

# A spatial multi-criteria decision-making model for planning new logistic centers in metropolitan areas

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## ABSTRACT

The logistics center concept has been discussed in the literature for over four decades. Logistics centers simplify the logistics network and have many advantages, such as lower transportation costs, an economy of scale, and integrated service capabilities. We propose a spatial multi-criteria decision-making model for new logistic centers in metropolitan areas. The first focus of the study is identifying the logistic concerns, defining the factors affecting the replacement decisions and determining the weights of the factors in metropolitan areas with many expert opinions. The second focuses on spatial analysis to locate new logistics centers serving urban areas. We present a case study in Istanbul, the most populous metropolis in Europe, to demonstrate the applicability and exhibit efficacy of the method proposed in this study. Outputs of the study pointed out where the convenient places are to locate new logistics centers.

## 1. Introduction

The demand for logistic services is generally fulfilled by multiple logistics companies in the logistics centers with their facilities that provide integrated logistics services. In this manner the integration means a holistic logistics service capability which creates harmony that leads lower business costs for logistic service providers. Another aspect of the logistics centers is the discordance of the transportation vehicles regarding size and the number. Inbound activities towards to the centers generally done by larger trucks and the outbound activities such as deliveries to final customers or distribution centers can be completed by relatively smaller but more vehicles. Thus, the decision of establishing a new logistics center will affect the whole logistics network strategies in cities in the long term, and the consequences of this decision will be permanent or hard to change due to the decision's initial investment outlay. Hereby, it can be concluded that a full consideration should be given to the decision of establishing a logistics center with different aspects of the choice.

In addition to the complexity of the location decision, there are various advantages of these facilities discussed by researchers. The concept has been debated for more than forty years in academic

literature [55] and the interest on the topic is growing day by day. Primary advantages of having logistic centers can be counted as reduced costs, decreased travelled distance of the trucks, integrated and better service capabilities [46]. Secondary advantages of the primary factors can be counted as less exhausted harmful gases, relieved traffic congestion therefore decreased negative impacts on environment [43] and lower variable costs. The relationship between logistic activities and transportation studies showed that important percentage of traffic are caused by transshipments [15], and the location of strategic logistics facilities can have influences on traffic volume [64]. Therefore, right location decisions may lower traffic problems, logistics costs and carbon emissions. These studies also show that there is correlation between the logistics facilities' locations and life quality of a city.

However, location selection is accepted as a sophisticated research area. There are different solution approaches and multi-criteria approaches are successful to incorporate the various effective factors into the problem. Moreover, spatial multi-criteria decision analysis approaches are powerful to add the spatial features to the analyses with geographical suitability consideration [42,32,39]. Location analysis is related with spatial information and affecting criteria's effects. Multi-criteria spatial analysis is capable of integrating both of these inputs.

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When spatial information is considered, emerging Geographic Information Systems (GIS) in location analysis is the case. In the beginning of the seventies, Tobler's statement [61] "*everything is related to everything else, but near things are more related than distant things*" had a huge impact on geography researches due to spreading use of GIS. The statement is accepted as the first law of the geography, and decades after it is proven by using big data [27]. In addition to the Tobler's statement, when the spatial convenience is the subject, determining the relevant criteria is crucial for the location analysts. Multi-criteria tools are suitable for measuring criteria effects. And spatial multi-criteria decision making is a specialized subset of the multi-criteria analysis with their spatial analysis capabilities. Spatial multi-criteria decision-making approaches are emerged in the literature due to their analyzing capabilities based on integration of GIS and multi-criteria approaches. GIS are used with different methodologies for location analysis [9,14,30], and with multi-criteria spatial approach different location selection processes are completed [10,63]. The main idea of the spatial multi-criteria analysis is the integration of multi-criteria decision making and GIS by using the data that is generated by GIS in multi-criteria analysis before reaching the final decision. There are various spatial and non-spatial factors affecting location selection decision of a logistic center. Also, this decision-making problem considers both quantitative and qualitative criteria [35,51,53]. In the literature, proximities to the transportation network [23,41,44,65], demand and supply nodes [44,48], costs [12,21,23,37,41], transportation availability, capacity and quality [12,41,44], traffic [22,36,53], social benefits [13], environmental considerations [13,53], land specialties [22,23], labor characteristics and availability [23,37,41,62] are used as decision parameters. Addition to these micro parameters, [58] used Logistics Performance Index (LPI) data developed by the World Bank for the time periods 2012, 2014, 2016 and 2018 while selecting the logistics center.

All in all, spatial multi-criteria analysis provides certain advantages for location analysis. This assumption needs to be tested, and also it should be scientifically supported in large areas where complex logistics are needed such as huge metropolises.

Regarding these considerations, the aim of the study is the evaluation of the spatially convenient locations for new logistic centers that will serve for city logistics needs. For the implementation, Istanbul selected as the study area for testing the methodology due to Istanbul's high demand. Istanbul is the most populous city in Europe with its over 15 million population divided between two continents and excluding over 10 million tourists annually. Additionally, the city has important industrial facilities, this characteristic even makes city's transportation structure more complicate. Thus, the city stands out as an important case, not only as a human settlement, but also as an important production and trade center.

GIS/Spatial Analysis and survey studies are combined experiences' knowledge with GIS' quantitative capabilities. Over twelve thousand stakeholders are participated the questionnaire study. Their expressions and judgments over transportation and logistics activities showed the professionals thoughts on location selection decision and spatial analysis abilities let us to illustrate these findings on the maps. During the analysis phase, different scenarios are created the convenient locations and the findings expressed the spatially attractive regions for logistics centers.

In this respect the framework of the current research and its results are reported with the following structure. Background of the study is described in detail in the Section 2 with that a brief literature is given about centralization of the inventories and logistic activities. After necessary definitions are given for the logistic centers; then, the characteristics of the study area are given. Section 3 presents the methodology and experimentations; firstly, the method is explained and then the survey results and the mappings are given. Section 4 gives the findings of the experimentations, then, the final section is summarizing the study and including the final discussion.

## 2. Background

In this section, most relevant literature in centralization of the inventories (2.1) and logistics centers and location selection (2.2) for those centers have been reviewed.

### 2.1. Centralization of the Inventories

Inventory centralization aims to decrease the number of the facilities into one or fewer numbers of facilities to create cost benefits to companies. However, there is a trade-off between distances to customers and inventory costs. Decreasing the numbers of the facilities causes lower investment and warehousing costs; yet, also causes higher distances to the customers. This complexity attracts researchers and there are various studies which deal with these problems. Centralization concept firstly emerged in textbooks in 1960 s without mathematical proofs [56,7]. After the first examples, with the proposal of the square root law, the positive effects of the centralization on inventory levels are measured practically [28]. According to the square root law, in the case of centralization of 20 facilities into 1 facility cause 78% of decrement of inventory cost. Then, [38] proved the square root law mathematically. As a following study, [20] proposed newsboy problem framework and calculated the total cost of decentralized system is higher than the centralized system. In another study, the question of "does the effect of centralization show a variety according to the applied sectors?" is answered by [3], and the results show that all sectors are affected positively by centralization with different degrees of cost profits. The mentioned centralization literature expanded with the researches of lateral shipments [33,59] and portfolio effects [60]. In a recent study Stevic and colleagues are applied an economic analysis to analyze centralized vs. decentralized warehouse system for a paper production company and they asserted and proved that "total cost of decentralized system is higher than the centralized system" [57].

### 2.2. Logistics centers and location selection

Logistics center concept appeared in the literature more than forty years ago [55]. During this long research period different names used for a logistics center such as logistics center, distribution center, central warehouse, freight/transport terminal, transport node, logistics platform, freight village, logistics depot, distripark etc. [40,57]. Although there is no clear consensus on the name logistics centers have been placed at the hearth of the modern freight transport system and act as the strategic nodal points. Thus, it can be accepted as the most common term. In addition to the variety in the names, the functions, sizes, proposed service varieties of the facilities showed significant changes in time due to the changes in transshipment flow volumes. The logistics centres are the areas including various sets of logistics facilities that are being able to present carry out different logistics services on a commercial base to their customers relating to transportation and distribution of goods and supporting multi-modal shipments and geographic coverages [19,55].

Location selection problems for logistics centers also has been a popular research topic for researchers, and different solution approaches are discussed for different cases. Some of these studies contributed to the selection of criteria to be used in location selection, while others provided information about the most appropriate methodology.

Electre III/IV is used for logistics center research in Poland by Żak and Weglinski (2014). Wang and He used a robust optimization for location and allocation of the logistics center under uncertain environment [4]. Awasthi and colleagues used fuzzy TOPSIS for the location selection process of an urban distribution under uncertainty [1]. [49] presented a smart and sustainable operations and supply chain management in Industry 4.0. [23] used Analytic Hierarchy Process (AHP) -a structure technique for organizing and analyzing complex

decisions- for their location study of a logistic center that will serve for textile sector in Marmara Region of Turkey. [18] proposed an analytics approach to the decision alternative prioritization for zero-emission zone logistics. [6] studied logistic autonomous vehicles assessment using decision support model.

