolidated, and distributed with smaller environmentally friendly vehicles (e.g., light electric vehicles, cargo bikes, and foot). In addition to enabling speedy logistics operations in terms of delivery time, UMC can be used as an order pick-up point for customers who prefer it and makes flexible delivery options possible (Rudolph et al., 2022). As an urban distribution platform, the UMC is operated collaboratively, mainly through planning and carrying out the last-mile activities of multiple logistics service providers (LSP) together (Urban Freight Lab, 2020). Sharing assets and capacities helps prevent the financial resources allocated to inefficient facility infrastructures while ensuring that urban logistics activities are coordinated (He, Zhou, Qi, Wang, 2020). Also, from the view of the social aspect, reducing the freight traffic volume on the roads and improving traffic security, close communication with citizens, and better management in returns service can be achieved by integrating UMC into LML (Özbekler and Karaman Akgül, 2020). The initiatives in cities where UMCs are piloted by courier, express, and parcel (CEP) service providers, mainly in Europe and the US, present many examples of the impact of micro facilities on the sustainability of LML. As a well-known example of deliveries via UMC, Gnewt Cargo in the UK has experienced a significant reduction in $CO_2$ emissions per cargo by 88%, total urban vehicle distance by 52%, and vehicle density and disturbance levels to the community (Urban Freight Lab, 2020). This improved effect is also evident in the cases of La Petite Reine in France, Binnenstadservice in the Netherlands, and KoMoDo in Germany.

Regarding studies in the LML field, authors generally emphasize the criticality of UMC location selection (Aljohani and Thompson, 2018; Rudolph et al., 2022). As a strategic decision, the UMC location should demonstrate a performance that can outweigh the effectiveness of LML activities within the city's characteristics (e.g., high land costs and unavailability of suitable facilities). Regarding UMC location, central location, high upstream and downstream accessibility, and dedicated infrastructures highlight topics to consider (Arrieta-Prieto et al., 2021). In addition, the issues of minimizing firm costs, avoiding traffic density, and having a sufficient area to expand the facility come to the fore when the location selection of UMC (Urban Freight Lab, 2020; Novotná, Švadlenka, Jovčić, Simić, 2022). Since determining an optimum UMC location requires fulfilling multiple priorities simultaneously, this becomes a challenging selection problem. Although the positive effects of UMC on the processes of LML have been identified in many studies (Katsela, Güneş, Fried, Goodchild, Browne, 2022; Bertolini et al., 2024), it is seen that the number of studies that systematically examine the criteria for the location of UMC and determine the optimum location in urban areas is very scarce (Aljohani and Thompson, 2018; Arrieta-Prieto et al., 2021). Further, previously published studies are mostly limited to organizational and economic aspects of UMC location decisions (Rudolph et al., 2022). Since the necessities for optimal UMC location alters in compliance with economic, social, and environmental concerns in LML (Kumar and Anbanandam, 2019), it is essential to clarify how sustainability can be achieved in the location selection (Katsela et al., 2022). This paper seeks to systematically investigate a sustainable framework for UMC's location selection, which will help address these research gaps.

The research on UMC's location selection has focused chiefly on mathematical programming, and multi-criteria decision-making (MCDM) approaches. While few authors have drawn on any systematic research into UMC location based on the Geographic Information Systems (GIS) approach (Aljohani and Thompson, 2018; Kedia, Kusumastuti, Nicholson, 2020; Bayliss, Bektaş, Tjon-Soei-Len, Rohner, 2023; Wang, Li, Lu, 2023), there has been no detailed investigation of the location selection process from a sustainability aspect. GIS enables us to understand the subject more deeply by collecting, storing, processing, and presenting information obtained through location-based observations in an integrated manner. In this respect, the methodological approach taken in this paper is a comprehensive, integrated solution methodology based on a GIS-based MCDM Approach, including AHP and TOPSIS methods. To the authors' best knowledge, this paper makes a significant contribution to research on logistics and supply chain management from a methodological aspect by demonstrating sustainable location selection of UMC from the real-life case visualization.

The remaining part of the paper proceeds as follows: Section two examines the literature review, and section three addresses the main methodologies adopted. Section four gives insights through an evaluation system for UMC location selection under sustainability. Lastly, section five delves into a discussion part, and section six presents the conclusion and future directions of the research.

## 2. Literature Review

Land suitability assessment (LSA) is a crucial process that evaluates specific land areas to determine their optimal use for industries, facilities, and settlements (Zolekar and Bhagat, 2015). By utilizing a variety of weighted criteria and the weighted overlay method, LSA effectively assesses suitability levels, ensuring that land use is both efficient and sustainable. This evaluation is not just important; it is imperative for effective urban planning and rational land use (Ramya and Devadas, 2019). Identifying suitable locations for UMCs based on sustainability criteria can be viewed as a location selection problem within the scope of LSA. There are some studies to localize suitable locations for UMCs by using expressed methods such as hybrid MCDM combining AHP and Preference Ranking Organization Method for Enrichment of Evaluations (PROMETHEE) method (Rudolph et al., 2022), a greedy- heuristic-aided Bi-level mixed-integer programming (Arrieta-Prieto et al., 2021), a fuzzy multi-attribute group decision making (FMAGDM) based on a linguistic 2-tuple (Rao et al., 2015) and using couple MCDM techniques including The Best-Worst Method (BWM), Criteria Importance Through Intercriteria Correlation (CRITIC) method, and Weighted Aggregated Sum Product Assessment (WASPAS) method (Novotná et al., 2022). However, the effectiveness of deciding on a suitable location for a UMC requires reliability in the considered criteria; spatial decision problems put forth the need to integrate spatially referenced data in a problem-solving environment (Cetinkaya et al., 2016). Accordingly, in most recent studies of location selection problems in LML literature, GIS has been used with MCDM methods to acquire powerful techniques for converting spatial and non-spatial data into information within the decision maker's judgment (Bayliss et al., 2023).

Many researchers have utilized various MCDM techniques in related literature to reach the "best/optimal" solution in decision problems. In addition to no technique being superior to the others, researchers can use it separately or integratively according to the handled problem (Özkan, Özceylan, Korkmaz, Cetinkaya, 2019; Özbekler and Karaman Akgül, 2020). The method to be followed for this research required the creation of a mixed scientific framework by blending more than one research design within the complex nature of the location selection issue addressed. Within the study's scope, AHP and TOPSIS were preferred among the MCDM methods used in decision-making problems in operations science. At the same time, GIS analysis supported the study in terms of processing and visualizing the quantitative variables related to the problem within an integrated structure with the MCDM technique. There are some location selection studies on the GIS-based MCDM, such as a model of Automated Parcel Delivery Terminals with GIS-based AHP (Muerza et al., 2018), a model of a Central City Transshipment Facility with a GIS-based Analytic Network Process (ANP), and TOPSIS (Aljohani and Thompson, 2018), and a model of optimal planning of electric vehicle charging stations with GIS-based AHP, PROMETHEE, and VlseKriterijuska Optimizacija I Komoromisno Resenje (VIKOR) (Kaya, Tortum, Alemdar, Çodur,2020). While the use of MCDM for assessing the suitability of delivery nodes is recognized, its adoption for mapping the suitability of UMCs for the last leg of last-mile delivery is lacking. Furthermore, the absence of studies that have utilized the GIS, AHP, and TOPSIS approaches, incorporating locally available variables such as economic conditions, environmental awareness, security, and land use, to identify sustainable dimensions-based suitable sites, highlights the need for further research in this area.

Although there are a lot of different MCDM methods integrated with GIS, AHP is the most used one for assigning criteria weights, and the TOPSIS is the most used one to rank the alternatives (Al-Abadi et al., 2025; Haktanır and Kahraman, 2024). AHP, which Saaty (1980) proposed, is one of the most well-known methods for assessing complex decision-making problems by hierarchical structures to obtain the best among many possible results. Gathering insights from AHP provides a significant opportunity to advance the understanding of holistic structure by collecting data from logistics experts. VIKOR, an effective decision-making method used in literature, provides an alternative to TOPSIS for ranking alternatives based on conflicting criteria (Kaya et al., 2020). Similarly, PROMETHEE analysis can produce better results with the preference function determined by decision-makers (Rudolph et al., 2022). In this study, the evaluated alternatives were assessed with a neutral lens, effectively aligning with the core research topic. Notably, the characteristics of the criteria and alternatives employed gauge fundamentally distinct concepts, underscoring the robustness and depth of our analysis. This unique approach piqued our interest and led us to choose TOPSIS analysis for our study. Also, limited literature exists that focusses on UMCs mapping and analyses, much less utilizing AHP and TOPSIS methods. This study aims to make new contributions to the literature by combining GIS and MCDM (AHP and TOPSIS) and developing an integrated model.

## 3. Methodology

This paper uses a hybrid approach integrating AHP (for prioritization criteria), GIS (for visualization criteria through actual data), and TOPSIS (for ranking potential sites) to gain insights into a sustainable UMC location selection problem. The methodology for the study can be seen in Figure 1. The section that follows presents a brief explanation of MCDM methods and GIS. Research and publication ethics were followed in this study.

