Selecting Interchange Scheme for Traffic Intersections, A Combined Dematel and Network Analysis Methods (Case Study: Sanaat Square, Tehran, Iran)

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Abstract
While selecting the most appropriate interchange type is a major concern that transport and traffic experts are dealing with, one of the essential questions that repeatedly appears on the table is how to select the best interchange based on the contributing criteria. In the present study, the influencing factors on selecting interchange type are extracted by Delphi method followed by their clustering utilizing card sorting technique to the environment, safety, cost, executive constraint, regional, geometric characteristics, and traffic, and eventually applied the multi-criteria decision-making process of Dematel to select the best interchange type. The well-known intersection of Sanaat Square in the Iranian capital of Tehran has been selected as a case study and the proposed procedure performed by receiving experts' opinions. After validating the proposed procedure, the results revealed that land use, accident reduction rate, domestic interchange construction experience, noise pollution reduction, distance to adjacent interchange, and construction cost are the main factors that play significant roles in interchange type selection for interchange.

Keywords
Traffic Intersection, Interchange type, Card Sorting, Multi-criteria decision making process

1. Introduction and Literature

The increase in population which causes travel demand, as well as the growth of car ownership in Iran, has scaled up the traffic volume in the country that has faced transport authorities and decision-makers with the challenge of providing a safe, efficient, and high-speed transportation system. One of the most important elements of urban structures is an intersection where the traffic is dispatched based on their desired directions. The main purpose of building a road intersection is to enable cars to move safely in different directions. Establishing a two-level interchange is probably the best, but it is the costly way to manage approached traffic at intersections. Due to the increase in traffic at intersections, the rate of accidents that cause network delays, and accidents' impacts, constructing intersections is obviously necessary (Ashto, 2011). The first step in designing an intersection on urban roads is to select the most appropriate form of interchange according to the existing traffic directions and geometric situations, but a wide range of quantitative and qualitative factors that can affect the choice of interchange may confuse decision-makers. In the meantime, selecting a structured method for selecting the form of interchange depends on the experiences, engineering judgments, and recommendations of the regulations while many factors may be ignored.

Traffic experts consider traffic factors such as capacity, safety, accessibility, accidents' history and facilities, land acquisition, construction, and maintenance costs to select the most appropriate form of the interchange (Garber and Fuentain, 1999). Factors like socioeconomic measures (Hui, 2009), and adaptation to the environment such as reducing land use (Qiao, Li and Sang, 2011), as well as cost-benefit analysis (Long et al., 2007) are also considered through proposing the form of intersection. In practice, Fang et al. (2005) simulated the traffic conditions of two types of one-point and diamond interchanges with each other based on the criteria of interchange shape, design geometry, and traffic characteristics. Based on the projection tracking technique, they presented a nonlinear map analytical method for multi-criteria classification of interchange types. Selecting the form of intersection is another approach where Zhao et al. (2006) examined 25 common interchange patterns and classified them into six categories with similar characteristics and performances. Qualitative approaches are also represented where Lin et al. (2002) developed a model for the combined fuzzy evaluation of interchange selection criteria to select the best interchange form. This method is logically based on urban design issues and does not pay attention to other criteria such as rural or remote areas. Considering many criteria lead experts to utilize multi-criteria decision-making systems (MCDM) (Loulizi et al., 2011) to focus on the most essential criteria of geographical conditions, traffic demand, type of road, and economy which sometimes resulted in selecting them by ranking approach (Long et al., 2007).

Following the above mentioned, it seems that a method for selecting the form of interchange should be provided to cover a part of the shortcomings of the previous methods. Therefore, in the proposed method, all quantitative and qualitative factors involved in the selection of the interchange form have been studied and carefully selected to design a more practical technique. Consequently, the steps for conducting the study would be defined as 1) Identify all the quantitative and qualitative factors affected in selecting the form of interchange, 2) Reveal the connections between the aforementioned factors, 3) Provide a holistic model, and eventually, 4) Evaluate the decision model employing experimental data.

2. Research Methodology and Procedure

The present research work is to make a decision support system for selecting the form of interchange for urban intersections based on the influencing factors in three stages of identifying factors, clustering them based on relations utilizing card sorting technique, and eventually ranking the scores that each interchange receives from experts' opinions. To identify the influencing factors among all of them introduced in previous studies, the well-known ranking method of the Delphi technique is utilized. Given that methods such as Delphi rely on the opinions of experts, qualifying the respondent team is the first and one of the most crucial steps (Minghat et al., 2012). Therefore, the nominated experts are qualified based on the indicators proposed by Hallowell & Gambettas (2010).