Recently many researchers attempted to integrate existing techniques to reach better solutions. A conceptual model based on integration of the artificial neural network and AHP is proposed for intermodal freight logistics centers by [34]. Li and colleagues used axiomatic fuzzy set and TOPSIS methodology to determine the location of the logistics centers [36]. Basciftci and colleagues derived an exact mixed-integer linear programming reformulation in order to solve a facility location problem in terms of robust distribution [5]. The results of this approach provided evidence of significant improvements in profitability and service quality. Çakmak and colleagues proposed integrated methodology to solve location selection problem which used Binary Particle Swarm Optimization (BPSO) and GIS which provides the optimum solutions faster than 0–1 Integer Programming [8]. [41] integrated ANP and TOPSIS as an effective model to solve the distribution center location problem. In this approach ANP method used to define the weights of the selection criteria, while the TOPSIS applied to rank alternatives. Decision support systems have been successfully applied to many problems such as: Pamucar et al. [50], [2,16,47,52].

### 3. Methodology

In this study a continuous plane is considered for a facility location problem. For the solution approach a multi-criteria spatial decision analysis is carried out. For this analysis two main analysis tools are combined to reach the decision. The first analysis tool is a questionnaire to represent experts' evaluations. Because to do a comprehensive spatial analysis it is necessary to select a suitable logistics center, Rikalovic and colleagues suggested that Geographical Information Systems are ideal [54]. Thus the second tool is selected as GIS/Spatial analysis. A multi-criteria analysis reaches the decision with contribution of a set of decision criteria. Spatial multi-criteria analysis uses GIS' analysis capabilities to understand the effects of geographic criteria. There are different analysis approaches such as distance-based algorithms, clustering algorithms and so on.

The application is completed in two main analysis tools. These are Field Study and GIS Analysis. In field analysis, decision criteria for location analysis are determined and these decision criteria are evaluated with different questions. The use of these techniques in the methodology followed an iterative structure and Fig. 1 shows the flow of the used methodology in the study.

In Fig. 1, there are two main analysis steps. The left-hand side in Fig. 1 express how a field study to collect and calculate decision criteria weights can be created. According to this part of the figure, firstly decision criteria should be determined, then, a questionnaire should be designed. In the design step what questions are adequate, who can be correct sample for the analysis should be determined. After this step, data should be collected. After data collection, decision weight will be found as the results of the experts' answers in the survey study and these values will be the input of the spatial analysis.

The right hand side in Fig. 1 expressed the GIS analysis. These steps start with questionnaire study. The questions also express the geographic decision criteria of selection of the logistics centers. Due to that in accordance with survey study data collection and digitization of data should be started as the first step. Then a geographic database (geodb) should be created. After data are ready to analyze, spatial analysis can be performed. In this step distances towards to focal entities such as demand nodes, supply nodes or transportation network can be performed. In the next step combining different maps, which also named as overlaying can be performed to map different scenarios. In this step constraints can be added to eliminate inconvenient locations from decision environment. And also different decision criteria weights should

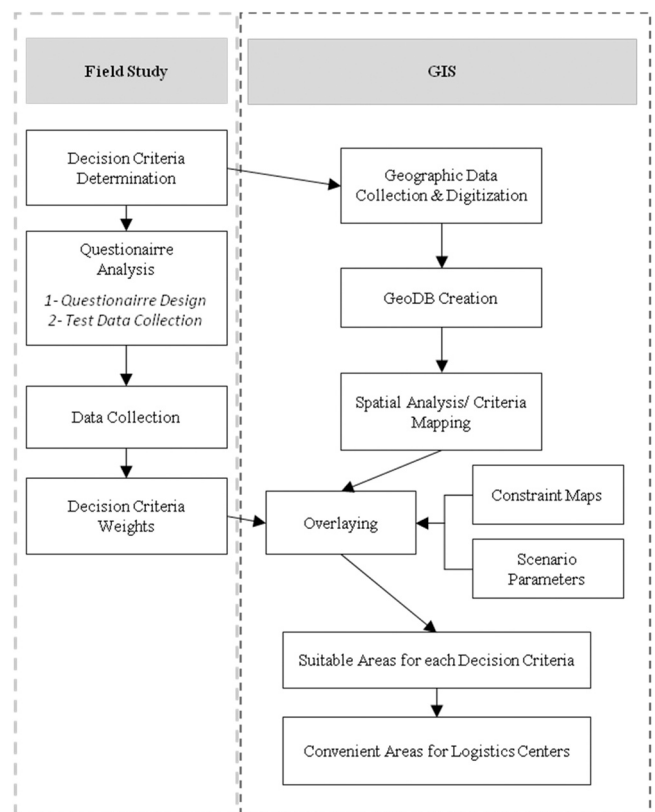


Fig. 1. The flowchart of the methodology.

be tested as different scenarios to understand how decision is changing. The results of these scenario analysis will represent the suitability levels of different geographical part of the analysis region. The final step of the methodology is to pointing out the most convenient areas in the city.

#### 3.1. Questionnaire

In multi-criteria analysis, researchers use different techniques such as: weighted sum, AHP, TOPSIS, ELECTRE, PROMETHEE, and so on with their fuzzy derivatives. These techniques are often used to reflect a limited number of expert opinions. Survey study can be used to reflect views of higher participation. In the scope of the study, it will be appropriate to use the survey method since an important decision on a complex metropolitan area will be taken. The questionnaire can accurately reflect the opinions of the experts in case of high participation. Due to this reason fuzzification of the decision judgements is not seen as a necessity. It is suitable to report the results and weights of decision criteria with crisp values.

There are two stages in the survey study. These are the selection of survey criteria and the selection of questionnaire questions which will be an input to the analysis. The second step is to determine what alternative scenarios should be considered for site selection analysis and to determine these scenario parameters.

#### 3.2. Decision criteria determination and questions

In the scope of the study, a survey data was analyzed for the analysis of the site selection. At this point, the first step is to determine the criteria and questions about the location of the logistics facility in the metropolitan area that constitutes the scope of the study. These questions should be appropriate for site selection analysis. The point being evaluated is that expert opinions should be converted into numerical values. The linguistic values are converted to numerical values as low,

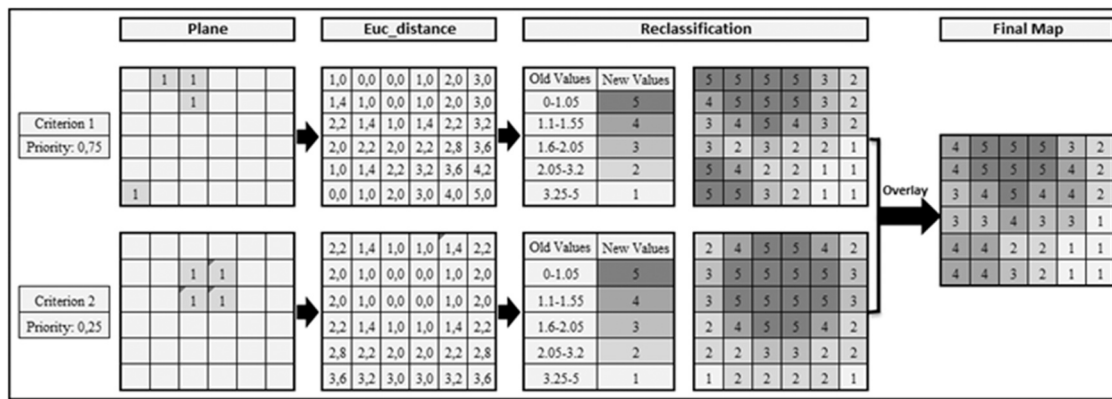


Fig. 2. Spatial analysis tools: Euclidean distance, reclassification, overlay <sup>42,46</sup>.

1; medium, 3; high; 5. The main motivation for using 3 basic evaluation judgments in evaluation is to see the difference in the opinions of the experts in detail.

### 3.3. Scenario creation and weight calculation

The survey will provide input to GIS analyzes, the second step of the method. In this phase, the criteria to be assessed were determined in the previous phase of the survey study. At this stage, the assessment of the effect of the relevant criteria will be carried out. Metropolitan areas have complex structures with crowded population. For this reason, different expertise has different opinions to reflect this complexity. Within the scope of the study, scenarios reflecting different expertise considerations should be discussed.

