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GIS and *f*-AHP Integration for Locating a New Textile Manufacturing Facility

DOI: 10.5604/12303666.1161751

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Abstract
Location analysis for a textile manufacturing facility is a strategic decision due to its long-term effects on profitability, accessibility, and sustainability. Thus an analysis should be made using a comprehensive approach. The facility location selection problem can be represented with a multi-criteria structure. This study considered locating a new manufacturing facility and accepted seven decision criteria as decision parameters. Istanbul was the study area, and seven candidate locations were considered to start a new manufacturing facility. During the evaluation process, Geographic Information Systems and the fuzzy analytic hierarchy process were combined to order the preference levels of candidate areas. A novel methodology for the textile industry is proposed to integrate experts' thoughts and geographic information.

Key words: *textile facility selection, location analysis, geographic information systems (GIS), fuzzy analytic hierarchy process (f-AHP).*

Introduction

Planning and setting up a new facility is a strategic decision due to its long-term effects on sustainability, accessibility and profitability. Therefore inaccurate location decisions may cause irrecoverable outcomes for any industry in today's competitive world. On the other hand, determining the convenient areas is based on using suitable decision tools and representing the decision environment properly.

To avoid long-term negative effects, a holistic approach that integrates multiple analytical tools can be used. This approach considers first the experiences of experts in location selection to represent the decision environment. However, the location selection decision should not be given solely based on the experts' thoughts. Different solution approaches are discussed in the existing literature, and multi-criteria decision-making techniques are frequently used for a wide range of location selection problems [1 - 3] due to their calculation capability. Multi-criteria analyses are able to convert experts' thoughts to numerical values with linguistic scales and they can be integrated with fuzzy logic. Having a very large variety usage area and ability of integration with different decision analysis tools, multi-criteria approaches can offer important solutions for facility setup and planning problems as well.

GIS, on the other hand, is able to capture, store, manipulate, manage and, most importantly, analyze geographic data. Due to its analyzing capability, GIS is used to solve location selection problems. The GIS approach is also integrated with multi-criteria methods and widely used for location problems [4]. Various location problems can be solved using these integrated methods, such as hospital location selection [5, 6], energy related facility location problems [7, 8], waste related problems [9], and the like. The number of problem areas applied can be increased easily. However, the locations of any textile manufacturing facilities have not been investigated with GIS/spatial analysis and multi-criteria integration methods. Due to this gap in the literature, a multi-criteria spatial approach for a plant location can be seen as an interesting research area for the textile industry. The results can create benefits for any textile manufacturer that is considering locating a new facility.

The following section describes details of the proper analysis, in which the methodology is explained. After that, the next section is devoted to the application, in which the attributes of the decision environment and evaluation process are given. Subsequently the results are summarized. The discussion section reviews the contributions of the methodology. In the concluding chapter, the outputs of the holistic approach, contributions to the existing literature, and possible benefits for private sectors are summarized.

Methodology

To locate a new textile manufacturing facility, a multi-step evaluation methodology is discussed. Before the mathematical calculations, the decision makers who have enough experience in the textile industry should be selected to determine location alternatives for the investment decision. The Delphi technique can adequately represent the experiences of the experts during this step.

After determining the decision alternatives, the evaluation process can begin using the step-wise process. The first step involves determination of the decision criteria to represent the decision-environment. Decision makers should determine the decision criteria for the analysis. After determining the decision criteria, *f*-AHP will compare the decision criteria with each other to prioritize and compare the alternatives with the priority values calculated to finalize the location selection process. Based on this structure, pair-wise comparisons for evaluations of the decision criteria are conducted based on experts' judgments, which are important due to the unique problem environment. Alternative location comparisons are conducted with certain geographic information based on the outputs of the GIS analyses. The *f*-AHP approach combines these two judgments to calculate the preference orders of the location alternatives.

