Smart Last Mile Delivery Solution Selection for Cities

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***Abstract*—City logistics is a field, which can affect the residents' quality of life directly, refers to the optimization of logistics and transport activities while supporting economic and social development of the city. "Last mile delivery" is the micro-level logistic operations in city logistics. It is directly related to the e-commerce activities of city residents so; it continues to grow as a consequence of new technologies. This study focuses on the smart technology selection subject for last mile delivery solutions in order to augment its efficiency for companies and customers. The selection is approached as a multi-criteria decision-making (MCDM) process. First, a SWOT analysis is conducted to obtain an in-depth evaluation of last mile delivery from a smart city perspective. Then this evaluation is used to generate criteria to select the most suitable smart last mile delivery solution. The 2-Tuple integrated DEMATEL-VIKOR methodology is applied for Istanbul, and the results are provided for this application.**

***Index Terms*— 2-Tuple Linguistic, Last mile delivery, Multi-Criteria Decision Making (MCDM), Smart Logistics, Technology selection**

I. Introduction

CITY logistics; being influenced by Industry 4.0, the internet of things (IoT), artificial intelligence and wearable technologies, is trying to exist in the supply chain of the future. The constraints that directly affect customer satisfaction such as delivery in a short time and delivery at the right time have become more challenging. In the face of such a situation, the last step in urban transport, which is the last mile delivery, has particular importance in city planning. Last mile delivery, is the final stage of the delivery process, from the delivery center or the factory to the end user [1]. With the considerable growth of e-commerce in the market, the presence of last mile delivery in a supply chain becomes essential. The growth in technology also influences the last mile delivery unfavorably [2]. E-commerce is expanding due to the technology, and it challenges the last mile delivery with narrow timeframes and dense urban areas [2]. Furthermore, this urban density shows that a larger quantity of goods will be forecasted to be delivered in the near future [3].To be able to handle this expansion in good-flow, innovative solutions such as collaborative urban logistics, optimization in routing, proximity stations, and innovative vehicles are generated to optimize last mile delivery which is the least profitable stage of the supply chain [3].

Motivated by these innovative solution proposals and the challenging situation of last mile delivery, this study focuses on proposing a methodology to select the most suitable smart solution for the last mile delivery in cities. This study wanted to be evaluated around the notion "smart" because of the fact that the cities in the future are expected to be use and adapt to developing technologies. While being concerned with the future of the cities, its clearly relevant to focus on the smart technological applications

In the literature, still, it is not clear that last mile delivery covers business-to-business (B2B) deliveries to small business [4]; so, this study only focuses on business-to-customer (B2C) deliveries in cities as a result of its upward trend [5]. In this study, the selection problem is approached as multi-criteria decision-making (MCDM) process, and 2-Tuple linguistic integrated DEMATEL-VIKOR methodology is proposed.

DEMATEL tool is suggested thanks to its power to deal with interdependent relationships of criteria [6]. It is a structural modeling tool which is practical to analyze cause and effect relationships among components of a system [6]. So, this tool will help to assess the interrelations between the criteria detected for the selection problem, while it helps to weight the criteria. Moreover, it is integrated with a 2-Tuple linguistic model to empower its ability to deal with linguistic data. Also, the 2-Tuple linguistic model provides a flexible linguistic decision-making environment to the decision makers (DMs).

Moreover, VIKOR is suggested as an MCDM tool to select the most suitable last mile solution due to its computational simplicity and solution accuracy to find a compromise solution. It is also integrated with 2-Tuple linguistic to empower the tool to deal with linguistic data.

The remainder of this paper is organized as follows: Section 2 provides a literature review about the last mile delivery studies conducted in recent years. Section 3 gives the methodology with SWOT analysis for last mile delivery in the perspective of smart cities and selection methodology. Finally, Section 4 and Section 5 provide the application of the methodology with results and the final assessments respectively.

II. Last Mile Delivery

Last mile delivery subject is a prevalent subject in literature for the last few years. When the "last mile

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delivery" word is searched on Web of Science portal for the last five years, eighty-two different works have been focused on the last mile delivery as a subject. Most of the works have been done between the years 2016 and 2018. However, every work has approached the same subject from different perspectives and have suggested different solutions for city freight transportation with last mile delivery. Table I provides the basic topics threated under the last mile delivery subject.