Two views should be reflected in the scenario analysis design. These are the evaluation of decision criteria by all experts for site selection. This assessment will give a general idea. The second is to evaluate the criteria according to the expertise. With these two approaches, it will be possible to determine the difference in the points of view of different specializations. The values to be used in the scenario will be derived from the quantification of the opinions of the linguistic experts mentioned in the questionnaire. Criteria weights are measured with weighted average method. The formulation of the method is given in Eq. (1). The weights there were evaluated as at least 1 and maximum 9 according to the evaluation scale. In the Eq. (1), w<sub>i</sub> values represents the weights of the spatial decision criteria and x<sub>i</sub> represent the each decision criteria from i to n. Normalization with total value of the weights will give the  $\bar{x}$  value.

$$\bar{x} = \frac{\sum_{i=1}^n w_i x_i}{\sum_{i=1}^n w_i} \tag{1}$$

### 3.4. GIS/spatial analysis

The next step in the article study is GIS / Spatial Analysis. This step will give the convenient areas for logistics centers under different scenario considerations. The input criteria and weights will be provided by the previous step. As a novelty a vast number of decision makers' expression is analyzed with GIS.

During the analysis, there is a need of geographic data for both illustration and analysis. Thus, geographic data should be gathered or created to be able to perform the spatial analysis. The data to be collected in this step will be determined by the decision criteria determined in the survey study. Then, a geographic database should be created for the analysis. After data preparation, spatial analysis can perform to analyze the decision criteria.

There are different ways to analyze the decision criteria under GIS such as spatial analysis, spatial statistics analysis or network analysis.

All the counted analysis approaches have different analysis structures, and their capabilities show differences. In case of there are high number of data for a map, creating a density map [24] will illustrate how the considered data sprawled on the study area; on the other hand, in the event of studying with low number of the data Euclidean distance analysis [26] will illustrate the geographic sprawl of the data. After creating a density or distance map, these maps are needed to be reclassified to perform the overlay analysis [25]. Jenks natural breaking points [31] is suitable to measure the impact areas of these decision criteria geographically.

However, the amount of data does not always the correct parameter for the GIS analyses. Suitability analysis for the location decision is based on combining expert thoughts and spatial analysis results. That is why an overlay analysis is needed to combine weights and spatial information.

Overlaying is the integration tool of outputs of the applied spatial analysis for the decision criteria. The idea of overlaying is to create a final map that draws the borders of convenient levels of the regions. This approach needs input parameters which are mainly weights of input maps in the study. Overlaying is often used in GIS and multi-criteria integration in previous studies [1,54]. Fig. 2 illustrated the how the given GIS analyzes work. In this study, it is suggested to create final maps which include classes that represent suitability levels. The overlaying results will show how the experts' thoughts can be illustrated on a plane, and these results will need a final evaluation.

The considered facilities should not be in some sensitive areas. These musts can be solved with constraint maps. While creating suitability maps for convenient areas the sensitive areas will erase from the decision environment.

#### 3.4.1. Point density analysis

Density analysis can determine the distribution of point data over the considered plane. In the scope of this study, this analysis method was used in the analysis of high number of points. Density analysis output is a raster dataset. The inputs are vector and point data set. For the analysis, a neighborhood around each raster cell center defined. And the number of points that fall within the neighborhood is totaled and divided by the area of the neighborhood [24].

#### 3.4.2. Euclidean distance analysis

When a continuous plane is considered, Euclidean distance analysis applied for calculating the distances between each grid to the considered feature. The input features of the analysis are vector data such as point, line or polygon.

#### 3.4.3. Mapping operations

In addition to the analysis tools described in this methodology, two more mapping operations were used. One of these is the erase tool. This function removes the restriction maps from the current workspace. In

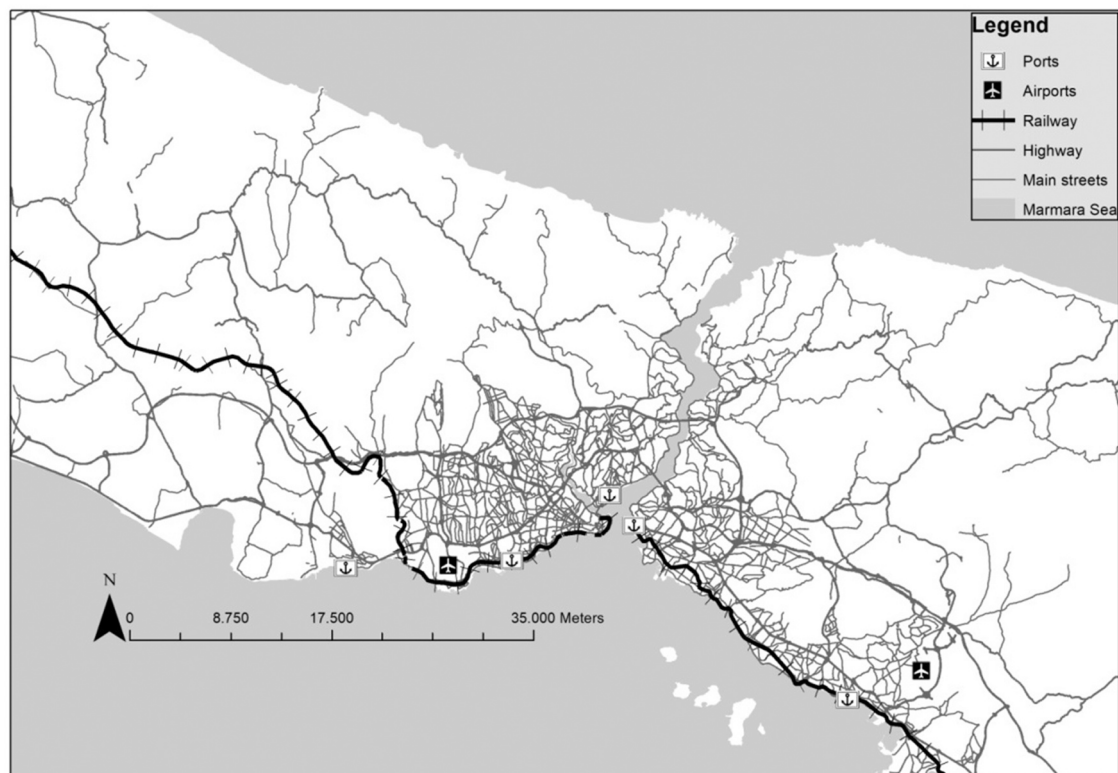


Fig. 3. Transportation network of the study area.

this context, placement of the installation in undesired zones can be avoided.

The second used tool is the weighted overlay tool [26]. This tool allows you to combine multiple maps according to their importance and calculate final suitability map for the location analysis. Input maps must be in raster format. These maps may have been obtained from Euclidean distance or density analysis results. While raster maps converge at different ratios, class ratios must carry the same values. For this reason, it is necessary to reclassify the results of the distance or density analysis. This will ensure that the values of the maps to be merged are included in the same class. This could lead to a meaningful output of the result map.

Another GIS tool used within the scope of the study is the mean center algorithm. This algorithm considers all features and analyzes where the midpoint is. When it is thought that this assessment is made for a city, it can be said that all data are taken into account and the mean center can be determined as weighted or weightless.

## 4. Application

### 4.1. Study area

Istanbul, a megacity which is located at the intersection point of the Europe and Asia serves as a logistical gateway between these continents. In addition to being a logistical gateway, the city is the most populated and largest metropolitan area in Europe as well. On one hand, the city has a deep historical background, on the other hand, there are very active industrial and trade activities within and the periphery of the city. Because of these attractions, city has over 15 million inhabitants [17] and make the city a huge demand and supply center. Active industrial and touristic activities increase both service needs of inhabitants and manufacturing centers' demand. Consequently, total volumes of the local and international logistics activities are very intense in the region. Additionally, city struggles one of the worst traffic problems in the world, and to overcome this problem any

contribution is needed to be taken into account. Due to this problem, investments continue to expand the transportation network. The current transportation infrastructure is illustrated in Fig. 3. On the other hand, it is known the logistics activities aggravate traffic problem, and logistics centers' positive effects over congestion is identified [15,34,64].

The logistics network structure of Istanbul is an example of the decentralized systems. Each logistics company has to build its logistics network and companies have to operate their own fleet and complete the transshipments by their individual capability. Even the logistics structure is decentralized, the previous study [45] showed that the logistics companies are clustered in some districts. That means even the city management does not regulate logistics companies geographically, the nature of the logistics business environment forces them to be in some regions. Furthermore, city management is expressed that the city is in a need of the logistics zones [11]. This statement makes Istanbul an interesting study area for logistics center studies.

### 4.2. Dataset

According to the methodology two types of data are necessary for the analysis processes. The first data is the judgments of the experts on decision criteria. Logistics questionnaire of Metropolitan Planning Department of Istanbul Greater Municipality (IMP) is used for that data requirement [29]. Survey data represents the opinions and experiences of the stakeholders of Istanbul's transportation and logistics sector. The second data type is geographic data which gives chance to illustrate and analyze geographic patterns of decision criteria. The details of the used data are explained in the following chapters.