GIS/spatial analysis is proposed for converting geographic data to certain geographic information. GIS analyses are able to measure distances, densities, or the continuous plane's statistical structure. To be able to create useful

Table 1. *Triangular fuzzy scale for F-AHP analysis [13].*

Eq	Equally important	1	1	3
Wk	Slightly important	1	3	5
Es	Essentially important	3	5	7
Vs	Very strongly important	5	7	9
	Extremely important	7	9	9
1/Eq		0.33	1	1
1/Wk		0.2	0.33	1
1/Es		0.14	0.2	0.33
1/vs		0.11	0.14	0.2
1/Ab		0.11	0.11	0.14

geographic information, necessary geographic data should be created or gathered from data sources, and a geodb that keeps these geodata should be created to constitute a proper environment to perform the spatial analysis suggested. The euclidean distance analysis is suggested to measure the dispersion of the decision criteria on the surface of the study area. Hence euclidean-based analysis results can be used to measure suitability levels of the decision criteria (more detail, see: [10]). GIS is a useful tool for location analysis; however, due to uncertainty during the startup of a new textile manufacturing facility, the experiences of experts are valuable. Thus, *f*-AHP is accepted as the evaluation and decision-making technique, which should be used first to determine the importance of the decision criteria. Subsequently with the integration of the results of the GIS analyses, *f*-AHP will be used to finalize the location decision. The linguistic fuzzy scale expressed in ***Table 1*** should be used for comparisons by experts. Buckley's *f*-AHP approach would be a good suggestion for these types of analysis [11], being an extension of the crisp AHP technique proposed by Saaty [12].

The following chapter describes the selection process based on the methodology expressed using an actual case study example.

Application

The study focuses on selecting a proper site for a new textile manufacturing problem, and Anatolian Region of the Istanbul is selected as the study area. Istanbul has the highest population volume in Europe, and in addition to the population density, its economic potential made it a desirable city for any sector. Due to the mentioned causes, the city was selected as the study area, and proposed methodology was applied for the textile sector.

In the first step of the study, four experts were selected due to their knowledge of the problem environment. The first decision maker (DM) is a business analyst who is familiar with the location selection issues and has experience in locating new facilities. The second expert is an owner of an international textile manufacturing firm that produces known firms' goods under contract. The third expert is the process development and marketing manager of a multi-national fast fashion textile firm. The last expert is the general manager of a textile factory that produces a wide range of products.

The primary question about the location analysis was: 'What decision criteria affect a new textile manufacturing decision?' The experts in this study used the Delphi approach to answer these questions. As a result of the Delphi study, transportation abilities (highway (c1), airport (c7), seaport (c3), railway (c4)), distances to demand nodes (malls (c5), retail (c6)) and supplier (c2) nodes were accepted as geographic decision criteria located as close as possible. A geographic representation of the decision criteria is illustrated in ***Figure 1***.

The secondary question was: 'How do the decision criteria affect the decision environment in the study?', and the answer was found with pair-wise comparisons of the *f*-AHP analysis. The experts conducted pair-wise comparisons of the decision criteria with *f*-AHP and linguistic comparisons, as shown in ***Appendix I.*** The converted fuzzy triangular values of these comparisons are given in ***Appendix II*** (see page 21).

GIS/spatial analysis was used to determine the sprawling of the decision

Table 2. *Weights of the criteria.*

	Fuzzy value	Defuzzied and normalised value
w1	(0.093, 0.204, 0.461)	0.203
w2	(0.086, 0.203, 0.466)	0.203
w3	(0.026, 0.057, 0.154)	0.062
w4	(0.019, 0.036, 0.091)	0.038
w5	(0.094, 0.208, 0.5)	0.214
w6	(0.094, 0.234, 0.489)	0.222
w7	(0.024, 0.058, 0.131)	0.058

parameters and at the same time with the judgments of the decision makers, Euclidean distance analyses were performed multiple times for each criterion, and the results of the euclidean distance were reclassified with Jenk's natural break rule [15]. The seven distance maps created are illustrated in ***Appendix III*** (see page 22), where value 1 shows the closest area to the considered criteria and value 9 shows the most distant area. Interval values express the other distance values based on the expressed scale.

With Jenk's classification approach, the distance maps were reclassified for integration of the *f*-AHP. The preference orders according to the distance maps were converted to the fuzzy scale. These numbers were used in pair-wise comparisons of the *f*-AHP analysis to reach the final preference orders with the criteria weights based on decision makers' comparisons. The comparisons of the experts are given in ***Appendix I*** and final fuzzy comparisons are given in ***Appendix II***.