The next step is the factors' clustering in which to cluster the influencing factors for selecting the type of interchange, experts will be asked to put them in a cluster with the same characteristics, functionality, and nature. While Professor Satitekhin (Chen and Huang, 2013) presented the process of network analysis as a comprehensive technique for decision-making based on internal relations and their feedback on the one side and between cluster elements on the other side, a combination of Dematel and ANP techniques so-called DANP is proposed to improve the normalization process of traditional network analysis process (Lee and Hong, 2011) where respondents are asked to rate the effects of each factor on the other one based on the five-rate Likert scale of 1 to 5.

Next, the effect of each factor on alternatives or scenarios is explored by pair-wise comparisons. Since the relationships between the factors explored in the Dematel technique, fewer questions are asked to re-build the super-matrix. The respondents, therefore, state only the effect of each factor on the branch and the effect of each branch on the alternative. Finally, to validate the proposed procedure, the correction method presented by Mohammadi (2016) initially proposed by Maynard (Maynard, 2001) is then utilized.

In this method, the case study is first analyzed by experts considering a series of multi-criteria decision-making techniques. The proposed decision-making system would be valid if there is no significant difference between the results of the two methods. Experts are then asked to evaluate the decision-making system based on the selected factors. The result of the experts' opinions, after weighting and normalization, will be associated with each interchange form. If the decision-making system scores are at least 50% in all domains, the validity of the system is approved (Mohammadi, 2016). The overall steps are now depicted in Figure 1.

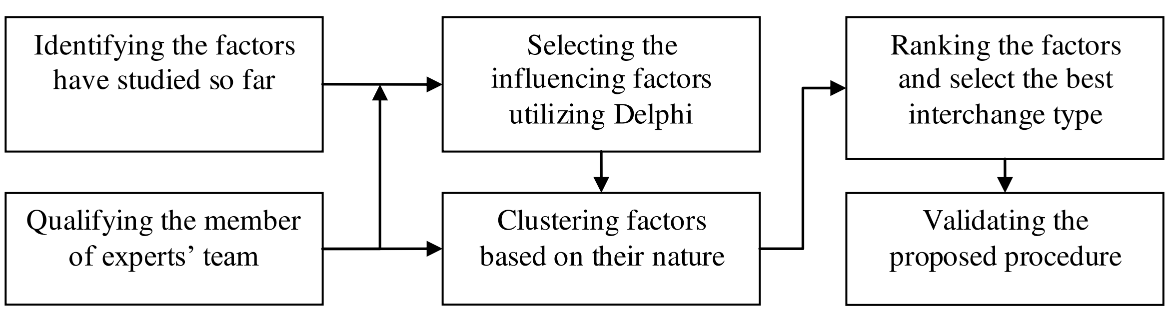

Figure 1: The overall scheme of research methodology

3. Performing the proposed procedure

The first step is to identify and qualify the eligible experts to fill out the technical questionnaires. While, it is recommended that the number of experts should be between 8 and 12 (Hallowell & Gambettas, 2010), eleven experts were qualified to participate out of a set of 30 experts in such a way that at least half of the experts' indicators met. The indicators, recommended by Hallowell & Gambettas (2010) and corresponding experts who meet them have been listed in Table 1 followed by completing that with the number of eligible numbered as E01 to E11 in the second column of the table.

Table 1: Experts and the indicators met

Experts' Indicator	Experts who meet the indicator
The first or second author of the last three related articles in journals	E01, E02, E03, E05, E06, E08, E09, E10, E11
Invitation to participate to a conference	E01, E02, E03, E04, E05, E06, E07, E08, E09, E10, E11
Membership or a seat on a national committee	None
At least 5 years of professional experience in the subject	E01, E02, E03, E04, E05, E06, E07, E08, E09, E10, E11
Membership in the faculty of higher education institutions	E04, E05, E06, E08, E09, E10
Author or editor of a book or chapters of a book on the subject	None
Has an acceptable academic rank in the subject (Have at least a bachelor's degree)	E01, E02, E03, E04, E05, E06, E07, E08, E09, E10, E11
Have a professional degree such as a professional engineer (PE)	E04, E05, E08, E10

As mentioned before, the influencing factors for selecting the form of interchange have been explored by the Delphi method. Among explored factors, 36, shown in the left part of Table 2, were suggested to experts in three stages. As shown we identify them by codes CR01 to CR36. In this process, the experts were asked to point out their viewpoints on the influence of each factor in selecting the interchange form based on a five-point scale. The general form of technical question was: "To what extent do you agree with the impact of factor A on the interchange form?". In this case, the values 1, 2, 3, 4, and 5 are assigned to fully disagree, disagree, without comment, agree, and strongly agree. By analyzing the opinions of the experts, the results have been obtained and tabulated on the right part of Table 2. A list of all explored factors influencing the selection of interchange has been tabulated in the left part of the table.