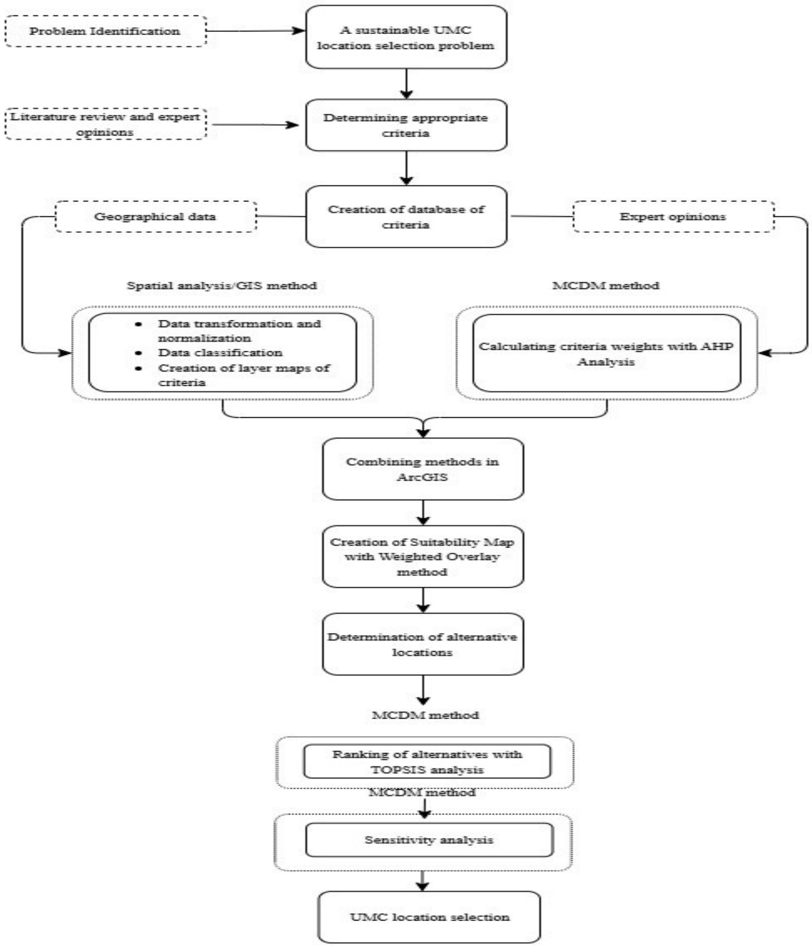


**Figure 1.** Applied methodology

## 3.1. AHP

The AHP method performs analytical procedures systematically, including defining the problem, determining criteria and sub-criteria, and calculating their relative weights on pairwise comparisons on a qualitative scale. This method is widely used in studying facility location selection problems to enable a logical and straightforward framework for evaluating multiple criteria simultaneously (Kumar and Anbanandam, 2019; Kaya et al.,2020; Rudolph et al., 2022). Regarding the AHP method, the steps are as follows:

- Step 1 "Defining the problem and determining criteria and sub-criteria": It includes clearly defining the problem intended to be solved and determining criteria and sub-criteria that fit the purpose.
- Step 2 "Creating hierarchical structure on specific criteria and sub-criteria": It involves establishing a hierarchical structure that is detailed from top to bottom depending on the complexity of the problem.
- Step 3 "Gathering the pairwise comparisons and generating of pairwise comparison matrix": First, the relative priorities of the criteria are gathered through numerically scaled levels of importance in a survey format by performing a pairwise comparison scale based on Table 1.

**Table 1.** Pairwise comparison scale (Saaty, 1980)

| Levels of importance | Linguistic judgments |
|---|---|
| 1 | Equal importance |
| 3 | Moderate importance |
| 5 | Strong importance |
| 7 | Very strong importance |
| 9 | Absolute importance |
| 2,4,6,8 | Intermediate values |

Secondly, a n×n paired comparison matrix is generated by comparing two criteria at the same hierarchical level. Equation (1) refers to the matrix $A^k$ whereby "n" represents the number of criteria or sub-criteria, and $a_{ij}^k$ value represents the kth expert's preference of the criterion "i" compared with the "j" criterion. Here, the $a_{ji}^k$ value is obtained from $1/a_{ij}^k$ based on the mutual comparison axiom of the AHP method. The components on the diagonal of the comparison matrix take the value 1 because it indicates i=j equality.

$$A^k=\begin{bmatrix} 1 & a_{12}^k & \dots & a_{1n}^k \\ a_{21}^k = 1/a_{12}^k & 1 & \dots & a_{2n}^k \\ \dots & \dots & 1 & \dots \\ a_{n1}^k = 1/a_{1n}^k & a_{n2}^k & \dots & 1 \end{bmatrix} \quad (1)$$

The AHP method usually requires group decision-making and the mathematical combination of personal judgments within the group since a single expert's judgment may seem too subjective (Saaty and Özdemir, 2014). According to a group decision-making scenario, $a_{ij}$ values are gathered from k number of experts, are calculated using the geometric mean of the comparisons as stated in equation (2), and then are presented as matrix A on equation (3).

$$a_{ij}=\sqrt[k]{a_{ij}^1 * a_{ij}^2 * \dots * a_{ij}^k} \quad (2)$$

$$A=\begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ a_{21} & 1 & \dots & a_{2n} \\ \dots & \dots & 1 & \dots \\ a_{n1} & a_{n2} & \dots & 1 \end{bmatrix} \quad (3)$$

- Step 4 "Calculating the weights of criteria and sub-criteria": The Eigenvector of n×n pairwise comparison judgment matrix can be calculated as stated in equation (4), where $\lambda_{max}$ is the maximum eigenvalue in the eigenvector of $\vec{W}$ of matrix $A_{n\times n}$

$$A\vec{W}=\lambda_{max}\vec{W}, \qquad \lambda_{max} \geq n \quad (4)$$

The weights resulting from calculating how important each subcriterion i compared with another subcriterion within the same criterion c is expressed as a local weight $LW_i^c$ (refer to equation (5)), and how important each criterion c in relation to the objective is called as criterion global weight $FW^c$(refer to equation (6)). Finally, the subcriterion global weight $GW_i$ is gathered by multiplying $LW_i^c$ and $FW^c$ (refer to equation (7)).

$$LW_i^c = \frac{\left(\prod_{j=1}^n b_{ij}\right)^{1/n}}{\sum_{i=1}^n\left(\prod_{j=1}^n b_{ij}\right)^{1/n}}, i,j = 1,2,\dots,n. \quad (5)$$

$$FW^c = \frac{\left(\prod_{j=1}^n a_{ij}\right)^{1/n}}{\sum_{i=1}^n\left(\prod_{j=1}^n a_{ij}\right)^{1/n}}, i,j = 1,2,\dots,n. \quad (6)$$

$$GW_i = LW_i^c * FW^c \; i,j = 1,2,\dots,n. \quad (7)$$

- Step 5 "Examining the consistency ratio (CR)": CR is calculated as in equation (9), based on the Consistency Index (CI) value (refer to Equation (8)) and the Random Index (RI) value. In RI, values were already estimated by Saaty (1987) according to the number of criteria compared in the study. If CR< 0.1, matrix A is interpreted as sufficiently consistent.

$$CI = \frac{\lambda_{max}-n}{n-1} \quad (8)$$

$$CR = \frac{\mathrm{CI}}{RI} < 0.1 \quad (9)$$

## 3.2. TOPSIS

TOPSIS is a widely accepted MCDM ranking technique developed by Hwang and Yoon (1981) to identify solutions from a finite set of alternatives. This method is based on the logic of determining ideal and negative ideal solutions and evaluating the distances of alternatives to these solutions in a geometrical (i.e., Euclidean) sense. While the ideal solution ($A^+$) maximizes the return of the criterion in terms of benefit or gain and minimizes the cost criterion, the negative ideal solution ($A^{-}$), on the contrary, minimizes the benefit and maximizes the cost. An alternative chosen by the decision-makers is expected to be with the shortest distance from the ideal solution and the farthest distance from the negative ideal solution. TOPSIS technique is frequently preferred because it does not contain complex algorithms and provides easy-to-understand outputs with few inputs. The main steps of the TOPSIS procedure are as follows:

- Step 1 "Creating the decision matrix": The decision matrix (D= $[x_{ij}]$) denotes the performance ($x_{ij}$) of each alternative ($A_i$) with each criterion ($C_j$) to be taken as a basis for ranking. Here, the decision matrix is created by representing a set of m alternatives, a set of n criteria, and a set of k decision-makers, which can be seen in equation 10.

$$D = \begin{array}{c} A_1 \\ A_2 \\ \cdots \\ A_m \end{array} \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \quad C_1 \quad C_2 \quad \cdots \quad \text{“} \tag{10}$$

- Step 2 "Obtaining the normalized matrix": The decision matrix D normalized by converting $x_{ij}$ into normalized measures $r_{ij}$ in Equation 11.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}, i = 1,2,\ldots,m; j = 1,2,\ldots,n. \tag{11}$$

- Step 3 "Calculating the weighted normalized decision matrix": Weighted normalized matrix (V) is formed by multiplying the weight values of the criteria ($w_i$) with the values obtained by the normalized matrix ($r_{ij}$) (refer to equation (12)). In this paper, the set of weight values is obtained by the AHP method.

$$v_{ij} = w_i * r_{ij} \quad i = 1,2,\ldots,m; j = 1,2,\ldots,n. \tag{12}$$

- Step 4 "Determining the ideal and negative-ideal solutions": The values in the V matrix are determined as in equations (13) and (14), respectively, as ideal solution ($A^{+}$) and negative ideal ($A^{-}$) solution.

$$A^{+} = \left\{(\underset{i}{max} v_{ij} \left| j \in J), (\underset{i}{min} v_{ij} \right| j \in J'\right\} A^{+} = \{v_1^{+}, v_2^{+}, \ldots, v_n^{+}\}, \tag{13}$$

$$A^{-} = \left\{(\underset{i}{min} v_{ij} \left| j \in J), (\underset{i}{max} v_{ij} \right| j \in J'\right\} A^{-} = \{v_1^{-}, v_2^{-}, \ldots, v_n^{-}\}. \tag{14}$$

- Step 5 "Identifying distances from the ideal and negative-ideal solutions": Using the Euclidean distance approach, the ideal distance ($d_i^{+}$) and the negative ideal distance ($d_i^{-}$) for each alternative are calculated in equations (15) and (16), respectively.

$$d_i^{+} = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^{+})^2} \ , i = 1,2,\ldots,m; j = 1,2,\ldots,n, \tag{15}$$

$$d_i^{-} = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^{-})^2} \ , i = 1,2,\ldots,m; j = 1,2,\ldots,n. \tag{16}$$

- Step 6 "Calculating closeness coefficient of each alternative": In calculating the closeness coefficient of each alternative to the ideal solution ($C_i^{*}$), distance measures from the ideal and negative ideal points are used. Ranking the alternatives considering the $C_i^{*}$ values is the final step of TOPSIS.

$$C_i^{*} = \frac{d_i^{-}}{d_i^{+} + d_i^{-}} \ , \ 0 \le C_i^{*} \le 1, \ i = 1,2,\ldots,m. \tag{17}$$

## 3.3. GIS

GIS is a computerized system that integrates spatial data (e.g., bus routes and existing bike roads) and attribute data (e.g., population density and traffic volume) and fulfills functions of collecting, storing, retrieving, manipulating, analyzing, and mapping (Çetinkaya, Özceylan, Erbaş, Kabak, 2016). The data utilized in GIS is classified into two main types: spatial data and attribute data. Spatial data refers to information that defines features' location and relationships with other spatial elements, such as transportation networks, topographic maps, and existing roadways. On the other hand, attribute data provides details about the characteristics of those geographical features within the database, including information like highway traffic volume and population density (Özkan et al., 2019). Attribute data is descriptive information used to analyze objects according to specific criteria and make them meaningful by transforming the obtained spatial data from vector or raster data formats within the software. Vector data refers to data represented by x and y coordinate pairs that allow the objects on the map to be shown as points, lines, and areas. For example, points can be used to show the locations of factories, lines can be used to show bicycle paths, and areas can be used to show green areas. Conversely, raster data is based on the expression of spatial data in squares consisting of cells defined as pixels with equal rows and columns and the geographical area represented by each cell. In particular, the visualization of attributes such as slope and aspect of a certain geographical area is performed via a raster data format (Çakmak et al., 2021).