The priorities of the decision criteria, alternatively the fuzzy weights of the criteria [...], were calculated and defuzzied using Liou and Wang's [16] total integral method, the results of which are summarised in ***Table 2.***

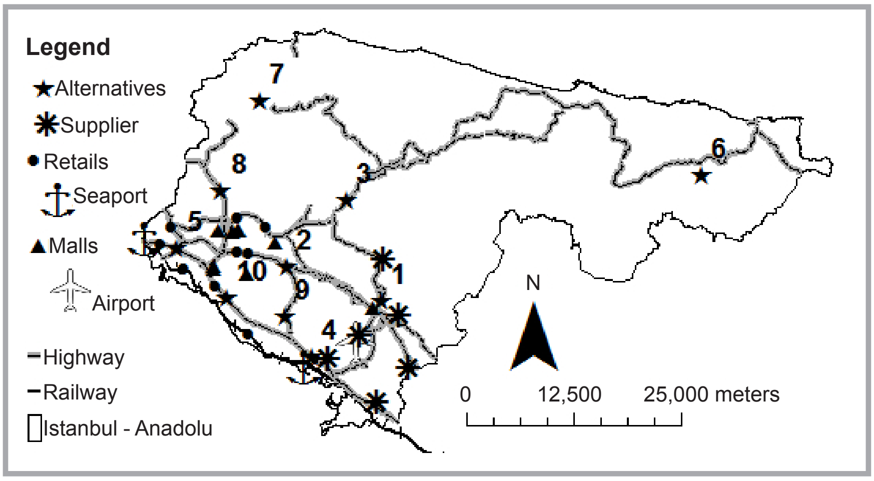

Figure 1. *Study area and geographic decision criteria.*

Table 3. *GIS analysis scores of the criteria.*

	c1	c2	c3	c4	c5	c6	c7
A1	1	2	2	3	6	2	2
A2	2	4	3	3	3	4	4
A3	1	3	4	5	4	3	5
A4	1	1	1	1	6	1	2
A5	1	9	1	1	1	9	7
A6	3	7	5	8	9	7	8
A7	1	8	4	6	5	8	9
A8	2	8	2	3	2	8	7
A9	1	3	2	2	3	3	3
A10	1	5	2	1	2	5	5

Table 4. *Calculated criteria weights gathered from GIS analysis.*

	A1	A2	A3	A4	A5	A6	A7
c1	0.12	0.27	0.11	0.08	0.04	0.25	0.23
c2	0.07	0.10	0.07	0.08	0.11	0.09	0.11
c3	0.12	0.15	0.04	0.04	0.07	0.13	0.08
c4	0.12	0.20	0.19	0.19	0.03	0.25	0.23
c5	0.12	0.02	0.19	0.19	0.24	0.02	0.03
c6	0.04	0.03	0.03	0.01	0.01	0.03	0.02
c7	0.07	0.02	0.04	0.03	0.07	0.02	0.02
c8	0.07	0.02	0.11	0.08	0.16	0.02	0.03
c9	0.12	0.13	0.11	0.15	0.11	0.13	0.17
c10	0.12	0.07	0.11	0.16	0.17	0.06	0.08

Table 5. *Preference orders of the alternatives.*

Alternative number	wi	Order
A4	0.18	1
A1	0.17	2
A9	0.13	3
A5	0.11	4
A10	0.10	5
A2	0.09	6
A3	0.09	7
A8	0.06	8
A7	0.03	9
A6	0.03	10

The spatial preference levels of the alternatives (A) are given in ***Table 3*** based on the analysis illustrated in ***Appendix III***. ***Table 3*** shows calculated values that represent the suitability levels of the alternatives in the criteria maps.