The number of experts who agree with the point is counted after the description column, followed by the middle of them. To cluster the influencing factors for selecting the type of interchange, experts are directly asked to put them in a cluster with the same characteristics, functionality, and nature in an overall perspective. For illustration, the factors that are related to air pollution and noise pollution would be assigned to the cluster titled "environmental factors (environment)", whereas traffic interchange capacity, design speed, traffic volume assigned to the cluster titled "traffic". There are relative interrelationships and interdependencies between factors, so the Dematel technique is utilized to check various degrees of correlation between each factor and its associated cluster.

Table 2: Criteria proposed to select the best interchange for intersection and experts' agreements

Code	**Category**	**Criterion Description**	**Number of experts agree**					**Middle**
			1	**3**	**5**	**7**	**9**	
CR01	Traffic	traffic volume	0	0	2	3	6	9
CR02		traffic combination	0	0	0	4	7	9
CR03		design speed	0	0	1	6	4	7
CR04		service level	0	0	0	8	3	7
CR05		travel time	0	1	2	6	2	7
CR06		traffic capacity	0	2	3	6	0	7
CR07		left turn rate	0	0	5	5	1	7
CR08		pedestrian facilities	0	3	6	1	1	5
CR09		compliance with other plans	0	0	4	3	4	7
CR10	Geometric	integrity of interchange shape	0	1	4	6	0	7
CR11		distance to near interchanges	0	2	2	4	3	7
CR12		interferences' conditions	0	1	1	5	4	7
CR13		multi-level adaptation	3	2	4	2	0	5

Code	Category	Criterion Description	Number of experts agree					Middle
			1	3	5	7	9	
CR14	Region	land use type	0	0	5	3	3	7
CR15		required facilities relocation	0	2	2	5	2	7
CR16		blockage of local streets	0	1	7	3	0	5
CR17		conflicting facilities	0	1	3	4	3	7
CR18	Executive restrictions	land topography	0	1	0	5	5	7
CR19		bed soil conditions	3	1	3	2	2	5
CR20		ease of maintenance	2	3	1	1	4	5
CR21		longitudinal slope	0	0	2	9	0	7
CR22		domestic experience	3	2	2	3	1	5
CR23	Cost	property value of land	0	0	0	5	6	9
CR24		construction cost	0	0	0	5	6	9
CR25		maintenance cost	0	0	4	7	0	7
CR26		fuel consumption reduction	0	0	0	7	4	7
CR27		land required to construct	0	0	0	9	2	7
CR28	Safety	crash reduction estimated	0	0	1	6	4	7
CR29		accident severity reduction	0	0	1	6	4	7
CR30	Environment	noise pollution reduction	2	1	2	5	1	7
CR31		air pollution reduction	0	0	3	7	1	7
CR32	Others	income tax of destruction	5	1	5	0	0	3
CR33		added/reduced property	2	4	2	3	0	3
CR34		visual beauty	5	1	3	2	0	3
CR35		flexibility	1	5	5	0	0	3
CR36		drainage	3	3	2	3	0	3

A combination of Dematel and ANP techniques so-called DANP is currently performed to improve the normalization process of the traditional network analysis process (Lee and Hong, 2011) where respondents are asked to rate the effects of each factor on the other one based on a nine-rate Likert scale of 1 to 9. The middle scores for each factor and its corresponding cluster have been presented in the last column of the table. At each stage out of three, the middle of the ranks obtained from the previous scoring was given to the experts as a rough to re-think on their previous judgments. The factors that received more than 50% of the probable scores (>4.5) were selected as influencing factors and the rest excluded. In this stage, factors with scores less than 4.5 have been omitted from the list, so the remaining 31 factors for selecting interchange type would be limited from CR01 to CR31.
In order to cluster factors, the card sorting technique has been utilized. After collecting and integrating the experts' opinions, the opinions were analyzed and factors with the lower distance between two cards are assigned to the same cluster. The results have been depicted in Figure 2. The square of the geometric distance in the single linking method is obtained from 0 and 58, so the factors those distances are less than 29 are were assigned to one cluster. Accordingly, the above 31 influencing factors were classified to experts in seven clusters including environment, safety, cost, executive constraint, regional, geometric characteristics and traffic factors.