#### 4.2.1. Logistics questionnaire

IMP, the planning agency of Istanbul conducted a large questionnaire and a part of this study dedicated for logistics to understand how logistics activities take place in Istanbul. For that aim different aspects of the logistics business covered by the survey such as inventory

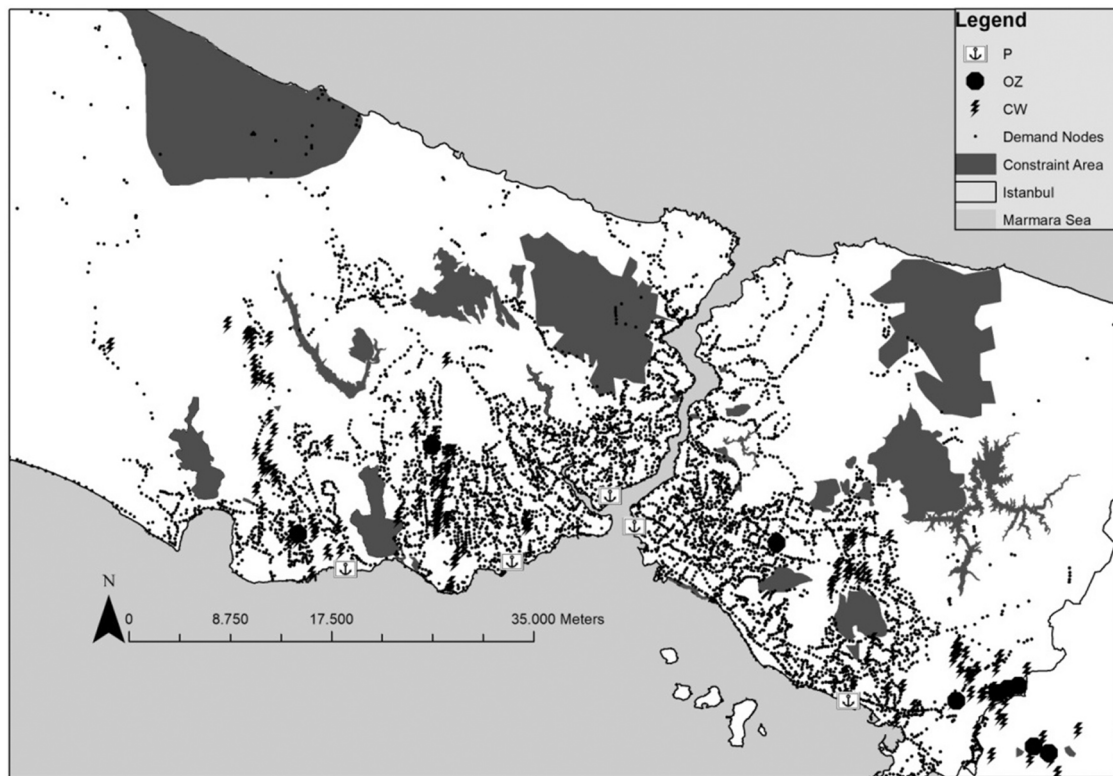


Fig. 4. Demand and supply nodes of the study area.

statistics, expert opinions on several topics, logistics movements, and so on. This survey firstly describes the statistics of logistics equipment inventory in the city. Types and numbers of the equipment, equipment age, and transshipments between the city districts and amounts are analyzed and described to manage the logistics activities in the city.

The questionnaire secondly determines the expert opinions in the logistics field. The related part of this survey to our study is that the survey asks numerous experts how a new logistics center should be located in the city. Furthermore, the survey drew the framework of location selection criteria and results expressed expert thought. Additionally, the expert judgements are described according to their professions in the logistics management environment. The number of the participants for the questionnaire is found as 12592. This value is collected by the local authority for such analysis. These experts answered the survey questions due to their experience in the business field. They represented the general business environment with their answers. The working fields of the participated logistics experts are given as follows:

- Organized Industry Zones (OZ) - 4297,
- Small Industry Sites (IS) - 4135,
- Major gas stations (MS) - 20,
- Ports (P) - 36,
- Shipyards (S) - 124,
- Distribution Centers (DC) - 592,
- Bonded Warehouses (BW) - 231,
- Fresh fruit and vegetables wholesale market hall (FWM) - 1746,
- Road transportation distribution warehouses (RDW) - 68,
- Container warehouses (CW) - 60,
- International transportation firms (IF) - 862,
- Retail Distribution Centers (RC) - 12,
- Manufacturing Distribution Centers (MC) - 76,
- Manufacturing Facilities (M) - 332.

4.2.2. Geographic data

Spatial analysis is used in the study. To carry out this analysis, there is a need for geographical data related to decision criteria of a new logistics center selection. In this context, the collection or creation of relevant geographic data is completed. The logistics environment and its all components such as demand nodes, supply nodes, transportation network and constraint maps are created as geographic data. The transportation network that contains railway, motorway, airway, and railway transportation infrastructures are created, and illustrated in the Fig. 3. The second data type is the demand and supply nodes of the city. Point data type is used for such features. M, OZ, CW and P locations are represented in Fig. 4. GCS\_WGS\_1984 used as coordinate system and D\_WGS\_1984 used as datum for created data. The data sets used in the analysis are 163 points for the warehouse location, 2 for the airport location, 4 for the seaport, and 1.506.896 land use points, which represent the demand points.

Another created data is the constraints of the decision analysis. In the study, forestry lands and fresh water supply areas are taken out of consideration. In addition to the environmental consideration, land uses such as residential area and industrial area are also taken out of consideration. Fig. 4 illustrated the constraints of the study area.

Table 1  
What criteria did effect to your current location decision?.

Criteria	Count	Normalized Value
Insufficient land space	1815	0.169
Located in logistics center?	1705	0.159
Proximity to demand and supply centers	1690	0.158
Infrastructure availability	1562	0.146
Convenience to goods flows	1387	0.129
Affordable facility rents	947	0.088
No other location alternatives for the logistics facility location (Regulation constraint of land use)	570	0.053
Affordable land cost	515	0.048
Proximity to seaports	334	0.031
Others	189	0.018
Total	10714	1

**Table 2**  
What criteria would you consider if you were to move to a new location?.

Criteria	Quantity	Normalized Value
Facility expansion limitation due to the insufficient land	1036	0.1816
Insufficient area	964	0.169
Increment of the rent costs	678	0.1188
Land convenience	555	0.0973
Infrastructure availability	506	0.0887
Land cost	467	0.0819
Inbound flow problems	439	0.077
Decrement of the demand orders due to the firms' locations	430	0.0754
Outbound flow problems	272	0.0477
Being located in the logistics zone	141	0.0247
Being not located in the logistics zone	113	0.0198
Others	104	0.0182
Total	5705	1

4.3. Results of the logistics questionnaire

The article summarizes the responses of 4 questions related to the study of the IMP logistic questionnaire. These questions are given below:

1. According to what criteria did you choose the current plant location?
2. What criteria would you consider if you were to move to a new location?
3. What spatial criteria are important for a new logistics center?
4. What are the criteria weights of a new logistics facility location decision?

**Table 3**  
What spatial criteria are important for a new logistics center?.

Criteria	OZ	IS	BW	FWM	IF
Proximity to the city center	77%	89%	81%	90%	84%
Proximity to main transportation arterial	88%	95%	91%	95%	94%
Proximity to manufacturing sites	87%	91%	74%	59%	75%
Being in a logistics zone	96%	94%	81%	90%	68%

**Table 4**  
What are the criteria weights of a new logistics facility location decision? (According to different professions).

Participant	Criteria	Expertise Area										
		OZ	IS	P	DC	BW	CW	FWM	IF	RDW	MC	M
c1	0098	0100	0096	0106	0087	0080	0099	0085	0073	0115	0090	
c2	0105	0104	0113	0117	0108	0119	0110	0105	0127	0120	0095	
c3	0047	0038	0102	0043	0081	0054	0044	0084	0131	0043	0085	
c4	0035	0032	0077	0028	0050	0044	0036	0054	0061	0041	0048	
c5	0048	0040	0055	0033	0064	0086	0045	0065	0032	0043	0072	
c6	0096	0095	0096	0099	0083	0083	0097	0086	0098	0099	0089	
c7	0113	0118	0102	0104	0113	0110	0106	0102	0085	0106	0101	
c8	0106	0107	0090	0107	0107	0110	0107	0100	0094	0103	0109	
c9	0095	0095	0083	0098	0081	0080	0086	0094	0106	0071	0085	
c10	0063	0069	0048	0063	0057	0041	0070	0055	0036	0060	0057	
c11	0081	0089	0055	0098	0067	0081	0098	0066	0065	0091	0070	
c12	0114	0114	0084	0104	0104	0113	0102	0103	0093	0107	0100	

**Table 5**  
Criteria weights of a new logistics facility location decision.

Criterion	C7	C12	C8	C2	C1	C6	C9	C11	C10	C3	C5	C4
Priority	0112	0111	0106	0106	0098	0095	0093	0085	0065	0047	0046	0036
Used in the GIS Analysis	Not used	Used	Not used	Used	Used	Not used	Not used	Used	Used	Used	Used	Used

The first evaluation question is what criteria was affected for the present logistics facility. Experts were asked whether the various parameters related to this question were effective. The survey participants also expressed their participation in whether the given parameters are effective in the decision of the current facility choice. Table 1 gives what parameters are directed to the experts. The table also gives the rates of influence of the parameters expressed by the experts on location selection. Experts were able to select more effective parameters for evaluation. The number of evaluations completed by this method is 10714. The results obtained were normalized to a total of 1. Priority order and importance ratios of parameters are calculated.