Within the scope of this study, the attributes related to the determined criteria formed the layers of the GIS analysis and were weighted with the AHP technique from the MCDM methods. The suitability map, the outcome of the GIS analysis, was obtained by applying the Weighted Overlay analysis method in ESRI ArcGIS 10.2 software. For the generation of the suitability map for the facility location selection problem in this study, the following five steps were followed, respectively: introducing the characteristics of the study area, determining the weights and indicators of the criteria attributes, gathering geographical data, preparing the data related to the relevant attributes in ArcGIS software and creating layers, and finally processing the data with appropriate weights and visualizing the most suitable areas for the facility through the Weighted Overlay analysis method.

## 4. An Evaluation system for location selection problem

### 4.1. Sampling and data collection

The universe of this study consists of all stakeholders affected by and affecting urban logistics activities. Since reaching all units in this universe would be difficult, time-consuming, and costly, the study was conducted using purposive sampling, a non-probability sampling. The sample consists of 18 people, six from the academic sector, seven from the industrial sector, and five from the public sector, with at least ten years of experience. In the study conducted by Saaty and Özdemir (2014), the issue of the sample size to minimize errors and obtain consistent comparison matrices in MCDM methods was discussed. Accordingly, it was stated that if the decision-making experts included in the study have a homogeneous area of expertise, the group should not exceed seven people. There is a strong correlation between a larger sample size included in the study and the possibility of inconsistent analysis results (Pun and Hui, 2001). The study sample was determined based on this information. It was aimed that academicians who provide a scientific approach to the study selected from the fields of logistics and supply chain, trade, business, and marketing, sectoral participants who provide a perspective on the real sector selected from people who undertake different roles in the fields of logistics and trade, and public sector participants selected from the fields of urban planning and transportation services in particular. The questionnaire regarding the criteria evaluation was delivered to the participants in the third week of July 2020 through a printed survey form and online survey form created via the website 1KA – One Click Survey and the data collection process was carried out.

The UMC location selection problem is addressed within the scope of İzmir province. To obtain the geographical data of the relevant province, a research permit letter dated 21.07.2020 and numbered 44513635 and a data request letter dated 24.07.2020 and numbered 53771667 were received from the Yıldız Technical University Social Sciences Institute Directorate. Accordingly, data from İzmir Metropolitan Municipality and The General Directorate of Security were obtained at the end of August 2020. Other data used in the GIS method were obtained from open databases.

### 4.2. Evaluation criteria

It is stated that the most important benefits of UMC will emerge when it is located relatively closer to the customer density points and the logistics center (Özbekler and Karaman Akgül, 2020), and at the same time, there is a need for the selected facility location to minimize the externalities created by urban logistics activities in economic, social and environmental aspects (Katsela et al., 2022). The hierarchical structure of the study was designed to address the three dimensions of sustainability: economic, social, and environmental and was determined as criterion (C), sub-criterion (SC), and attribute (A) by utilizing the relevant literature review and expert opinions, as seen in Figure 2.

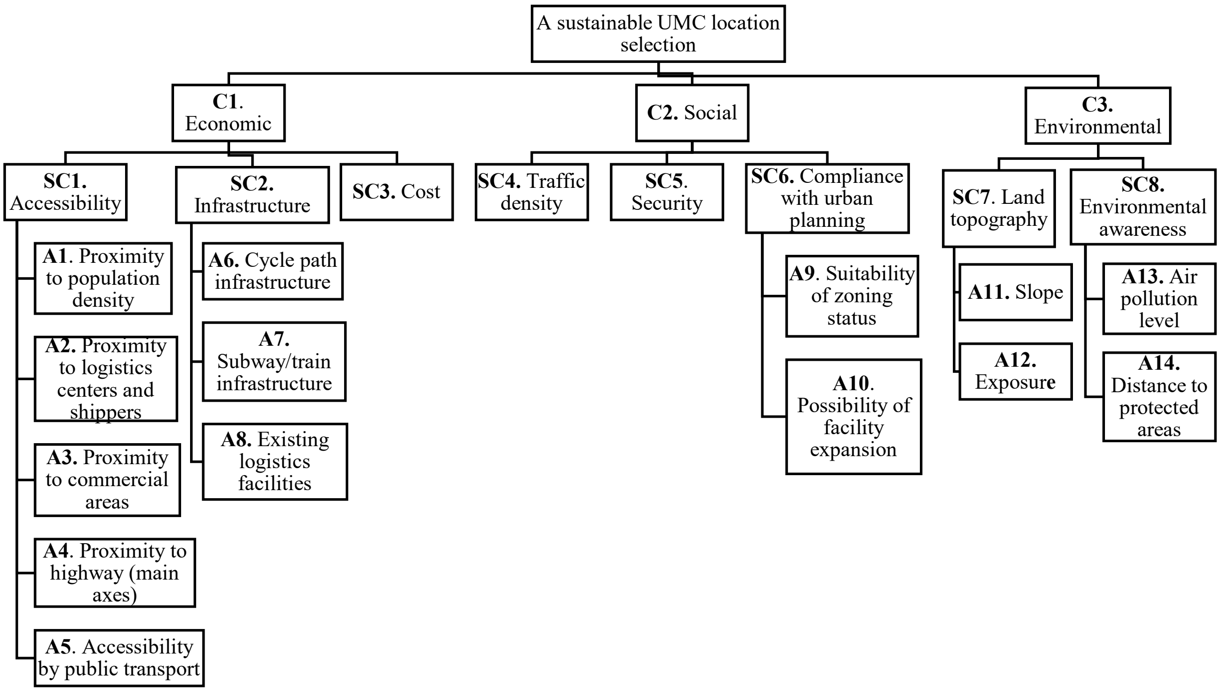


**Figure 2.** The hierarchical structure of the study

The hierarchical table, consisting of criteria and sub-criteria as well as attribute elements, was used to enable the analysis of AHP and to create a framework suitable especially for GIS analysis. The sources and a brief description of each criterion, sub-criterion, and attribute specified in the hierarchical table can be seen in Table 2.

**Table 2.** The sources and a brief description of each criterion, sub-criterion, and attribute

| Authors | | Description |
|---|---|---|
| (Rao et al., 2015), (Kumar and Anbanandam,2019), (Novotná et al., 2022), (Wang et al., 2023) | **Main Criteria** | **C1.Economic:** features regarding accessibility, infrastructure, and cost elements and emphasizes the economic sustainability of last-mile logistics. |
| | | **C2.Social:** features regarding traffic congestion, security, and regional planning, and emphasizes the social sustainability of last-mile logistics. |
| | | **C3.Environmental:** features regarding land structure and environmental sensitivity and emphasizes the environmental sustainability of last-mile logistics. |
| (Rao et al., 2015), (Aljohani and Thompson,2018), (Anderluh et al.,2020), (Kedia et al., 2020), (Novotná et al., 2022), (Wang et al., 2023) | **Sub-criteria** | **SC1.Accessibility:** accessing important points in the surrounding (e.g., consumer density, highways, shippers) |
| | | **SC2.Infrastructure:** the existing infrastructure features of the facility location (e.g. cycle path infrastructure, subway/train infrastructure, existing logistics facilities). |
| | | **SC3.Cost:** the cost features of facility location (e.g., land acquisition cost). |
| | | **SC4.Traffic density:** the impact of facility location on the city's current traffic density (e.g. urban road traffic volume). |
| | | **SC5.Security:** the traffic safety level of the area where the facility is located (e.g., traffic accident rate). |
| | | **SC6.Compliance with urban planning:** compatibility of the facility location with urban regulations and plans (e.g., compatibility of zoning status). |

| | | |
|---|---|---|
| | | **SC7.Land topography:** the characteristics of the land |
| | | **SC8.Environmental awareness:** the possible environmental impacts of the activities to be carried out at the location (e.g. air pollution level). |
| (Aljohani and Thompson,2018), (Kumar and Anbanandam,2019), (Anderluh et al.,2020), (Novotná et al., 2022), (Wang et al., 2023) | **Attributes** | **A1.Proximity to population density:** a point close to customer density in terms of the cargo delivery process. |
| | | **A2.Proximity to logistics centers and shippers:** suitability of the facility location in terms of the cargo's entry point into the city. |
| | | **A3.Proximity to commercial areas:** proximity of the facility location to organized industrial zones. |
| | | **A4.Proximity to the highway (main axes):** the ease of access for commercial vehicles to the facility by road. |
| | | **A5.Accessibility by public transport:** the possibility of using public transportation for transportation of customers receiving cargo from the facility and personnel working in the facility. |
| | | **A6.Cycle path infrastructure:** the existence of the necessary infrastructure for transportation activities to be carried out by bicycle. |
| | | **A7.Subway/train infrastructure:** the presence of subway/train infrastructure near the facility for efficient and rapid transportation of staff and customers and cargo transportation. |
| | | **A8.Existing logistics facilities:** suitability for increasing the efficiency of using existing logistics facility structures. |
| | | **A9.Suitability of zoning status:** land use suitability within the scope of urban development planning announced by the local government. |
| | | **A10.Possibility of facility expansion:** area to allow for facility expansion in line with increasing demands in the long term. |
| | | **A11.Slope:** the slope of the land structure. |
| | | **A12.Exposure:** the facility's location for receiving solar radiation and energy efficiency. |
| | | **A13.Air pollution level:** the impact on current air quality resulting from facility-related activities. |
| | | **A14.Distance to protected areas:** the facility's distance to areas that have been decided to be protected. |

## 4.3. Analysis of the AHP

After determining the research criteria, the group decision approach was followed to analyze the data, and the process of converting individual judgments within the group into a single judgment representing the entire group was carried out. The values of the experts in the pairwise comparison matrix within the group were combined with the geometric mean, the appropriateness of the consistency rate of the created group matrices was examined, and all group matrices were found to be consistent as CR<0.1. Then, the normalization process of the matrices was performed, and thus, with the help of the normalized matrix, the priority vector was calculated, and the weight importance value was found for each criterion, sub-criterion, or attribute. Finally, the $\lambda$max, CI, and RI values were calculated to calculate the consistency ratios of the matrices. It was seen that all CR values of the matrices were less than 0.10, and the comparisons made were consistent. The pairwise comparison matrix and normalized decision matrix of criteria are shown in Table 3.