TABLE I
RECENT STUDIES ABOUT LAST MILE DELIVERY WITH SMART CITIES

Topic	Reference
Network/Route Optimization	[7]–[12]
"Drone" usage	[13], [14]
Planning / Sequencing	[15]
Delivery Stations	[16], [17]

In this study, the main aim is to focus on the last mile delivery subject from the smart city perspective to be able to create smart solutions.

The concept of "smart city" is emerged from the integration of technology with the city. The definition of a smart city is done in many different ways. As a concept, it is a bit fuzzy and comes in different ways with different features in the literature [18]. The adjective smart in urban planning is generally addressed in a strategic dimension [18]. It refers to the adoption of different ideologies, strategies, and approaches in the planning of the city and use markup styles. When it is addressed in technological wisdom, it refers to the technological integration of whole sub-systems of the city such as transportation, infrastructure, buildings, etc.

In the literature, it exists three studies that have been assessed the last mile delivery subject with smart cities. Two of them have been published as conference papers in 2015. In the first one Navarro et al. have proposed new models for smart city logistics and have applied them for Spain [19]. In the second one, Lindawati et al. have suggested a platform with minimum data sharing based on a collaboration for city logistic[20]. As a third study, in 2017 Dispenze et al. have suggested an infrastructure study for sustainable mobility in cities [21].

Amid different studies investigated last mile delivery with smart cities, there is a lack of bottom-up review of the last mile delivery subject from a smart city perspective in order to create smart solutions. It is clear that today, in this digitalization age, cities are getting smarter and interactive places where all systems are connected to each other. At this point, last mile delivery which is the critical part of the city logistics must be well evaluated with smart city notion to be able to better adapt to the future's smart solutions.

III. METHODOLOGY

In this paper, the last mile delivery subject is investigated with smart city notion. In the first step, to be able to have an in-depth assessment of the subject, a SWOT Analysis has been conducted. This analysis has provided an environment for better understanding of the subject and generate the selection criteria for the smart solution selection.

As a second stage, 2-Tuple integrated DEMATEL-VIKOR methodology has been suggested for solution selection for smart last mile delivery. This selection phase has been approached as MCDM problem and MCDM tools such and Decision-Making Trial and Evaluation Laboratory (DEMATEL), and Vlse Kriterijumska Optimizacija Kompromisno Resenje (VIKOR) have been utilized to handle this selection. The DEMATEL method was first used in 1973 in a study conducted by The Battelle Memorial Institute [22]. The most important benefit of this method is that it provides a consensus-based relationship. It is suggested to obtain the weights of the detected criteria [23]. It is integrated with 2-Tuple linguistic model and the steps are given in Appendix A.

Opricovic first applied the VIKOR method in 1998 [24]. It is a method developed to make a multi-criteria selection in complex systems. It aims to find a solution by evaluating alternatives according to the criteria. In this study, it is also integrated with 2-Tuple model to choose the most appropriate solution for last mile delivery. Detailed steps of the suggested technique is given in Appendix B.

Furthermore, 2-Tuple linguistic model [25] is chosen as computing with words (CWW) tool thanks to its easy computational steps and its ability to calculate intermediate values in linguistic sets. It facilitates the aggregation process, and it decreases the loss of information during translation and aggregation [25].

In this section, the explanation of SWOT Analysis and its application for last mile delivery from smart city perspective will be given. Also, the detailed steps of the selection problem will be provided afterward.

A. SWOT Analysis

The SWOT analysis, which is widely preferred by business planners, is a tool for evaluating and measuring the internal and external environment of the company. SWOT consists of the initials of the words: strength, weakness, opportunities, and threats [26]. The SWOT analysis has become a widely used method for in-depth understanding of many subjects, not only on companies but also in order to see the interrelations of both the concept and the external systems in detail. The components of the SWOT analysis are described as follows [26]. We try to answer these questions for a better understanding of the SWOT components:

Strengths: What are the advantages? What can be best done about this? What resources and contacts can we reach?

Weaknesses: What are the missing parts? What can be improved more?

Opportunities: What opportunities can be found in the sector? What are the trends that can create new opportunities?

Threats: What are the obstacles that can be encountered in the external environment? Do these barriers affect the sustainability of the system?

B. SWOT Analysis for Last Mile Delivery for Smart Cities

With the result of the literature review and the help received from the experts, the last mile delivery from the smart city perspective was examined in depth. The obtained results of the SWOT Analysis are presented in Table II.