The second question to be answered is what parameters are influential in selecting a new plant site. Regarding this question, the method followed in the first question was followed. The survey results are given in Table 2.

The third question is how the spatial criteria affect the selection of a new logistics center. Experts were asked whether the spatial criteria should be effective. This question has been reported according to different expertise. Responses from OZ, IS, BW, FWM and IF experts show the variation of responses according to different specializations. 10671 experts answered to this question and their participation rates are given in Table 3.

The last question reported in the survey study is which features should be close to a new logistics facility. In this context, twelve features were determined by city logistics management. These are: Accessibility to supply and demand nodes (C<sub>1</sub>), Proximity to highway network (C<sub>2</sub>), Proximity to ports (C<sub>3</sub>), Proximity to railway network (C<sub>4</sub>), Proximity to airports (C<sub>5</sub>), Expansion capabilities of the facilities (C<sub>6</sub>), Geological suitability of the land (earthquake, landslide, etc.) (C<sub>7</sub>), infrastructure availability (C<sub>8</sub>), land cost (C<sub>9</sub>), proximity to the city center (C<sub>10</sub>), accessibility to the city center (C<sub>11</sub>), availability of the

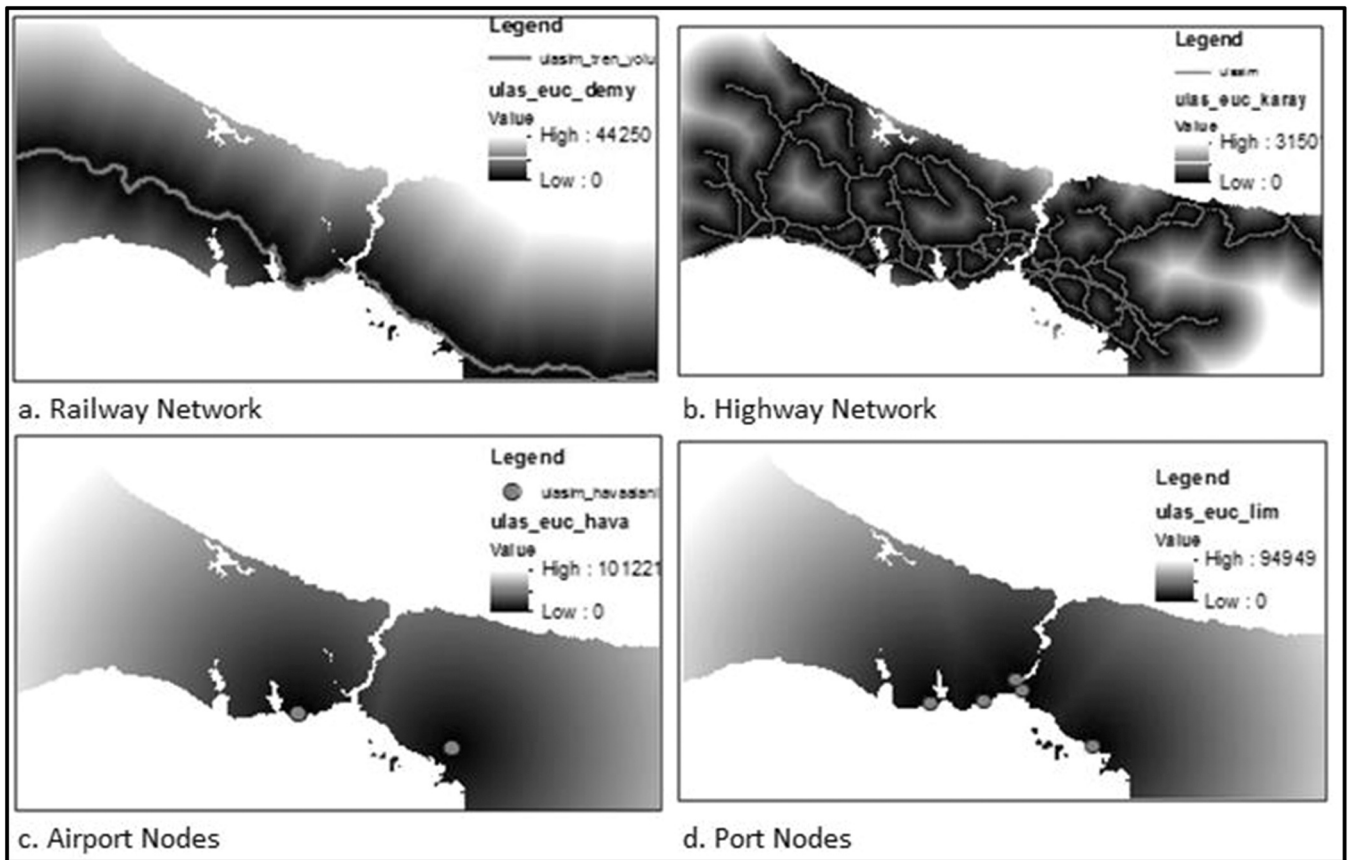


Fig. 5. Distance based transportation criteria maps.

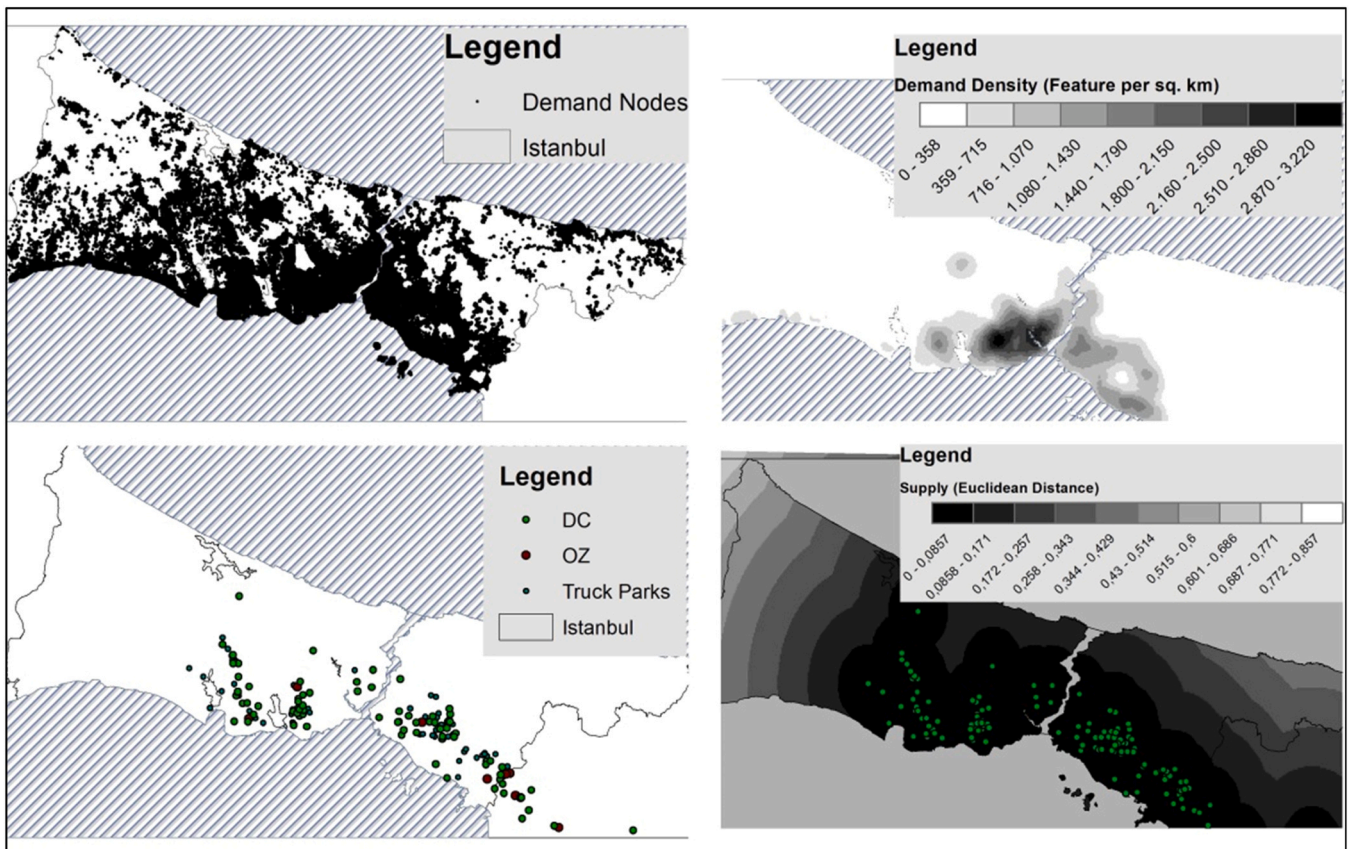


Fig. 6. Demand and supply criteria maps and analysis results.