**Table 3.** The pairwise comparison matrix and normalized decision matrix of criteria

| The pairwise comparison matrix | | | | Normalized decision matrix of criteria | | | | W |
|---|---|---|---|---|---|---|---|---|
| | **C1** | **C2** | **C3** | | **C1** | **C2** | **C3** | **The priority vector** |
| **C1** | 1 | 2,83 | 2,83 | **C1** | 0,586 | 0,623 | 0,540 | 0,583 |
| **C2** | 0,35 | 1 | 1,41 | **C2** | 0,207 | 0,220 | 0,269 | 0,232 |
| **C3** | 0,35 | 0,71 | 1 | **C3** | 0,207 | 0,156 | 0,191 | 0,185 |
| $\lambda$ max = 3,0131 | | CI= 0,0066 | | RI= 0,58 (for n=3) | | | | **CR= 0,0113<0,1** |

| The pairwise comparison matrix | | | | Normalized decision matrix of criteria | | | | W |
|---|---|---|---|---|---|---|---|---|
| | **SC1** | **SC2** | **SC3** | | **SC1** | **SC2** | **SC3** | **The priority vector** |
| **SC1** | 1 | 2,48 | 2,62 | **SC1** | 0,560 | 0,606 | 0,499 | 0,555 |
| **SC2** | 0,40 | 1 | 1,63 | **SC2** | 0,226 | 0,244 | 0,310 | 0,260 |
| **SC3** | 0,38 | 0,61 | 1 | **SC3** | 0,214 | 0,150 | 0,190 | 0,185 |
| $\lambda$ max = 3,0210 | | CI=0,0105 | | RI= 0,58 (for n=3) | | | | **CR= 0,0181<0,1** |

| The pairwise comparison matrix | | | | Normalized decision matrix of criteria | | | | W |
|---|---|---|---|---|---|---|---|---|
| | **SC4** | **SC5** | **SC6** | | **SC4** | **SC5** | **SC6** | **The priority vector** |
| **SC4** | 1 | 1,62 | 1,76 | **SC4** | 0,458 | 0,488 | 0,420 | 0,455 |
| **SC5** | 0,62 | 1 | 1,43 | **SC5** | 0,282 | 0,301 | 0,341 | 0,308 |
| **SC6** | 0,57 | 0,70 | 1 | **SC6** | 0,260 | 0,211 | 0,239 | 0,236 |
| $\lambda$ max = 3,0084 | | CI= 0,0042 | | RI= 0,58 (for n=3) | | | | **CR= 0,0072<0,1** |

| The pairwise comparison matrix | | | Normalized decision matrix of criteria | | | W |
|---|---|---|---|---|---|---|
| | **SC7** | **SC8** | | **SC7** | **SC8** | **The priority vector** |
| **SC7** | 1 | 1,03 | **SC7** | 0,507 | 0,507 | 0,507 |
| **SC8** | 0,97 | 1 | **SC8** | 0,493 | 0,493 | 0,493 |
| $\lambda$ max =2,0000 | | CI= 0 | RI= 0 (for n=2) | | | **CR= 0 <0,1** |

| The pairwise comparison matrix | | | | | | Normalized decision matrix of criteria | | | | | | W |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **A1** | **A2** | **A3** | **A4** | **A5** | | **A1** | **A2** | **A3** | **A4** | **A5** | **The priority vector** |
| **A1** | 1 | 1,38 | 1,99 | 0,48 | 1,58 | **A1** | 0,202 | 0,232 | 0,241 | 0,179 | 0,198 | 0,211 |
| **A2** | 0,72 | 1 | 1,96 | 0,42 | 1,50 | **A2** | 0,147 | 0,168 | 0,238 | 0,157 | 0,188 | 0,180 |
| **A3** | 0,50 | 0,51 | 1 | 0,41 | 1,17 | **A3** | 0,102 | 0,086 | 0,121 | 0,153 | 0,147 | 0,122 |
| **A4** | 2,08 | 2,38 | 2,44 | 1 | 2,71 | **A4** | 0,421 | 0,401 | 0,296 | 0,373 | 0,340 | 0,366 |
| **A5** | 0,63 | 0,67 | 0,85 | 0,4 | 1 | **A5** | 0,128 | 0,112 | 0,104 | 0,138 | 0,126 | 0,121 |
| $\lambda$ max = 5,0545 | | | CI= 0,0136 | | | RI= 1,12 (for n=5) | | | | **CR= 0,0122<0,1** | | |

| The pairwise comparison matrix | | | | Normalized decision matrix of criteria | | | | W |
|---|---|---|---|---|---|---|---|---|
| | **A6** | **A7** | **A8** | | **A6** | **A7** | **A8** | **The priority vector** |
| **A6** | 1 | 0,47 | 0,42 | **A6** | 0,182 | 0,147 | 0,211 | 0,180 |
| **A7** | 2,12 | 1 | 0,58 | **A7** | 0,386 | 0,312 | 0,288 | 0,329 |
| **A8** | 2,36 | 1,73 | 1 | **A8** | 0,431 | 0,541 | 0,500 | 0,491 |
| $\lambda$ max = 3,0216 | | CI= 0,0108 | | RI= 0,58 (for n=3) | | | | **CR= 0,0186<0,1** |

| The pairwise comparison matrix | | | Normalized decision matrix of criteria | | | W |
|---|---|---|---|---|---|---|
| | **A9** | **A10** | | **A9** | **A10** | **The priority vector** |
| **A9** | 1 | 0,92 | **A9** | 0,479 | 0,479 | 0,479 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **A10** | 1,09 | 1 | **A10** | 0,521 | 0,521 | 0,521 |
| $\lambda$ max =2,0000 | CI= 0 | RI= 0 (for n=2) | | **CR= 0 <0,1** | | |
| **The pairwise comparison matrix** | | | **Normalized decision matrix of criteria** | | | **W** |
| | **A11** | **A12** | | **A11** | **A12** | **The priority vector** |
| **A11** | 1 | 3,66 | **A11** | 0,785 | 0,785 | 0,785 |
| **A12** | 0,27 | 1 | **A12** | 0,215 | 0,215 | 0,215 |
| $\lambda$ max =2,0000 | CI= 0 | RI= 0 (for n=2) | | **CR= 0 <0,1** | | |
| **The pairwise comparison matrix** | | | **Normalized decision matrix of criteria** | | | **W** |
| | **A13** | **A14** | | **A13** | **A14** | **The priority vector** |
| **A13** | 1 | 1,12 | **A13** | 0,528 | 0,528 | 0,528 |
| **A14** | 0,89 | 1 | **A14** | 0,472 | 0,472 | 0,472 |
| $\lambda$ max =2,0000 | CI= 0 | RI= 0 (for n=2) | | **CR= 0 <0,1** | | |

Table 3 indicates the criteria' local weight (L) degrees within their own categories. In addition, the weights resulting from calculating the importance degree of each criterion, sub-criteria, and attribute, regardless of category, are expressed as global weight (G). G is obtained by multiplying the criterion's weight by which it is attached with the L belonging to each criterion (Saaty, 1988). Table 4 shows the general ranking of all criteria, sub-criteria, and attributes considered in the study according to L, G, and importance levels (I.L.).

**Table 4.** Priority ranking of criteria regarding facility location selection

| **Main Criteria** | | **Sub-criteria** | | **Attributes** | |
|---|---|---|---|---|---|
| C1. Economic | L: ,583 G: ,583 **I.L.: 1** | SC1. Accessibility | L: ,555 G: ,324 **I.L.: 1** | A1. Proximity to population density | L: ,211 G: ,068 **I.L.: 7** |
| | | | | A2. Proximity to logistics centers and shippers | L: ,180 G: ,058 **I.L.: 8** |
| | | | | A3. Proximity to commercial areas | L: ,122 G: ,040 **I.L.: 12** |
| | | | | A4. Proximity to the highway (main axes) | L: ,366 G: ,119 **I.L.: 1** |
| | | | | A5. Accessibility by public transport | L: ,121 G: ,039 **I.L.: 13** |
| | | SC2. Infrastructure | L: ,260 G: ,152 **I.L.: 2** | A6. Cycle path infrastructure | L: ,180 G: ,027 **I.L.: 15** |
| | | | | A7. Subway/train infrastructure | L: ,329 G: ,050 **I.L.: 9** |
| | | | | A8. Existing logistics facilities | L: ,491 G: ,075 **I.L.: 4** |
| | | SC3. Cost | L: ,185 G: ,108 **I.L.: 3** | - | **I.L.: 2** |
| C2. Social | L: ,232 G: ,232 **I.L.: 2** | SC4. Traffic density | L: ,455 G: ,106 **I.L.: 4** | - | **I.L.: 3** |
| | | SC5. Security | L: ,308 G: ,071 **I.L.: 7** | - | **I.L.: 6** |

| | | | | | |
|---|---|---|---|---|---|
| | | SC6. Compliance with urban planning | L: ,236<br>G: ,055<br>**I.L.: 8** | A9. Suitability of zoning status | L: ,479<br>G: ,026<br>**I.L.: 16** |
| | | | | A10. Possibility of facility expansion | L: ,521<br>G: ,029<br>**I.L.: 14** |
| C3. Environmental | L: ,185<br>G: ,185<br>**I.L.: 3** | SC7. Land topography | L: ,507<br>G: ,094<br>**I.L.: 5** | A11. Slope | L: ,785<br>G: ,074<br>**I.L.: 5** |
| | | | | A12. Exposure | L: ,215<br>G: ,020<br>**I.L.: 17** |
| | | SC8. Environmental awareness | L: ,493<br>G: ,091<br>**I.L.: 6** | A13. Air pollution level | L: ,528<br>G: ,048<br>**I.L.: 10** |
| | | | | A14. Distance to protected areas | L: ,472<br>G: ,043<br>**I.L.: 11** |