In this study, based on the data obtained from the SWOT

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analysis, it is aimed to make a suitable last mile delivery solution selection with 2-Tuple integrated DEMATEL-VIKOR method. The detailed calculation steps of the proposed methods are available in Appendix A and Appendix B.

Strengths indicate the advantages achieved when the last mile delivery in smart cities is implemented. Particularly in the last mile delivery, the benefits gained by the companies which are looking for smart solutions were mentioned. These benefits, as mentioned above, have important features in terms of financial and customer satisfaction.

When we look at weaknesses, it is considered as the problems that may arise on the firm side when the subject is applied. Here, the importance of technological infrastructure and trained employees constitute a critical point.

Opportunities focus on the gains of the city and the city's stakeholders, as an evaluation was made from the smart city perspective. This section focuses on the city's gains more than the companies. The most prominent criterion in the Opportunities section is the increase in the quality of life of the city and the increase in the level of welfare.

When the Threats section is evaluated, the challenges that the smart city may face in the last mile delivery practices are discussed. The last step is to indicate the problems that may be encountered for delivery. Here, the weak stakeholder collaboration in the city is one of the major threats identified for the final step.

TABLE II
SWOT ANALYSIS FOR LAST MILE DELIVERY FROM SMART CITY PERSPECTIVE

Strengths
S1: Less cost for delivery companies [26]
S2: Increased rate of on-time deliveries [26]
S3: Detection of the exact location of the cargo in the transport chain [26]
S4: Energy-saving and CO_2 emission reduction with less truck transportation [26]
Weaknesses
W1: Confidentiality and security problem due to information sharing [26]
W2: The system does not function properly unless it has a robust technological infrastructure [26]
W3: The need for staff to be well trained in new technologies and complex systems [26]
W4: High investment cost [27]
Opportunities
O1: Strengthening stakeholder cooperation [27]
O2: The city has a positive power in the fight against climate change [27]
O4: A city with a high level of prosperity with less traffic [27]
O4: Help reduce the crime rate in the city [27]
Threats
T1: Weak stakeholder cooperation [28]
T2: Legal and political barriers to transportation [28]
T3: Poor signal-induced accidents [28]

C. Proposed Methodology for Selection Problem

The detailed steps of the selection process are given as follows:

1. Conducting a literature review about the subject
2. In-depth evaluation of the subject with SWOT Analysis
3. Detecting selection criteria with the help of SWOT Analysis and experts about the subject
4. Criteria weighting with the DEMATEL method.
5. Detecting alternatives for last mile delivery solutions.
6. Making alternative evaluations with the VIKOR method using the criteria weights obtained from DEMATEL.
7. Choosing the most suitable alternative for applying the VIKOR method.

The next section gives the application of the suggested techniques for Istanbul city.

IV. APPLICATION: LAST MILE DELIVERY SOLUTION SELECTION FOR ISTANBUL

Nowadays, we know that cities are in a transformation to provide a good environment for their inhabitants. In Istanbul, it is the same, and it aims to provide a better environment for its inhabitants with plans such as the Climate Change Action Plan and Air Quality Action Plan.

Urban traffic is a big problem in this city. It was determined that most of the traffic was caused by urban transportation. As a solution proposition to this congestion, an application of the proposed method was conducted for the city of Istanbul by following the steps given in the previous section.

Steps 1-2: A literature research and a SWOT Analysis have been conducted as in the previous sections. A decision-making group of three people is formed to make assessments. A linguistic set is defined to them to express their opinions about the subject. They have given their assessments in five-labeled linguistic set which consists of : No influence (N)-Low influence (L)-Medium influence (M)-High influence (H)- Very High influence (VH).

Step 3: According to the information obtained from SWOT Analysis and the help of the experts, selection criteria have been detected as in Table III. In the table, related SWOT analysis components are given between parentheses beside the criteria. Also, cost (C) or benefit (B) characteristics of the criteria have been indicated in the same table.

TABLE III
SELECTION CRITERIA

C#	Criteria	
C1	Decreasing cost (S1)	B
C2	Increasing customer satisfaction (S2)	B
C3	Improved traceability (S3)	B
C4	More adaptive city for climate change (S3-O2)	B
C5	Decreased information security (W1)	C
C6	Issues resulted from lack of infrastructure (W2-T2)	C
C7	Need for well-trained staff (W3)	C
C8	High cost of investment (W4)	C
C9	Barriers to the operation of the system (T2)	C
C10	Strengthening the cooperation between stakeholders (O1-T1)	B
C11	Ease to reach a city with a high level of welfare (O3-O4)	B
C12	Efficiency gain [29]	B
C13	Ease of multiplication [29]	B
C14	Connectivity [30]	B

Step 4: Criteria weighting have been obtained with 2-Tuple integrated DEMATEL method. This method also provides us to investigate the interrelations between criteria. The assessment of the first experts is given as an example in Table IV, afterward *nWi* values; the normalize weights of each criterion, are given in Table V.