Using ***Equation 1*** below, the criteria scores calculated were first converted to pair-wise comparisons (x_{ij}) based on the values of Alternative weights (Aw_i). Then a comparison table was formed based on these comparisons.

$$x_{ij} = Aw_i - Aw_j + 1 \quad (1)$$

After fuzzification, GIS analysis weights are calculated, with weights () given in ***Table 4***. Buckley's method was used to determine the decision makers' thoughts [11], and defuzzification was done based on Liou and Wang's [16] approach.

The *f*-AHP method was used to finalise the selection of the manufacturing site. Both experts' judgment of decision criteria (***Appendix I***) and GIS comparisons based on the criteria maps calculated (***Table 4***) were integrated and a final decision made based on this integration. The results of the analysis and the preference orders are given in ***Table 5***.

The results indicated alternative preference orders, and, as seen in ***Table 5,*** the fourth alterative appears to be the best alternative investment decision.

The *f*-AHP method was used to evaluate the effects of the decision criteria, and retailers, malls, highways and suppliers were found to be important decision criteria, respectively, in order of their weights. The results of the comparison (***Appendix II***) showed that each decision criterion has a different effect on the location decision. According to the *f*-AHP results (***Table 2***), retail stores are the most important criterion, followed by malls, highways, suppliers, seaports, airports and the railway network, respectively, according to their weights.

Spatial analysis was performed to measure distance maps of the decision criteria. These maps were used to define alternative preferable locations, and the values reached were converted to fuzzy pairwise comparisons. The preference levels calculated by GIS/spatial analysis and weights of the decision criteria were integrated with *f*-AHP, with which the final preference order of the decision alternatives were determined. According to this calculation, alternative 4 was found to be the best one. Alternative 1 was found to be the second best, followed by alternative 9.

Discussion

The study has shown that the textile location has different aspects, and the location decision can be given with an interdisciplinary methodology that integrates different professions. On the other hand, it has been found that different decision criteria have an effect on the decision with different priority values. Thus as each decision environment is unique, the criteria weights should be evaluated or a decision should not be given based on cost minimization or distance minimization, both of which have been the focus of many studies.

In the literature, different applications use multi-criteria spatial methods because of the analytical abilities of both multi-criteria approaches and GIS for location selection problems [17 - 19]. Despite the existing studies that use spatial approaches to identify location problems, the textile industry has not taken advantage of the analytical capabilities of spatial decision-making. The study showed that the approach proposed has the capability to represent the spatial environment of the decision criteria and to order the preferences of the decision alternatives in textile industry location problems.

The results were shared with the textile manufacturer. The manufacturer commented that the methodology could be used not only in strategic location decisions, such as a textile manufacturing facility, but also in tactical decisions, such as locating retail stores. The methodology and necessary modifications are discussed with the decision makers and used for retail store location, which has been done before using similar approaches.

The approach proposed is suitable for single location evaluation. For multiple facility consideration, a new step in the methodology should be created to represent the changed decision environment after siting the first facility.

Ten alternative evaluations emerged, and the *f*-AHP was capable and consistent during the calculations. However, when considering high numbers of candidates, *f*-AHP may be insufficient. With a large number of alternatives needed to be considered, land suitability approaches can be used to solve the problem (see:[10]). Land suitability maps also integrate the multi-criteria approaches and GIS for location problems. Moreover after criteria considerations, GIS reaches the preference orders of the decision alternatives.

Conclusions

A multi criteria spatial approach was used to evaluate location alternatives to establish a new textile manufacturing facility. To select the best location alternative, a multi-step selection process is used. First, experts who have experience related to the study area were identified. who then expressed the decision environment using the Delphi method. The decision criteria's weights were calculated with pair-wise comparisons. The GIS/spatial analysis approach was used to evaluate the alternatives' preference levels for the study area for each decision criteria. GIS results calculated and experts' comparisons were combined with the *f*-AHP, and the best location alternative was reached with the integrate methodology.

In the study, ten location alternatives were evaluated to make a single facility decision. In the calculation of the convenience of the alternatives, seven decision criteria were used. The fourth alternative was found to be the most acceptable location. The second best location was A1, followed by A9. However, the decision criteria map of performance cannot explain these ranks. Their rankings were found through integration of both the weights of the criteria and preference levels gathered with distance maps.