## 4.4. Analysis of GIS approach

### 4.4.1. Study area

İzmir is the third largest city in Turkey, located on the coast of the Aegean Sea in western Turkey, between the north latitudes 37° 45' and 39° 15' and the east longitudes 26° 15' and 28° 20'. İzmir's total surface area is 11,973 km², and its districts are 30 (İzmir Governorship, 2024). The districts of İzmir are Aliağa, Balçova, Bayındır, Bayraklı, Bergama, Beydağ, Bornova, Buca, Çeşme, Çiğli, Dikili, Foça, Gaziemir, Güzelbahçe, Karabağlar, Karaburun, Karşıyaka, Kemalpaşa, Kınık, Kiraz, Konak, Menderes, Menemen, Narlıdere, Ödemiş, Seferihisar, Selçuk, Tire, Torbalı, Urla. The population of İzmir as of 2024 is 4,479,525 people (TÜİK, 2024).

### 4.4.2. The data set

The approach taken in the GIS analysis regarding the existing attributes determined in the AHP analysis differed in two aspects: (1) The attribute of the existence of the subway/train infrastructure was included in the analysis in a way that also included the attribute of accessibility by public transport. (2) In addition to attributes in the AHP analysis, the security sub-criterion was included in the analysis as traffic accident rate, the cost sub-criterion as land acquisition cost, and the traffic density sub-criterion as road traffic volume. The attributes, weights, indicators, and data sources regarding the layers included in the GIS analysis are presented in Table 5. The indicators were included in the analysis based on the points emphasized in similar logistics facility location selection studies regarding the suitability of the selected areas in the creation of map layers.

**Table 5.** Data set for GIS analysis

| Attribute | AHP weight | Indicator / suitability | | Information regarding geographic data | Data source |
|---|---|---|---|---|---|
| **Proximity to population density** | 0,068 | High | Suitable | Current population data | TÜİK |
| | | Medium | Moderately suitable | | |
| | | Low | Not suitable | | |
| **Proximity to logistics centers and shippers** | 0,058 | Close | Suitable | Logistics center location and connection roads to city center | OpenStreetMap (OSM)<br><br>and<br><br>Ministry of Environment and Urbanization, General Directorate of Spatial Planning |
| | | Medium | Moderately suitable | | |
| | | Far | Not suitable | | |
| **Proximity to commercial areas** | 0,040 | 0-250 m | Very suitable | Organized industrial zones and free zones | |
| | | 250-500 m | Suitable | | |
| | | 500-750 m | Moderately suitable | | |
| | | 750-1000 m | Slightly suitable | | |
| | | 1000+ m | Not suitable | | |
| **Proximity to the highway (main axes)** | 0,119 | 0-250 m | Very suitable | Highways | |
| | | 250-500 m | Suitable | | |
| | | 500-750 m | Moderately suitable | | |
| | | 750-1000 m | Slightly suitable | | |

| | | | | | |
|---|---|---|---|---|---|
| | | 1000+ m | Not suitable | | |
| **Cycle path infrastructure** | 0,027 | 0-250 m | Very suitable | Locations and routes of the bike path | İzmir Metropolitan Municipality Transportation Department |
| | | 250-500 m | Suitable | | |
| | | 500-750 m | Moderately suitable | | |
| | | 750-1000 m | Slightly suitable | | |
| | | 1000+ m | Not suitable | | |
| **Subway/train infrastructure** | 0,089 | 0-250 m | Very suitable | Metro, İzban and Tram station points and routes | |
| | | 250-500 m | Suitable | | |
| | | 500-750 m | Moderately suitable | | |
| | | 750-1000 m | Slightly suitable | | |
| | | 1000+ m | Not suitable | | |
| **Existing logistics facilities** | 0,075 | 0-250 m | Very suitable | The points where the cargo companies' distribution facilities are located | OpenStreetMap (OSM) |
| | | 250-500 m | Suitable | | |
| | | 500-750 m | Moderately suitable | | |
| | | 750-1000 m | Slightly suitable | | |
| | | 1000+ m | Not suitable | | |
| **Land acquisition cost** | 0,108 | High | Not suitable | Land m² unit prices | Revenue Administration |
| | | Medium | Moderately suitable | | |
| | | Low | Suitable | | |
| **Road traffic volume** | 0,106 | Low density | Suitable | Traffic density of highways | General Directorate of Highways |
| | | Balanced | Moderately suitable | | |
| | | High density | Not suitable | | |
| **Traffic accident rate** | 0,071 | High intensity | Not suitable | Traffic accident hotspots with fatalities/injuries within the provincial borders | Police department regional directorate |
| | | Medium intensity | Moderately suitable | | |
| | | No accident | Suitable | | |
| **Suitability of zoning status** | 0,026 | City | Suitable | Land use purpose | CORINE 2018 Map |
| | | Industrial and Commercial | Suitable | | |
| | | Transport | Not suitable | | |
| | | Agriculture | Not suitable | | |
| | | Planted area | Not suitable | | |
| | | Pasture | Not suitable | | |
| | | Forest | Not suitable | | |
| | | Meadow | Not suitable | | |
| | | Bare field | Not suitable | | |
| | | Water area | Not suitable | | |
| **Possibility of facility expansion** | 0,029 | 0-250 m | Very suitable | Suitable land size and surroundings | Ministry of Environment and Urbanization, General Directorate of Spatial Planning |
| | | 250-500 m | Suitable | | |
| | | 500-750 m | Moderately suitable | | |
| | | 750-1000 m | Slightly suitable | | |
| | | 1000+ m | Not suitable | | |
| **Slope** | 0,074 | >%30 | Not suitable | Topography | USGS Earth Explorer |
| | | %10 - %30 | Moderately suitable | | |
| | | <%10 | Suitable | | |
| **Exposure** | 0,020 | North | Not suitable | | |
| | | East-West | Moderately suitable | | |
| | | South | Suitable | | |
| **Air pollution level** | 0,048 | Good 0-50 | Suitable | Air quality level ($PM_{10}$, $SO_2$) | Ministry of Environment and |
| | | Medium 50-100 | Moderately suitable | | |

| | | | | | |
|---|---|---|---|---|---|
| | | Sensitive 100-150 | Not suitable | | Urbanization Air Quality Data Bank |
| **Distance to protected areas** | 0,043 | 0-250 m | Not suitable | Cultural and natural conservation areas | Ministry of Environment and Urbanization, General Directorate of Spatial Planning |
| | | 250-500 m | Slightly suitable | | |
| | | 500-750 m | Moderately suitable | | |
| | | 750-1000 m | Suitable | | |
| | | 1000+ m | Very suitable | | |

### 4.4.3. Preparation of data and creation of map layers

The map layers created for each attribute are shown in Figure 3. The creation of these map layers involved some data preparation processes.