C10, C3 and C14 are detected as the most important criteria by the DMs. The cooperation between stakeholders are detected as the most critical criteria, since it has large effect on city’s transportation. The (D-C) values on the third column refers to the net effect that the factor contributes to the system. When the (D-C) value is negative, it is mean that the factor is effected by the others in the system. In that case, the most important three critea are influenced by the other criteria in the system.

Step 5: Three different alternatives have been detected for this problem [31].

First, fixed or temporary smart cabinets (A1) are identified as an alternative [31]. This alternative includes temporary or permanent lockers, which are placed in the busiest part of the city and can be reached by public transport. These cabinets are connected to a cloud system and are used with an application on the users' phone. When the delivery is placed in the smart closet, a notification is sent to the customer via the system and the customer can access the delivery at any time of the day with the code sent. Another alternative is autonomous electric vehicles (A2).

These vehicles are usually small and traffic-independent vehicles [32]. They have a system that manages the road information and the locations to be traveled, and they have the least impact on the environment as it works with electricity.

TABLE IV
PAIRWISE ASSESSMENT OF THE FIRST EXPERT

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14
C1	N	L	L	N	N	VH	H	VH	M	VH	N	H	M	L
C2	L	N	VH	M	L	N	VH	N	N	H	H	VH	L	H
C3	M	VH	N	N	H	H	M	M	H	H	N	VH	L	VH
C4	N	L	N	N	N	N	N	N	N	H	VH	L	N	N
C5	N	L	H	N	N	H	VH	L	N	H	L	N	N	L
C6	N	N	N	N	L	N	M	N	L	L	N	N	N	L
C7	M	VH	H	N	M	L	N	H	N	L	L	VH	H	M
C8	N	L	M	L	N	N	L	N	M	H	L	L	L	M
C9	N	N	L	L	M	M	N	M	N	H	N	N	L	N
C10	L	H	H	H	VH	L	H	M	L	N	H	VH	H	VH
C11	N	M	L	VH	L	N	N	N	L	M	N	L	N	L
C12	M	VH	M	L	L	L	M	N	L	M	N	N	M	L
C13	M	L	N	N	N	M	L	H	M	N	N	L	N	M
C14	L	H	VH	L	H	M	H	L	L	VH	N	M	H	N

TABLE V
NORMALIZED WEIGHTS OBTAINED BY DEMATEL

C#	D_i+C_i	D_i-C_i	W_i	nW_i	Rank
C1	0,25	-0,13	0,28	**0,044**	**8**
C2	0,79	0,03	0,79	**0,123**	**4**
C3	0,89	-0,14	0,90	**0,139**	**2**
C4	-0,16	0,06	0,17	**0,027**	**11**
C5	0,32	0,07	0,33	**0,051**	**7**
C6	0,08	0,08	0,12	**0,018**	**12**
C7	0,71	0,02	0,71	**0,110**	**5**
C8	0,16	-0,07	0,18	**0,027**	**10**
C9	0,03	0,05	0,06	**0,009**	**14**
C10	1,02	-0,18	1,04	**0,160**	**1**
C11	-0,10	-0,04	0,11	**0,017**	**13**
C12	0,64	0,23	0,68	**0,105**	**6**
C13	0,18	0,20	0,27	**0,041**	**9**
C14	0,82	-0,16	0,83	**0,129**	**3**

The workforce is also not required. Although the initial investment is high, it is easy to multiplicate and has a high-efficiency rate in the long term.

The electric cargo bike (A3) is a human-powered system [33]. Due to its electrical operation, its effect on the environment is still low. It is a recently preferred method for delivery in cities. The amount of cargo that can be transported by this method is relatively less than other methods.

Steps 6-7: By following the steps of the 2-Tuple integrated VIKOR method, an evaluation has been done for each alternative. The aggregated ultimate decision matrix is given in Table VI.