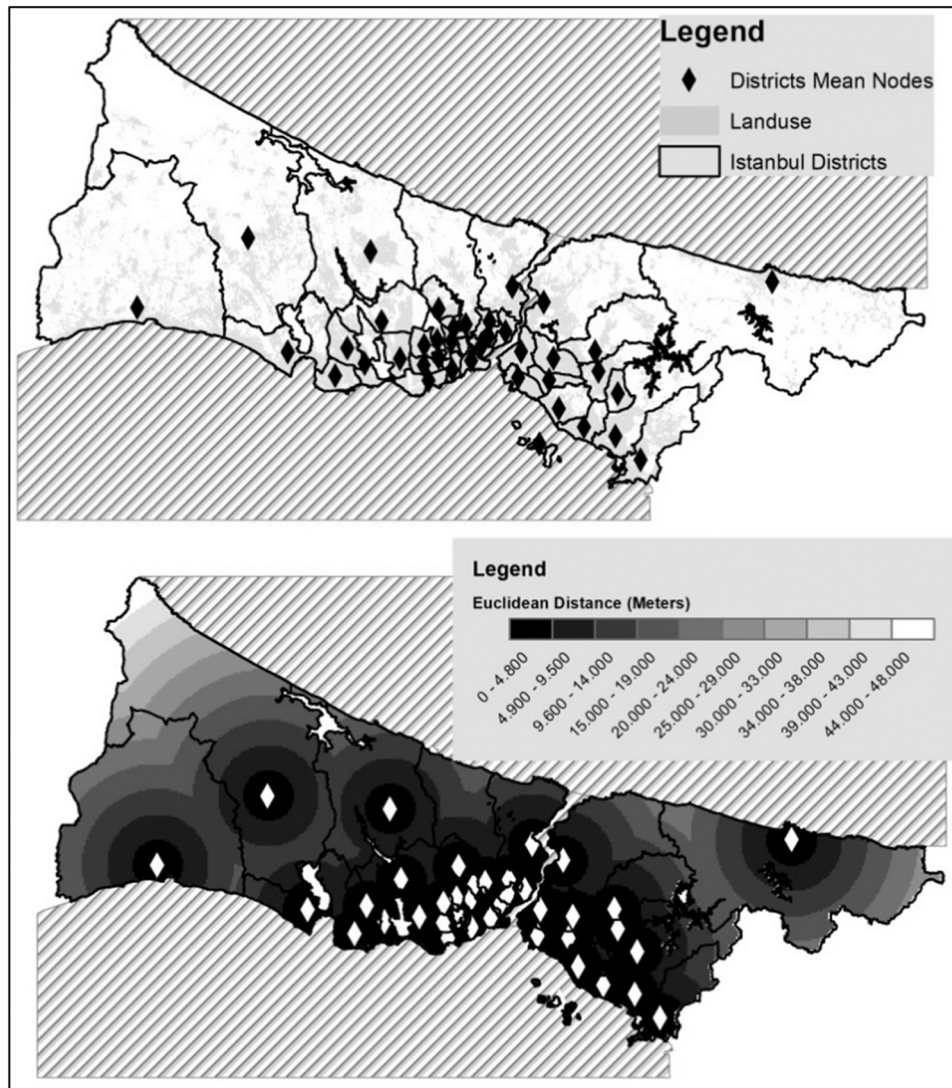


Fig. 7. Proximity to city center criteria map.

personal accessibility ( $C_12$ ). Criterion evaluation was carried out by 12123 experts.

Experts assessed how close they should be to the new logistics facility. However, as a compromise is expected a triple Likert scale was used in the evaluation to force abstaining participants make a decision. This scale offers two polar point along with a neutral option. In the current research expert judgments are linguistically expressed as very important (VI), important (I) and not significant (NS). These linguistic judgments are digitized with VI = 9, I = 5 and NS = 1 coefficients. Linguistic scale values' numeric equivalent and the number of experts expressing that linguistic value in the questionnaire are multiplied. The values obtained are normalized to a total of 1 according to the expertise groups. The obtained values are given in Table 4. The table also reflects how many expert opinions are collected from the different expertise.

All the evaluations were pooled and the criterion weights were evaluated with normalization process. The calculated criteria weights are provided in Table 5. The table also explains if the criteria are used in spatial analysis. In the analyses, some criteria that are discussed in the field study have not taken into consideration. There are different reasons for not being considered. The expansion capabilities of the facilities are excluded. Because a new logistics facility will provide sufficient space for all logistics companies. Geographical suitability is an output determined by the result of this research. The regions to be found at the end of the study will be geographically convenient. The

criterion was not taken into consideration for this reason. Infrastructure availability is considered equal for every region with the reason that the analyzed city is Istanbul. The land cost criterion has been excluded from the scope of the need for the construction activity to be carried out on state subsidies.

#### 4.4. GIS/spatial analysis for determination of the convenient areas

The methodology section explains how to perform GIS/Spatial analysis in the study. The information obtained as a result of the questionnaire survey will be combined with the geographical data and the suitability analysis will be performed. According to expert opinions, various scenarios were determined. And analyzes were repeated according to alternative scenarios. The calculated suitable regions for a new logistics center are expressed in this section.

##### 4.4.1. Criteria maps

In order for spatial analyzes to be carried out, it is first necessary to collect or create the required data. In the data creation stages, the maps related to the criteria determined in the survey study must be created in order to complete the analyses. Since the assessed facility is related to logistics, data items related to supply, demand and transportation network have been prepared for analysis. ESRI's data source is used for railway network; highway network and city borders are provided by

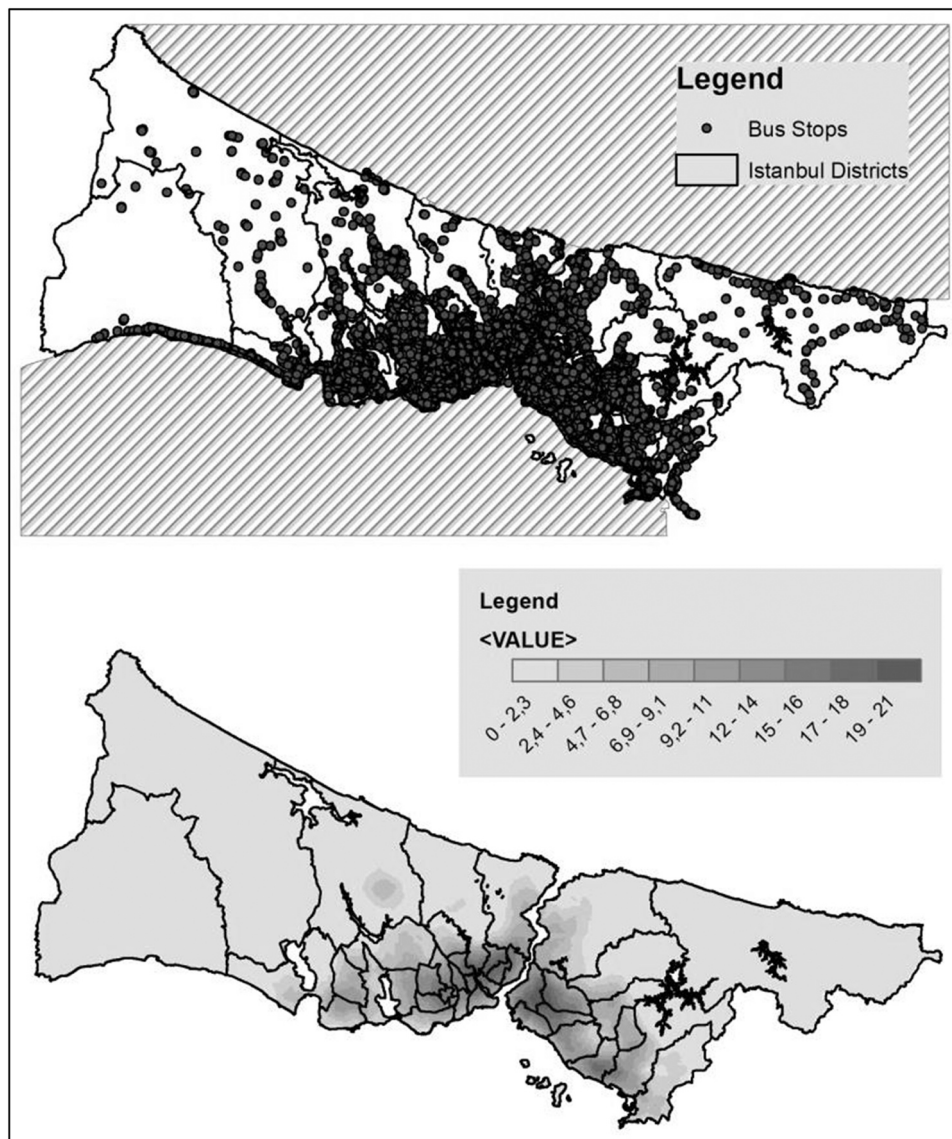


Fig. 8. Personnel accessibility criteria map.

local authority. Other considered geographic data is created by research group. These data are illustrated in Figs. 5 and 6.