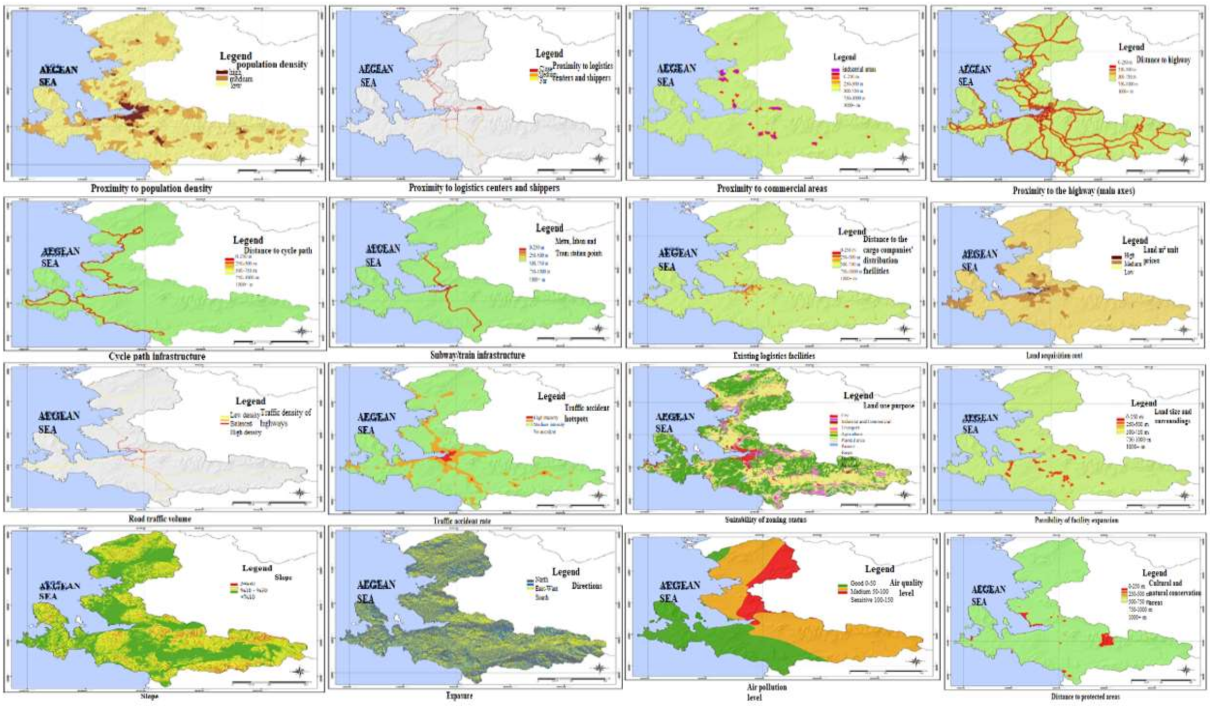


**Figure 3.** Map layers of each criterion

The GIS-MCDM framework demands that values across different criterion layers be transformed into comparable units to ensure robust analysis. Among various methods, linear scale transformation stands out as the most widely adopted deterministic approach for achieving this comparability (Ozturk and Batuk, 2011). In this study, we strategically implemented the maximum score procedure to standardize all criteria effectively. First, the process of converting all data into vector data format was performed. At this point, the slope, aspect, traffic accident rate, and air pollution level data obtained as raster data were reclassified according to the indicators determined within the scope of the study with the Reclassify function in the ArcGIS Spatial Analysis module and the process of converting the raster data into polygon vector type was performed. Then, the conversion of 16 attributes included within the scope of the study into a single coordinate system was performed. Vector data with different projection systems were included in the projection conversion process in a way that they would be matched with the TUREF/TM27 coordinate system covering the western provinces of Turkey using the Turkish National Reference Frame (TUREF) and Transverse Mercator (TM) projection for the Coordinate Reference System. Then, the vector data that were ready for analysis were examined according to the feature class as point, line, or polygon vector type. At this stage, the buffer zoning in the ArcGIS Spatial Analysis module was applied and the analysis was performed according to the Distance and Density functions. As indicated in Table 5, layers were created for all attributes, classified within themselves, and a value score was assigned according to the most appropriate (10) / not appropriate (0) scale for each class.

### 4.4.4. Creation of a suitability map for the facility

The weighted overlay analysis method was applied in this analysis stage, which requires raster data. Therefore, all vector data were converted into raster format. We then began evaluating the raster data layers and the scale weights established during the AHP analysis. This process resulted in a suitability map created by multiplying the criterion maps by their corresponding weights and overlaying them. The GIS analysis ultimately produced a map indicating the most suitable locations for UMCs within the province of İzmir, as shown in Figure 4. A facility located in designated areas that are ‘suitable’ is anticipated to perform exceptionally well in urban logistics.

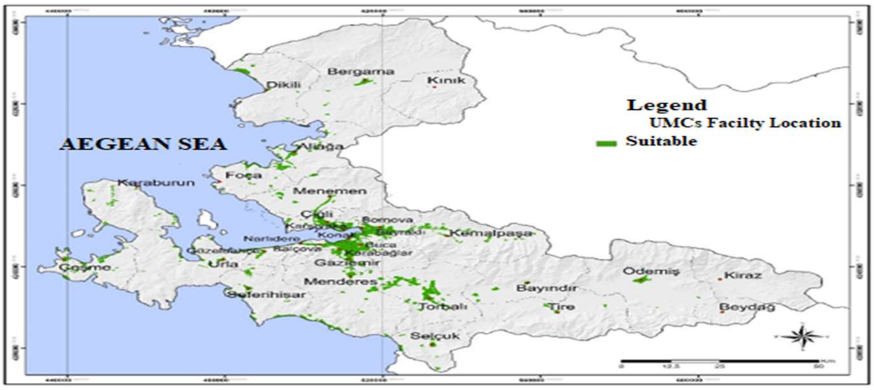


**Figure 4.** Suitability Map for UMCs within the province of İzmir

## 4.5. Analysis of the TOPSIS

This section discusses the selection of location indicated by the GIS analysis suitability map for establishing UMC. Based on GIS analysis results, the districts included in the TOPSIS analysis were Çiğli, Karşıyaka, Bayraklı, Bornova, Buca, Konak, Karabağlar, Gaziemir, and Balçova. According to the İzmir Sustainable Urban Logistics Plan (LOPİ 2030) published by the İzmir Metropolitan Municipality (2020a), these districts were also identified as problematic and densely populated areas in terms of urban logistics. The study was structured to conduct this analysis as follows effectively:

- The decision matrix is based on 16 criteria evaluated through GIS analysis, with their weights determined by AHP analysis. The rankings of the districts in the study were established by reviewing reports published by the İzmir Chamber of Commerce and the Master Plan Branch Directorate of the İzmir Metropolitan Municipality's Zoning and Urbanization Department (İzmir Metropolitan Municipality, 2020b). The LOPI 2030 report served as the primary source, along with data obtained from digitized geographic information used for the GIS analysis.
- In the criteria used in the decision matrix, district governorships were considered the district centers for distance calculations. Additionally, the study identifies the Kemalpaşa logistics center as the primary logistics center. The criteria evaluated in this study are coded with abbreviations ranging from C1 to C16. These criteria, along with their weights, evaluation focuses, and the objectives of maximizing or minimizing, are listed in Table 6.

**Table 6.** Review of Criteria for TOPSIS Analysis

| Weight | Criteria | | Evaluation Focus | Purpose |
|---|---|---|---|---|
| 0,068 | C1 | Proximity to population density | Population density | Maximum |
| 0,058 | C2 | Proximity to logistics centers and shippers | Distance from district center to logistics center (km) | Minimum |
| 0,040 | C3 | Proximity to commercial areas | Distance from district center to organized industrial zone (km) | Minimum |
| 0,119 | C4 | Proximity to the highway (main axes) | Distance from district center to highway (km) | Minimum |
| 0,027 | C5 | Cycle path infrastructure | Distance from district center to cycle path infrastructure (km) | Minimum |
| 0,089 | C6 | Subway/train infrastructure | Distance from district center to rail system infrastructure (km) | Minimum |
| 0,075 | C7 | Existing logistics facilities | Number of current cargo branches and transfer centers in the district | Maximum |
| 0,108 | C8 | Land acquisition cost | Average m2/unit prices of land in the district (TL) | Minimum |
| 0,106 | C9 | Road traffic volume | Annual average number of vehicles entering and exiting the district | Minimum |

| | | | | |
|---|---|---|---|---|
| 0,071 | C10 | Traffic accident rate | Annual average number of traffic accidents in the district | Minimum |
| 0,026 | C11 | Suitability of zoning status | Total area allocated for housing and industry in the district (%) | Maximum |
| 0,029 | C12 | Possibility of facility expansion | Empty area allocated for public institution areas in the district (ha) | Maximum |
| 0,074 | C13 | Slope | Maximum slope rate in the district (%) | Minimum |
| 0,020 | C14 | Exposure | Annual solar radiation potential of the district (kWh/m2) | Maximum |
| 0,048 | C15 | Air pollution level | Average air pollution level of the district ($PM_{10}$, µg/m³) | Minimum |
| 0,043 | C16 | Distance to protected areas | Distance from the district center to the area designated as protected area (km) | Maximum |

The decision matrix and weighted normalized matrix for selecting the UMC location, with alternative districts listed in the rows and criteria used for ranking in the columns, can be found in Table 6.

**Table 6.** The decision matrix and weighted normalized matrix for TOPSIS Analysis

| | | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 |
|---|---|---|---|---|---|---|---|---|---|
| **The decision matrix** | **Çiğli** | 200.211 | 34,5 | 3,5 | 1,9 | 0,75 | 0,5 | 21 | 1.110 |
| | **Karşıyaka** | 349.290 | 32,4 | 12 | 4 | 0,75 | 0,5 | 27 | 2.520 |
| | **Bayraklı** | 312.264 | 25,5 | 15 | 1 | 0,75 | 0,5 | 23 | 1.970 |
| | **Bornova** | 450.992 | 19,1 | 17,5 | 1,4 | 3,50 | 0,5 | 70 | 1.770 |
| | **Buca** | 510.695 | 33,6 | 4,3 | 2 | 10,00 | 2 | 29 | 1.720 |
| | **Konak** | 351.572 | 28,7 | 10,7 | 3,1 | 0,75 | 0,5 | 78 | 2.480 |
| | **Karabağlar** | 480.925 | 34 | 10,3 | 3,5 | 6,00 | 1 | 24 | 1.480 |
| | **Gaziemir** | 137.808 | 41,9 | 1,6 | 2 | 12,00 | 1 | 24 | 1.750 |
| | **Balçova** | 79.681 | 37,2 | 14 | 2 | 3,00 | 2 | 9 | 1.120 |
| | | **C9** | **C10** | **C11** | **C12** | **C13** | **C14** | **C15** | **C16** |
| | **Çiğli** | 81.994 | 650 | 33,84 | 111,6 | 5 | 1550 | 51,08 | 8,7 |
| | **Karşıyaka** | 159.098 | 700 | 48,59 | 45 | 8 | 1575 | 39,65 | 16,1 |
| | **Bayraklı** | 485.048 | 800 | 51,68 | 41,2 | 10 | 1575 | 44,62 | 14,9 |
| | **Bornova** | 968.057 | 900 | 58,05 | 153,2 | 15 | 1575 | 62,82 | 9 |
| | **Buca** | 160.141 | 700 | 69,77 | 122,8 | 20 | 1600 | 33,25 | 12,5 |
| | **Konak** | 833.851 | 900 | 89,67 | 21 | 10 | 1600 | 67,29 | 18 |
| | **Karabağlar** | 145.080 | 700 | 62,5 | 22,7 | 20 | 1600 | 55,34 | 21 |
| | **Gaziemir** | 696.736 | 850 | 56,33 | 46,3 | 25 | 1600 | 64,98 | 27,5 |
| | **Balçova** | 39.047 | 550 | 78,89 | 11 | 15 | 1550 | 38,47 | 27,3 |
| **Weighted normalized matrix** | | **C1** | **C2** | **C3** | **C4** | **C5** | **C6** | **C7** | **C8** |
| | **Çiğli** | 0,013 | 0,021 | 0,004 | 0,030 | 0,001 | 0,013 | 0,013 | 0,022 |
| | **Karşıyaka** | 0,023 | 0,019 | 0,014 | 0,063 | 0,001 | 0,013 | 0,017 | 0,050 |
| | **Bayraklı** | 0,020 | 0,015 | 0,018 | 0,016 | 0,001 | 0,013 | 0,014 | 0,039 |
| | **Bornova** | 0,029 | 0,011 | 0,021 | 0,022 | 0,005 | 0,013 | 0,043 | 0,035 |
| | **Buca** | 0,033 | 0,020 | 0,005 | 0,032 | 0,015 | 0,053 | 0,018 | 0,034 |
| | **Konak** | 0,023 | 0,017 | 0,013 | 0,049 | 0,001 | 0,013 | 0,048 | 0,049 |
| | **Karabağlar** | 0,031 | 0,020 | 0,012 | 0,055 | 0,009 | 0,027 | 0,015 | 0,029 |
| | **Gaziemir** | 0,009 | 0,025 | 0,002 | 0,032 | 0,019 | 0,027 | 0,015 | 0,034 |
| | **Balçova** | 0,005 | 0,022 | 0,017 | 0,032 | 0,005 | 0,053 | 0,006 | 0,022 |
| | | **C9** | **C10** | **C11** | **C12** | **C13** | **C14** | **C15** | **C16** |
| | **Çiğli** | 0,006 | 0,020 | 0,005 | 0,013 | 0,008 | 0,007 | 0,016 | 0,007 |
| | **Karşıyaka** | 0,011 | 0,022 | 0,007 | 0,005 | 0,013 | 0,007 | 0,012 | 0,013 |
| | **Bayraklı** | 0,033 | 0,025 | 0,007 | 0,005 | 0,016 | 0,007 | 0,014 | 0,012 |
| | **Bornova** | 0,066 | 0,028 | 0,008 | 0,018 | 0,024 | 0,007 | 0,019 | 0,007 |
| | **Buca** | 0,011 | 0,022 | 0,010 | 0,015 | 0,032 | 0,007 | 0,010 | 0,010 |
| | **Konak** | 0,057 | 0,028 | 0,012 | 0,003 | 0,016 | 0,007 | 0,021 | 0,014 |
| | **Karabağlar** | 0,010 | 0,022 | 0,009 | 0,003 | 0,032 | 0,007 | 0,017 | 0,016 |
| | **Gaziemir** | 0,047 | 0,027 | 0,008 | 0,006 | 0,040 | 0,007 | 0,020 | 0,021 |
| | **Balçova** | 0,003 | 0,017 | 0,011 | 0,001 | 0,024 | 0,007 | 0,012 | 0,021 |