Weighted Aggregation Operator (WAO) is applied to obtain the matrix[34]. Based on the evaluations in Table VII. S, R and Q values are obtained for each alternative. They are ranked increasingly as in Table VII.

TABLE VI
FINAL EVALUATION MATRIX

C#	A1	A2	A3	C#	A1	A2	A3
C1	(L,0.33)	(N,0.33)	(L,0.33)	C8	(L, -0.33)	(L,0.33)	(L,0.33)
C2	(L,0.33)	(N,0.33)	(N,0.33)	C9	(L, -0.33)	(L,0)	(N,0.33)
C3	(L,0.17)	(L,0.33)	(L,0)	C10	(N, 0.33)	(N, 0.33)	(N,0.33)
C4	(L,0.25)	(L, 0.25)	(L,0.33)	C11	(L, 0.08)	(L,0)	(L,0)
C5	(L, -0.33)	(L,0.33)	(N,0.33)	C12	(L,0.33)	(L,0)	(L, -0.33)
C6	(L, -0.33	(L,0.33)	(L, -0.33)	C13	(L,0.33)	(L, -0.33)	(L,0)
C7	(N,0.33)	(L,0.33)	(N,0.33)	C14	(L,0.33)	(L,0.25)	(L, -0.33)

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TABLE VII
VIKOR RANKING

S	Alt.	R	Alt.	Q	Alt.
0,012	A1	0,700	A1	0,000	A1
0,694	A3	0,160	A2	1,998	A3
0,696	A2	0,160	A3	2,000	A2

As a result of these processes, the most appropriate alternative is the temporary smart cabinets. It has obtained the lowest S, R and Q values in the VIKOR method and it could be selected as the most suitable last mile delivery solution for this application.

V. FINAL ASSESSMENTS

Smart solutions for cities are topical subjects due to emerging technologies. Transportation, which is often a major hot spot for most cities, is on the mend as a consequence of new technologies. Emerging optimization techniques such as smart routing, congestion planning help to reduce the negative impacts of city transportation for the residents.

Last mile delivery is one the critical part of the city transportation which constitutes of commercial operations. It has become indispensable for logistic companies and residents due to active e-commerce activities. Motivated by this growth of last-mile logistics for B2C applications, this study is proposed a smart solution selection methodology. The selection process is approached as MCDM procedure and MCDM tools, DEMATEL and VIKOR, are integrated with a 2-Tuple linguistic model in order to create a flexible decision-making environment with linguistic variables to the DMs.

First, the last mile delivery was examined with SWOT analysis from different aspects within the concept of a smart city. This review is a preparation for the selection problem, and it forms the basis of the selection criteria.

The DEMATEL method was preferred to observe the relationships between the criteria and to determine the weights of the criteria. The detected alternatives were assessed in the selection process according to these criteria by the VIKOR method. Both methods are integrated with a 2-Tuple linguistic model to facilitate the aggregation process and prevent the loss of information during the translation of linguistic variables to crisp numbers.

According to the application, temporary smart cabinets are selected as the most suitable solution for the last mile delivery implementation in smart cities. As a result of the criteria weighting, the cooperation between the stakeholders, improved traceability and connectivity are assigned as the most critical three criteria. The selected alternative proposes good efficiency for these criteria by reducing the failed deliveries rising from the absence of customers at home. Furthermore, it necessitates the joint tenancy of cabinets by different logistic firms and that creates a cooperative environment between stakeholders.

Sensitivity analysis may be a starting point for future studies to observe how the changes in criterion weight affect selection. On the other hand, the fact that the new generation of urban logistics has an approach that unites most stakeholders and directs them to cooperate with each other, it may open the horizons to the new research areas about the distribution of the tasks of the stakeholders and how cities can easily implement this system on their own.

In addition, the resistance of cities to climate change as a result of the smart solutions can be examined in future studies.

APPENDIX

A. Appendix A

2-Tuple Integrated DEMATEL

The DEMATEL technique can convert the interrelations between factors into an intelligible structural model of the system and divide them into a cause group and an effect group. Hence, it is an applicable and useful tool to analyze the interdependent relationships among factors in a complex system and rank them for long-term strategic decision making and indicating improvement scopes. The formulating steps of the 2-Tuple integrated DEMATEL can be summarized as follows [35] :

Step 1: Generate the group direct-influence matrix Z.
To assess the relationships between n factors $F = \{F_1, F_2, \ldots, F_n\}$ in a system, suppose that l experts in a decision group $E = \{E_1, E_2, \ldots, E_l\}$ are asked to indicate the direct influence that factor F_i has on factor F_j, using linguistic variables.
By aggregating the l experts' opinions, the group direct-influence matrix $Z=[(Z_{ij},\alpha_{ij})]_{nxn}$ can be obtained. 2-Tuple aggregations operators can be used to aggregate the decisions [34].