The calculations determined the priorities of the seven decision criteria. As a result of the proximity to customers, retailers and malls are the most important decision criteria, with a weight of 0.222 and 0.214. Proximities to a highway network and supplier nodes emerged as other important criteria, with a weight of 0.203. The weights of the other decision criteria, although not as important as the first four decision criteria, still had impacts on the decision environment with the following priority weights: seaport 0.062, airport 0.058, and railway 0.038.

The approach presented in this paper is novel, since no existing studies have used spatial decision-making alternatives to determine a new textile facility location. Additionally the use of geographic information and the conversion thereof to judgments in the *f*-AHP contribute to the decision-making literature, and the approach can be applied to other location problem types. Lastly the paper identified the criteria that affect the localisation of a new manufacturing facility as well as priorities of the decision criteria under linguistic scales and the fuzzy environment.

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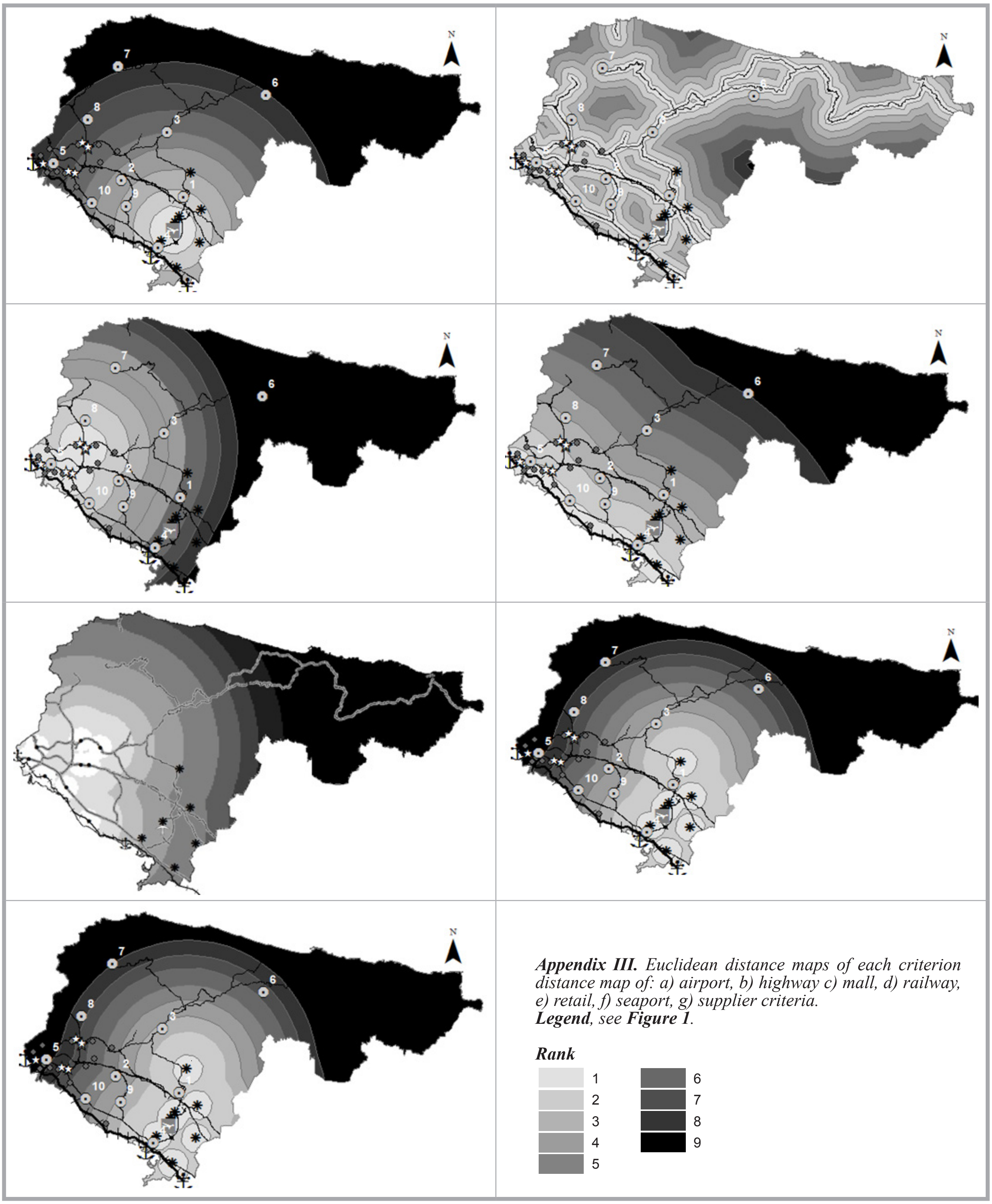
Appendix I. *DM judgments of decision criteria.*