After obtaining the weighted matrix, the ideal and negative ideal solution values were determined according to the specific goals of each criterion (whether a maximum or minimum value was desired). Subsequently, the distance values to both the ideal and negative ideal points were calculated as shown in Table 7.

**Table 7.** Ideal and Negative Ideal solution values

| | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | Ideal distance ($S_i^*$) | Negative Ideal distance ($S_i^-$) |
|---|---|---|---|---|---|---|---|---|---|---|
| Ideal Solution | 0,033 | 0,011 | 0,002 | 0,016 | 0,001 | 0,013 | 0,048 | 0,022 | 0,047752 | 0,095111 |
| | **C9** | **C10** | **C11** | **C12** | **C13** | **C14** | **C15** | **C16** | 0,068836 | 0,079428 |
| | 0,003 | 0,017 | 0,012 | 0,018 | 0,008 | 0,007 | 0,010 | 0,021 | 0,056862 | 0,080100 |
| Negative Ideal solution | **C1** | **C2** | **C3** | **C4** | **C5** | **C6** | **C7** | **C8** | 0,072736 | 0,080067 |
| | 0,005 | 0,025 | 0,021 | 0,063 | 0,019 | 0,053 | 0,006 | 0,050 | 0,063246 | 0,076829 |
| | **C9** | **C10** | **C11** | **C12** | **C13** | **C14** | **C15** | **C16** | 0,074861 | 0,071478 |
| | | | | | | | | | 0,064348 | 0,074018 |
| | 0,066 | 0,028 | 0,005 | 0,001 | 0,040 | 0,007 | 0,021 | 0,007 | 0,078394 | 0,054592 |
| | | | | | | | | | 0,072981 | 0,081628 |

Finally, the relative proximity of each decision point to the ideal solution was assessed, resulting in a ranking of the alternatives. The relevant data can be found in Table 8.

**Table 8.** Ranking alternatives for TOPSIS analysis

| Alternatives | Relative closeness to the ideal solution($C_i^*$) | Ranking |
|---|---|---|
| **Çiğli** | 0,665748 | **1** |
| **Karşıyaka** | 0,535719 | **4** |
| **Bayraklı** | 0,584831 | **2** |
| **Bornova** | 0,523986 | **7** |
| **Buca** | 0,548484 | **3** |
| **Konak** | 0,488441 | **8** |
| **Karabağlar** | 0,534944 | **5** |
| **Gaziemir** | 0,410509 | **9** |
| **Balçova** | 0,527965 | **6** |

## 4.6. Sensitivity Analysis

The suitability ranking of Izmir districts for UMC site selection was established using TOPSIS analysis. However, an inaccurate set of criteria weights presents a significant risk, as even a minor deviation can greatly impact the outcome. To ensure the integrity of the results, a sensitivity analysis was conducted. In this context, two scenarios were created where the criteria weights were altered, and their effects on the ranking of alternatives determined by the current criteria were evaluated. Common methods for sensitivity analysis include evaluating criteria with equal weights and adjusting the weights of the criteria with the highest and lowest values (Yavuz and Baki, 2019; Więckowski and Sałabun, 2023). Within this study, these approaches are referred to as scenario 1 (S1) and scenario 2 (S2), respectively. The relevant scenarios, along with current criteria weights (CW), are presented in Table 9.

**Table 9.** Criteria weights for sensitivity analysis

| | CW | S1 | S2 |
|---|---|---|---|
| **C1** | 0,068 | 0,063 | 0,068 |
| **C2** | 0,058 | 0,063 | 0,058 |
| **C3** | 0,040 | 0,063 | 0,040 |
| **C4** | 0,119 | 0,063 | 0,020 |
| **C5** | 0,027 | 0,063 | 0,027 |

| | | | |
|---|---|---|---|
| **C6** | 0,089 | 0,063 | 0,089 |
| **C7** | 0,075 | 0,063 | 0,075 |
| **C8** | 0,108 | 0,063 | 0,108 |
| **C9** | 0,106 | 0,063 | 0,106 |
| **C10** | 0,071 | 0,063 | 0,071 |
| **C11** | 0,026 | 0,063 | 0,026 |
| **C12** | 0,029 | 0,063 | 0,029 |
| **C13** | 0,074 | 0,063 | 0,074 |
| **C14** | 0,020 | 0,063 | 0,119 |
| **C15** | 0,048 | 0,063 | 0,048 |
| **C16** | 0,043 | 0,063 | 0,043 |

Figure 5 shows the change in the ranking of the alternatives as a result of the evaluation made with the TOPSIS method according to two different scenarios.

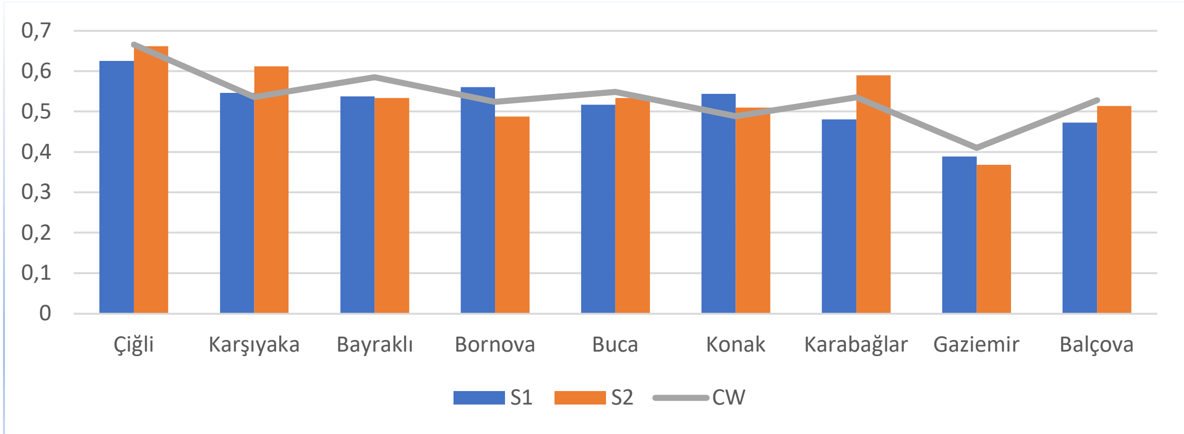


**Figure 5.** Sensitivity analysis results for TOPSIS analysis

## 5. Discussion

In the first part of the study, we examined the perspectives that should be considered when selecting a location based on the sustainability dimensions of UMCs. It was found that the most significant perspective, representing a consensus among all expert groups regarding the selection of UMC locations, focused on economic sustainability, which accounted for 58% of the responses. Additionally, accessibility was identified as the most important sub-criterion for the effective operation of the last-mile logistics, receiving a rating of 56%. Obviously, as the most important precondition of operating urban freight transport activities is increasing revenues, poor location decisions can lead to a lack of success in economic and efficiency objectives through transport costs, time flexibility, and agility (Wang et al., 2023). This result parallels similar studies (Rosenberg et al., 2021; Novotná et al., 2022). The accessibility sub-criterion revealed that easy access to highways, particularly major routes, is the most significant factor in selecting a facility location, accounting for 37%. The use of highways for the delivery of cargoes designated for intra-city distribution is a flexible transportation option. Additionally, the facility's ability to receive incoming cargo via highways aligns closely with the emphasis on highway access (Arrieta-Prieto et al., 2021). Considering that the primary purpose of the UMC is to make operationally efficient deliveries to consumer-dense points (Özbekler and Karaman Akgül, 2020), it is seen that proximity to population density is evaluated as the second most important attribute with a rate of 21%. In addition, considering that most of the cargoes, especially within the scope of e-commerce shipments, come from outside the city, proximity to the logistics center and shippers is evaluated as the third most important attribute with a rate of 18%. In this respect, it becomes clear that the proposed facility location should act as a bridge between consumer-dense points and the logistics center, and this supports the results of similar studies (Arrieta-Prieto et al., 2021; Rosenberg et al., 2021; Novotná et al., 2022).