The geographic data sets prepared for analysis were evaluated according to the analysis steps expressed in the methodology section. Considering the data, the railway and highway line are in data format. Ports and airports are in point datatype format. Euclidean distance analysis was applied to both features.

Another criterion that needs to be evaluated for logistic center location analysis is supply and demand points. Within this scope, building doors were taken as demand nodes. There are 1506,897 features in this data set. Density analysis was performed on the basis of the high number of features in this data set. Production centers and logistics facilities are taken into account as supply nodes. In this context, 163 features have been analyzed. Euclidean distance analysis was performed with the reason that the number of features is low. Base maps and analysis results are shown in Fig. 6.

Another criterion affecting the logistics center decision is the distance to the city centers. The city land use data has been taken into account for this analysis. Center points according to each district are calculated using the mean center algorithm with ArcGIS. Then, Euclidean distance analysis performed according to the center point

obtained. As a result of the analysis, the distance map is obtained and illustrated the results in Fig. 7.

In the survey study, it was found that personnel access to the company was an important criterion. The distance to the bus stops was taken as a criterion for access. Istanbul has a complex network of buses. Therefore, 12136 stops have been taken into consideration. Point density analysis is preferred due to there are a vast number of point data in the study area. The input data and the results are illustrated in Fig. 8.

#### 4.4.2. Spatial suitability analysis

Criterion maps were created to complete the geographic suitability analysis. In order to obtain the results of the geographical suitability analysis, the overlay analysis should be run as stated in the methodology. The overlay analysis is expressed as a weighted overlay analysis as it creates the suitability map with the criterial weights. The weights of the decision criteria come from the results of the logistics survey. In the survey study, experts were asked about different logistics questions and more than one result was obtained. For this reason, multiple scenarios and suitability values were analyzed to see different results spatially. In this respect it was possible to observe changes in suitability values according to different expertise judgements.

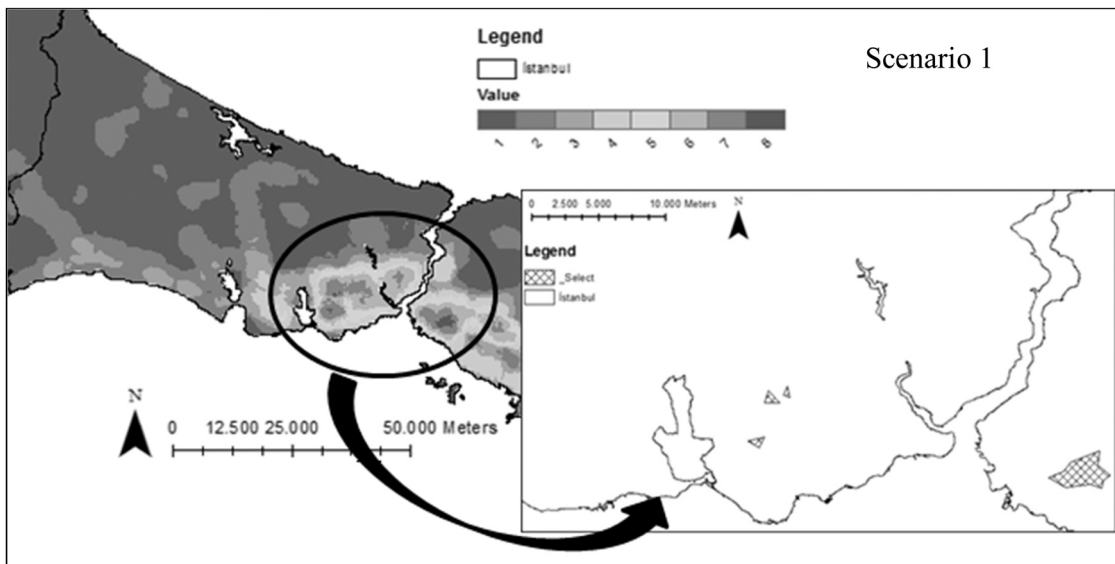


Fig. 9. Illustration of the land suitability values of the Scenario I.

- Scenario 1: Spatial suitability of a new logistics center based on solely spatial criteria

In the survey, there is a question about the spatial suitability of a new logistics center. Table 3 gives the evaluated criteria list by the survey question and summarizes the related results. This question gives the weight of the spatial criteria evaluated for a new logistic center in the study area. The scenario was primarily designed to calculate the spatial suitability of these results.

As can be seen in Tables 3 and 4 spatial features are taken into account. Being in a logistics center is not considered in this analysis. Remaining criteria which are distance to city centers, distance to transportation network and distance to production centers are considered with the weights of 0.31, 0.33, 0.34. These coefficients used with together criteria maps in the weighted overlay analysis. For the

analysis geographic analysis model and GIS toolbox is created and the result of the analysis is illustrated in the Fig. 9. Obtained suitability values are from 1 to 8 where 1 expressed the most suitable regions for the new logistics center. Level 1 suitable region is also shown in the Fig. 9.

- Scenario 2: What is the final suitability for a new logistics center

The Table 5 expresses the weights of location selection criteria with all profession’s judgements. The second scenario is devoted to understanding how the suitability values can be obtained if the average values is considered. For that reason, all considered criteria maps used as input maps and calculated the suitability values expressed in the Fig. 10. As a result, 5 suitability levels are found and the first and second levels are also given in the same figure.

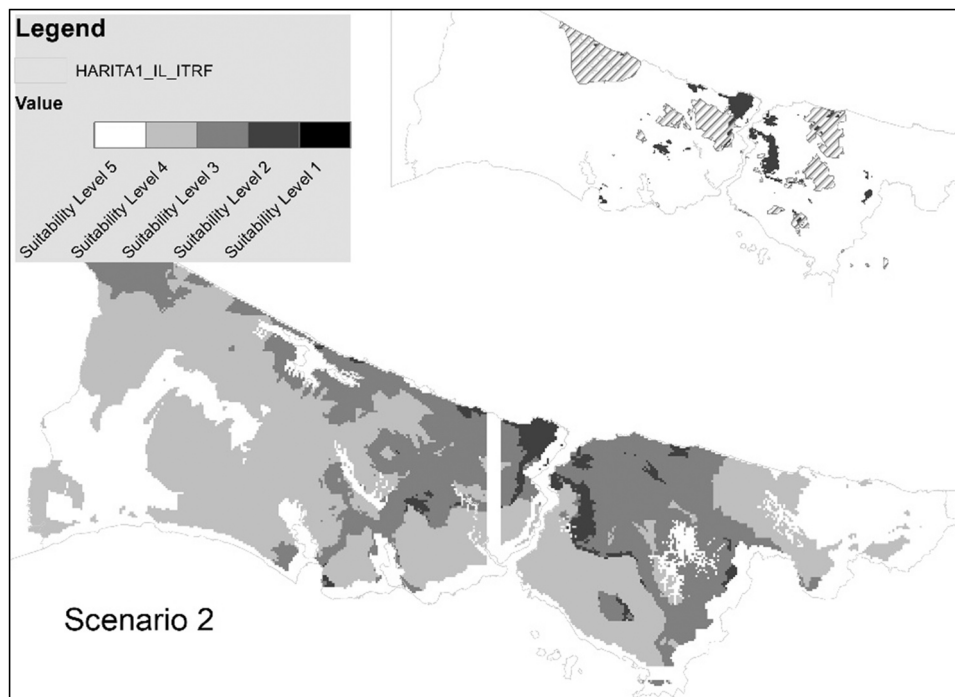


Fig. 10. Illustration of the land suitability values of the Scenario 2.

**Table 6**  
Scenario 2–5 criteria weights based on stakeholders’ groups.

Decision Makers	Scenario 2 - OZ	Scenario 3 - BW	Scenario 4 - IF	Scenario 5 - IS
Participant / Criteria	4297	231	862	4135
c1	0098	0087	0085	0100
c2	0105	0108	0105	0104
c3	0047	0081	0084	0038
c4	0035	0050	0054	0032
c5	0048	0064	0065	0040
c10	0063	0057	0055	0069
c11	0081	0067	0066	0089
c12	0114	0104	0103	0114

- Scenarios 3–6: Spatial convenience for a new logistics center based on different professions

Table 6 is a secondary table created based on expert judgements expressed in Table 4. It summarizes the priorities of location selection criteria for a new logistics facility. These scenarios extended the analysis carried out in the Scenario 2 and expressed the different profession’s point of view. Four professions are selected due to their dense use of logistics network. The results expressed in Table 6 presents there is a significant difference in the answers, which is why considering different expertise evaluations is important.