Step 2: Establish the normalized direct-influence matrix X.
All the values obtained from 2-Tuple translation equation are between 0 and 1. No normalization is needed. The process can be continued with the next step by constructing a total influence matrix.

Step 3: Construct the total-influence matrix T.
$T=[t_{ij}]_{nxn}$ can be obtained by Eq. (1):

$$T = X + X^2 + X^3 + \ldots + X^h = X(I - X)^{-1} \quad h \to \infty \tag{1}$$

where I is the identity matrix with dimensions nxn.

Step 4: Produce the influential relation map (IRM)

The vectors R and C, representing the sum of the rows and the sum of the columns, obtained from the total-influence matrix T. r_i is the *ith* row sum in the matrix T and displays the sum of the direct and indirect effects dispatching from factor F_i to the other elements. Similarly, c_j is the *jth* column sum in the matrix T and depicts the sum of direct and indirect effects that factor F_j is receiving from the other factors.
$(R + C)$ stands for the degree of the central role that the factor plays in the system. Alike, the vertical axis vector $(R-C)$ called "Relation" shows the net effect that the factor contributes to the system. If $(r_j - c_j)$ is positive, then the factor Fj has a net influence on the other factors and can be

grouped into cause group; if $(r_j - c_j)$ is negative, then the factor Fj is being influenced by the other factors on the whole and should be grouped into effect group. Finally, an IRM can be created by mapping the dataset of $(R+C,\ R-C)$, which provides valuable insights for decision making.

B. Appendix B

2-Tuple Integrated VIKOR

Step 1: Detect the best and the worst values. Here, the values of the decision matrix are in a 2-Tuple format; so, the rules for 2-Tuple comparison will be used to detect the maximum and the minimum value for each TR.

Step 2: Calculate the (S_j,α_j) and (R_j,α_j) values where $i=1,2,\ldots,m$ and m represents the number of alternatives. Values will be obtained with the following relation:

$$(S_i,\alpha_i)=\Delta\left(\sum_{i=0}^{t}\frac{\Delta^{-1}(v_j,\alpha_j)\times(\Delta^{-1}(f_j^*,\alpha_j)-\Delta^{-1}(x_{ij},\alpha_{ij}))}{\sum_{j=1}^{t}\Delta^{-1}(v_j,\alpha_j)\times(\Delta^{-1}(f_j^*,\alpha_j)-\Delta^{-1}(f_j^-,\alpha_j))}\right) \quad (2)$$

where, (v_j,α_j) is the weights of DRs obtained from QFD application, (x_{ij},α_{ij}) are the values from aggregated collective decision matrix. Here, (f^*_j,α_j) is the best and (f^-_j,α_j) is the worst DR value.

$$(R_i,\alpha_i)=\Delta(\max_i(S_i,\alpha_i)) \quad (3)$$

Step 3: Calculate the (Q_i,α_i) values where $i=1, 2,\ldots,m$ and m stands for the number of alternatives. Values will be obtained with the following relation:

$$(Q_i,\alpha_i)=\Delta\left(\left(\frac{q\times\Delta^{-1}(S_i,\alpha_i)-\Delta^{-1}(S^*,\alpha^*)}{\Delta^{-1}(S^-,\alpha^-)-\Delta^{-1}(S^*,\alpha^*)}\right)+\left(\frac{(1+q)\times\Delta^{-1}(R_i,\alpha_i)-\Delta^{-1}(R^*,\alpha^*)}{\Delta^{-1}(R^-,\alpha^-)-\Delta^{-1}(R^*,\alpha^*)}\right)\right) \quad (4)$$

where (S^*,α^*), (S^-,α^-), (R^*,α^*) and (R^-,α^-) have calculated as the minimum and maximum S and R values respectively.
Step 4: Rank the alternatives.
Alternatives will rank according to their (S_j,α_j), (R_j,α_j) and (Q_i,α_i) values in decreasing order. The warehouse alternative with the minimum value of (Q_i,α_i) is the most suitable alternative if it satisfies the VIKOR conditions [24].

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