The social sustainability criterion was identified as the second most important factor in UMC location selection, accounting for 23%. Within this framework, traffic density emerged as the most significant sub-criterion, with an importance rating of 46%. Traffic density, particularly the presence of numerous commercial vehicles for distribution purposes, is assessed based on its potential to increase congestion in existing traffic and negatively impact the city's livability. Therefore, it is crucial to position the facility in a location that does not exacerbate this congestion (Wang et al., 2023). Additionally, the density of accident rates around the proposed facility location was found to be the second most important sub-criterion regarding safety, with a relevance rate of 31%. The compatibility of the site selection with urban planning emerged as the third most significant sub-criterion, accounting for 24%. Various studies have explored these aspects, which have also reported similar trends (Rudolph et al., 2022; Bertolini et al., 2024). Finally, environmental sustainability emerged as the third most important criterion for selecting UMC locations, receiving a rating of 19%. The fact that environmental sustainability has been overshadowed by social and economic dimensions suggests that social responsibility awareness is particularly changed place to focus on economic aspects within logistics activities. As a result, priorities for urban goods movement tend to center more on operational issues (Novotná et al., 2022; Bertolini et al., 2024). The criteria for land topography and environmental awareness were assessed with importance levels of 51% and 49%, respectively. The characteristics of the land where the facility will be established are evaluated based on the ease of cargo operations and the energy efficiency of the facility. Additionally, the potential environmental impacts of the facility's location, such as air pollution and environmental protection, are considered important for social sensitivity (Wang et al., 2023).

In the following section of the study, TOPSIS analysis was conducted on the areas identified as most suitable for establishing a micro-consolidation center facility, based on a result map generated from GIS analysis. The top priority location for the Urban Micro-Consolidation (UMC) facility was determined to be the Çiğli district in İzmir Province. The districts that follow in terms of suitability are Bayraklı and Buca, respectively. After TOPSIS analysis, sensitivity analysis was applied by evaluating criteria with equal weights (S1), adjusting the weights of the criteria with the highest and lowest values (S2), and comparing them with the existing criteria weights (CW). Upon examining the sensitivity analysis, the ranking of the alternatives in S1 and S2 did not show significant differences compared to the selections determined by the TOPSIS results. Çiğli province consistently ranked first in suitability across both scenarios, while the second and third ranks were quite similar to the current situation, with only minimal differences. This indicates that the results of the TOPSIS analysis demonstrate both integrity and robustness. The advantages of selecting Çiğli district can be summarized as follows:

- The district center is located very close to the bicycle path and rail system infrastructure, making it feasible to distribute cargo from the facility to surrounding districts using electric cargo bikes and public transportation, such as the metro.
- The average land prices per square meter within the district are lower than those in neighboring districts. This provides a significant advantage regarding land acquisition costs. Furthermore, the district has vacant areas designated for public institutions, which present substantial opportunities compared to other districts. Given the challenges of finding sufficiently wide areas for micro-consolidation centers in high-density, heavily constructed areas, it can be concluded that Çiğli district has the capacity to serve a considerable part of İzmir, especially with its land suited for large-scale facility structures.
- The central districts of İzmir experience high traffic volumes, while Çiğli district has significantly lower traffic levels. In addition, the number of traffic accidents in Çiğli is lower than in neighboring districts, making it a more attractive location in terms of traffic safety.
- Within the boundaries of Çiğli district lies the İzmir Atatürk Organized Industrial Zone, one of the largest and most modern organized industrial zones in Turkey. This proximity enhances the district's suitability in terms of access to commercial areas.
- The Çiğli district is located 6 km from the Karşıyaka district and approximately 11 km from the Bayraklı district. Due to its proximity to the population, a facility in the Çiğli district can serve residents of both Karşıyaka and Bayraklı, reaching a potential customer base of around 900,000 people. Additionally, the İzmir Main Highway runs through the district, providing convenient transportation to the logistics center without getting caught in city traffic, thus saving time.

When evaluating the current situation in the sector, it is noted that İzmir has a daily cargo distribution need of approximately 10,000. There is particularly high demand for cargo distribution in the districts of Karşıyaka, Konak, Buca, Bornova, and Karabağlar. Additionally, it has been determined that a facility capable of managing the distribution of 1,000 cargoes requires an area of 300 to 400 square meters. To address the distribution problem, it is suggested to establish 500 square meter facilities in district centers where space is limited or to create 3,000 square meter facilities in areas that are relatively further from the consumer. In this context, it is believed that the current cargo density is unevenly distributed across different districts, making operations challenging. Establishing a single facility in İzmir province is unlikely to meet the expected demands in terms of scope. Therefore, there is a pressing need to develop solutions throughout the province by delineating the service area of the planned facilities to better accommodate the daily cargo volume in İzmir. To address this, a broader distribution strategy can be proposed, focusing on the districts of Çiğli, Bayraklı, and Buca, which have been identified as the three most suitable locations for establishing the facility. The proposed strategy includes:

- It is proposed that a UMC be established in Çiğli, primarily serving the districts of Çiğli and Karşıyaka. Çiğli offers suitable land availability and a well-developed transportation infrastructure. Establishing a 3,000 m² micro-consolidation center in this region is expected to significantly alleviate the logistics challenges faced by İzmir, particularly in light of the anticipated increase in cargo volume in the coming years.

- It is proposed that a second UMC be established in the Bayraklı district to serve both Bayraklı and Bornova districts. The distance between the centers of Bayraklı and Bornova is approximately 6.5 km. In Bornova, areas such as Işıkkent and Pınarbaşı suffer from heavy traffic and high air pollution levels. Establishing distribution services from Bayraklı to Bornova may help alleviate the urban logistics challenges faced by the city. Additionally, the Bayraklı district is well-positioned to serve around 765,000 consumers, including those in Bornova, by offering economical and environmentally friendly solutions due to its proximity to bicycle paths, rail system infrastructure, and the İzmir Main Highway. The proposed facility or facilities could range in size from 500 m² to 1,500 m², depending on the actual cargo volume and future needs of the region. Although the availability of vacant land and the potential for facility expansion in terms of land use suitability in Bayraklı district may pose challenges for future demand, repurposing idle buildings, warehouses, or centrally located structures into UMCs can be seen as a key solution to address these issues.
- Finally, it is proposed that the third facility be established in the Buca district. From this location, a comprehensive distribution network will serve not only Buca but also the neighboring districts of Konak, Karabağlar, Gaziemir, and Balçova. Buca is situated 8 km from Konak, 7 km from Karabağlar, 10.5 km from Gaziemir, and 18.5 km from Balçova. The choice of Buca district is influenced by its proximity to these surrounding areas, along with its lower traffic density compared to other districts. Additionally, Buca offers large, vacant land suitable for establishing the facility. It is anticipated that one or two micro-consolidation facilities, each covering 3,000 m², will be built in Buca, from which cargo distribution will be carried out to the surrounding districts.

## 6. Conclusion and future directions

This study aims to highlight the importance of UMC facilities designed to provide sustainable solutions in response to the growing cargo density in last-mile logistics processes and the critical factors involved in location selection. To achieve this, the study adopts a three-step integrated approach, focusing on selecting an exemplary UMC facility in the İzmir province based on its economic, social, and environmental sustainability. The first step involves determining the location selection criteria using the AHP method, along with prioritizing these criteria based on expert opinions. The second step consists of identifying suitable areas for establishing the facility in İzmir by combining the results of the AHP method with a GIS mapping process. Finally, the third step implements the UMC location selection in İzmir districts using the TOPSIS method and conducting sensitivity analysis.

In the UMC location selection problem, the most important criterion in terms of global importance was found to be economic. Within this criterion, the most significant sub-criterion was accessibility, and the key attribute was proximity to the highway. Additionally, it is crucial that the facility is located near critical access points, such as areas with high consumer density, highways, and shippers. Ensuring that commercial vehicles can easily access the facility via the highway is also important. As part of the same section, the criteria analyzed with AHP were combined with spatial data for GIS analysis. This approach enabled the visualization of areas in İzmir province that are suitable for selecting facility locations. The map layers created for each attribute allowed us to identify the most appropriate sites for establishing UMCs in İzmir through a weighted overlay analysis. The areas identified as suitable on the map were refined based on the LOPI 2030 report (İzmir Metropolitan Municipality, 2020a). Subsequently, a TOPSIS analysis and sensitivity analysis were conducted on the nine remaining districts. The results indicated that the most favorable location for establishing a micro-consolidation center is in the Çiğli district, followed by the Bayraklı and Buca districts.

However, this study has certain limitations. The study focuses on the flow of cargo to end consumers within the business-to-consumer (B2C) market and excludes intra-city cargo flow related to retailers, manufacturers, and other businesses in the business-to-business (B2B) sector. Furthermore, the model's assumptions lacked dynamic modeling, failing to effectively address fluctuations in traffic conditions and their impact on vehicle movement while concentrating only on static elements. Therefore, operational aspects such as daily cargo volume, required vehicle capacity, and route optimization specific to the distribution of goods within the İzmir province are not analyzed with precise measurements in this research. Additionally, the study encountered constraints regarding data availability, especially in determining the sustainable criteria of UMC's location and obtaining related spatial data, as it relied mostly on secondary sources. Lastly, the expert opinions used to determine the weights of the criteria can introduce potential dilemmas and compromise the generalizability of the study results due to the study's nature. To enhance future research, it is recommended that models be developed based on actual cargo volume using up-to-date data. Additionally, detailed optimization-oriented capacity calculation models should be created to determine the number of facilities needed in priority districts for the UMC, as well as their respective sizes in square meters. Also, the integrated model can be expanded and applied to the B2B sector in future research to obtain more effective results.

The practical insights derived from the study results are expected to assist decision-makers in the logistics sector in making effective decisions for the short, medium, and long term. Additionally, these insights will aid the public sector in developing appropriate policies and will provide guidance to all stakeholders in the city who are concerned about the externalities of the logistics sector and their impact on the city's livability, as they seek solutions.

## Conflict of interest

No conflict of interest was declared by the authors.

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## Contributions of Authors

Türkan Müge ÖZBEKLER: Investigation, Conceptualization, Methodology, Writing, Arzu KARAMAN AKGÜL: Supervision, Writing - review and Editing.

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