In Table 6, the results were grouped by the stakeholders’ clusters. Scenarios 2, 3, 4 and 5 are focused to create suitability maps based on each expertise. The result maps are given in the Fig. 11. Eight preference levels for calculated suitability map are found in the study area.

- Final Suitability Calculation

According to explained in methodology section, the final suitability regions have calculated. Intersection tool used to determine final suitability map with the results of Scenarios 2–5. The most suitable areas of these scenarios taken into consideration and intersection gave the final suitability. The calculated suitability classes illustrated in Fig. 11. After finding the suitable areas, constraint maps have erased from those regions and Fig. 12 is found suitable for the facility.

### 5. Results and discussion

The findings of the study can be grouped in two categories. The first is the findings gathered from the logistics questionnaire survey. In this field survey 12592 expert opinions were collected and a database was generated. Thanks to wide participation, the views of different specialties can be measured. This has shown the mindset of experts in a complex metropolis about the location of logistics facilities.

According to revealed results experts expressed that they want their facilities to be close to city centers, demand nodes and supply nodes. It is also found that experts consider space constraints and land suitability crucially for a new facility. Logistics centers are able to provide solution for such problems.

In the current study, judgements of the experts have been calculated to represent a consensus on the mean of the numeric values. According to results, suitability, personnel accessibility, infrastructure availability, accessibility to demand and supply nodes, expansion capabilities are found as the five important criteria in a sequence.

Experts also have expressed their sentiments regarding some problems. Some of the found problems which are bureaucracy, time constraints for transportation vehicles, regulation, technical infrastructure are caused due to lack of organization and insufficient communication between logistics sector and city management,

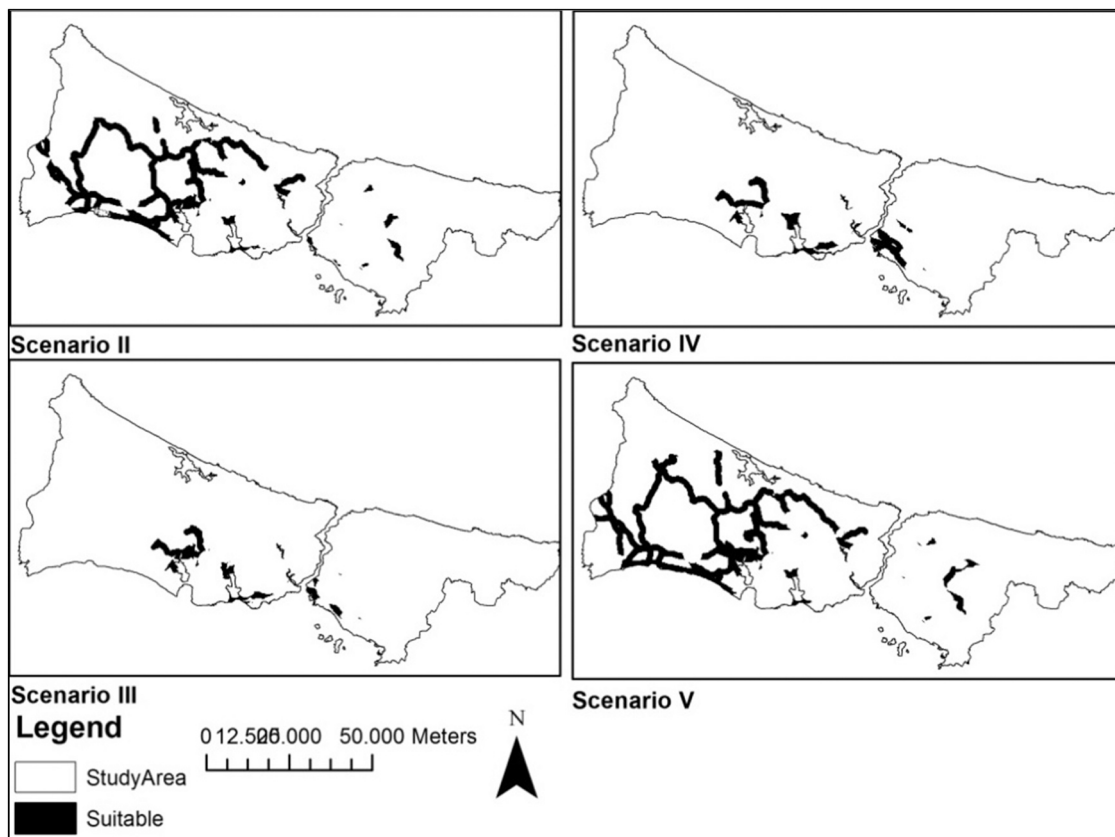


Fig. 11. Suitability results of the Scenario 3–6.

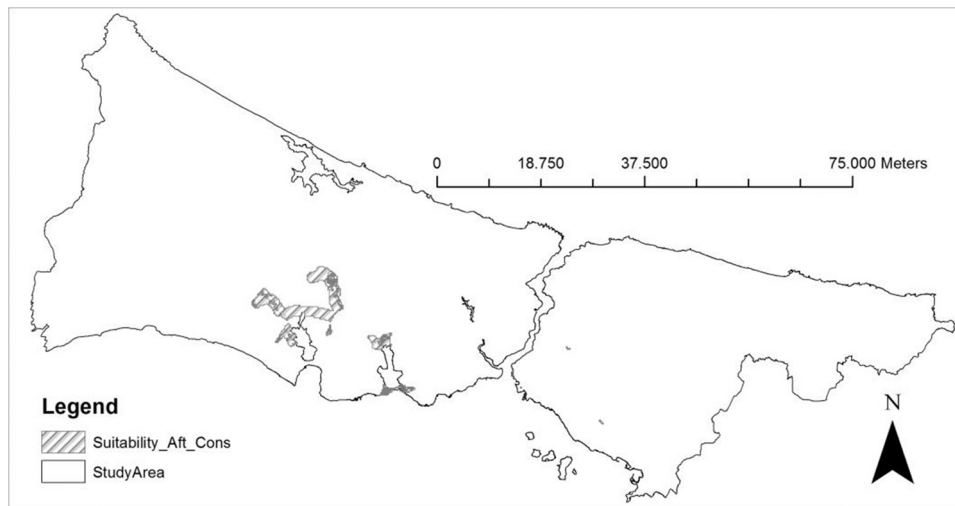


Fig. 12. Calculated suitable areas for the logistics center.

These findings are critical to discuss the location of a new logistics center. In the existing studies represented the limited number of experts' opinions. This situation can be seen as a problem due to differences between thoughts. For overcoming that subjectivity, including as much as experts who really have experience in the field is a necessity.

The second category is gathered from the suitability analysis based on the created scenarios. The GIS/spatial analysis is capable of determining the suitability levels for an urban area for a logistics center location selection problem, and scenario results successfully are mapped based on experts' judgments over decision criteria. Different regions can be clustered in the same preference levels and the most convenient areas can be found spatially distributed. This finding shows a difference from multi-criteria decision-making approaches which mostly reaches a best alternative in an alternative set. With another words, a limited alternative set might not be able to represent the whole decision alternative set. Thus, considering the continuous plane set will give better results compared to a limited set of discrete decision alternatives.

## 6. Conclusion

### 6.1. Implications and contributions

In this study, a case study application is performed for a location analysis of logistic center decision in Istanbul. The findings from spatial evaluation model showed that different professions' expectations deviate from each other, and the spatial convenient areas might be found in different areas based on the stakeholders' judgments. Thus, it can be said that it is required to work with professionals in different positions to represent different aspects of the decision environment. The high number of experts participating in the survey study provides an important contribution in terms of literature. In other studies, studies with a limited number of expert opinions pointed to important findings. The number of participants in this study was able to reflect the opinion of almost all experts in the region for a strategic decision such as a logistics center. Another contribution of the study is that these expert opinions are combined with spatial criteria. The survey results are important within this context and the findings led us to reach spatial convenient areas. In the future studies, other metropolitan areas' survey results, the differences of experts' thoughts, spatial regions and mapping result can be compared with this study. The comparisons might provide better evaluation of different logistics systems.

Another contribution of the work is that it shows how spatial appropriateness can be calculated on a plane. At this point, possible locations were determined by digitizing the parameters affecting the

location selection, and then those locations were weighted based on experts' opinions regarding the logistics center location. So, by performing this process, the survey data has been converted input into numerical values, and the formation of criterion maps is discussed by the method of digitization of expert opinions. It has been determined that this method can also provide a solution to the problem.

### 6.2. Limitations and future directions

This study has examined the location analysis of the logistic center decision in Istanbul according to a proposed methodology. Because the study has been focused on a particular city, similar results may not be obtained even in metropolitan cities of the same size. However, in future studies, the authors recommend that the methods of the current study can be performed by using the specific parameters of each city.

Additionally, this study can be considered as a judgmental study based on gathered data from logistics experts. Therefore, although their opinions were requested in the context of the whole city, their assumptions about their field of duty may have created bias in their answers to the questionnaire. Thus, in future studies, the authors recommend that the results can be provided or integrated with secondary data.

### Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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