	DM1							DM2							DM3							DM4						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7
C1	-	1/Es	Wk	Wk	1/Es	1/Es	Wk	-	Eq	Es	Vs	Es	Es	Es	-	1/Es	Vs	Ab	Es	Es	Vs	-	Es	Es	Vs	1/Es	1/Es	Eq
C2		-	Es	Es	Wk	1/Eq	Wk		-	Es	Es	Eq	Eq	Wk		-	Es	Vs	Es	Es	Vs		-	Eq	Wk	1/Es	1/Es	1/Es
C3			-	1/Eq	1/Wk	1/Wk	Wk			-	Eq	1/Wk	1/Wk	Eq			-	Es	1/Es	1/Es	Eq			-	Es	1/Es	1/Es	1/Es
C4				-	1/Es	1/Es	Eq				-	1/Es	1/Es	Eq				-	1/Ab	1/Ab	Eq				-	1/Es	1/Es	1/Es
C5					-	1/Wk	Vs					-	Eq	Es					-	Eq	Es					-	Eq	Es
C6						-	Vs						-	Es						-	Es						-	Es
C7							-							-							-							-

Appendix II. *Pairwise comparison matrices of the seven geographic criteria.*

	C1	C2	C3	C4	C5	C6	C7
C1	(1, 1, 1)	(0.492, 0.669, 1.230)	(2.590, 4.787, 6.853)	(3.637, 6.031, 7.770)	(0.648, 1.000, 1.52)	(0.648, 1.000, 1.520)	(1.968, 3.201, 5.544)
C2	(0.813, 1.495, 2.031)	(1, 1, 1)	(2.280, 3.344, 5.664)	(2.59, 4.787, 6.853)	(0.805, 1.316, 2.426)	(0.610, 1.000, 1.622)	(0.915, 1.884, 2.935)
C3	(0.146, 0.209, 0.386)	(0.177, 0.299, 0.439)	(1, 1, 1)	(0.313, 2.236, 3.482)	(0.167, 0.257, 0.574)	(0.167, 0.257, 0.574)	(0.612, 0.880, 1.963)
C4	(0.129, 0.166, 0.275)	(0.146, 0.209, 0.386)	(0.287, 0.447, 0.762)	(1, 1, 1)	(0.132, 0.172, 0.266)	(0.132, 0.172, 0.266)	(0.612, 0.669, 1.728)
C5	(0.658, 1.000, 1.543)	(0.412, 0.760, 1.242)	(1.741, 3.892, 5.976)	(3,755, 5,806, 7.587)	(1, 1, 1)	(0.669, 0.758, 2.280)	(3.409, 5.439, 7.454)
C6	(0.658, 1.000, 1.543)	(0.616, 1.000, 1.639)	(1.741, 3.892, 5.976)	(3.755, 5.806, 7.587)	(0.439, 1.319, 1.495)	(1, 1, 1)	(3.409, 5.439, 7.454)
C7	(0.180, 0.312, 0.508)	(0.341, 0.531, 1.093)	(0.509, 1.136, 1.635)	(0.579, 1.495, 1.635)	(0.134, 0.184, 0.293)	(0.134, 0.184, 0.293)	(1, 1, 1)



Appendix III. *Euclidean distance maps of each criterion distance map of: a) airport, b) highway c) mall, d) railway, e) retail, f) seaport, g) supplier criteria.*
Legend*, see* ***Figure 1****.*

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Received 11.03.2015 Reviewed 23.03.2015