4. Case Study and Data Analysis

It is time to perform the proposed procedure in practice. One of the well-known intersections named Sanaat Square has been selected as a case study. Due to its location near the junction of highways of Hakim, Hemmat, and Sheikh FazlollahNouri, and the important residential and commercial areas of Shahrak Gharb and Saadatabad, it is one of the most important squares in the Iranian capital of Tehran. Its overall diagram depicted in Figure 3, where entrance directions or approaches (seven approaches) are shown in Table 3 as well. The other reason for the selection of the case is that experts' opinions were available and experts who work in this field have enough information on it. On the other hand, working on the above square can make a conceptual framework for other students or experts interested in working more on it.
The super-matrix was initially formed according to the scores and powered six times to converge, and the score of each factor for selecting the form of interchange has been obtained. The super-matrix has been determined and results tabulated in Table 4. Table contains two columns of rates including overall scores obtained after six rounds of powering procedure and scores determined for the single point interchange evaluated by experts. As shown in Table 4, each factor has been individually obtained scored between 0 and 1 as normalized scores. It should be

mentioned some of the factors were not applicable (abbreviated to NA) in the case study even the factors have been scored in the overall procedure.

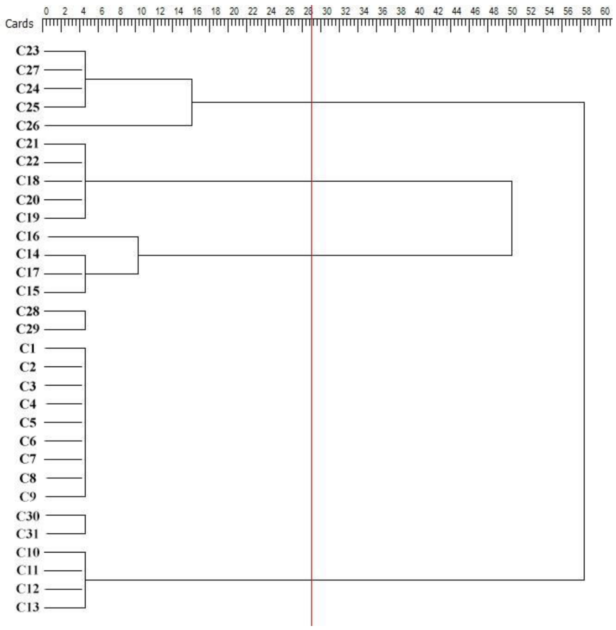

Figure 2: The results of clustering procedure based on Euclidean distance of scores

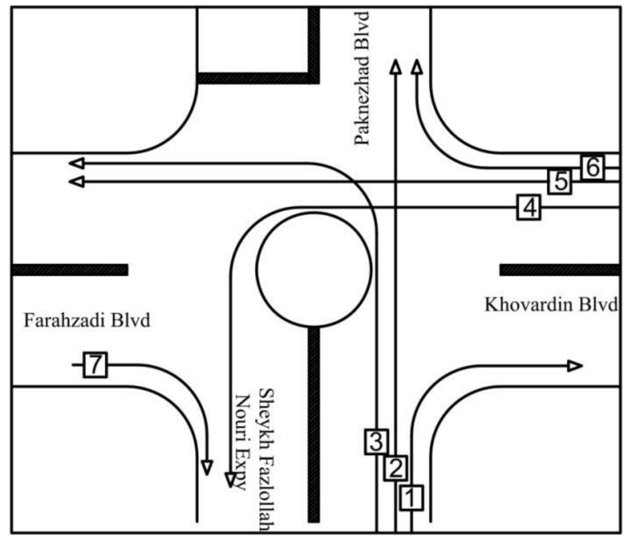

Figure 3: A schematic view of intersection for case study

Table 3: Current Approaches to Sanaat Square

Code	Origin (from)	Destination (to)
1	Sheikh-Fazlollah Express way North	Khovardin Blvd East
2	Sheikh-Fazlollah Express way North	Paknejad Blvd North
3	Sheikh-Fazlollah Express way North	Farahzadi Blvd West
4	Khovardin Blvd West	Farahzadi Blvd West
5	Khovardin Blvd West	Sheikh-Fazlollah Express way South
6	Khovardin Blvd West	Paknejad Blvd North
7	Farahzadi Blvd West	Sheikh-Fazlollah Express way South

Table 4: Scores obtained for overall factors and single point interchange of intersection

Code	Factor Description	Overall Score	Score on SP*	Code	Factor Description	Overall Score	Score on SP*
CR01	traffic volume	0.033	0.080	CR17	conflicting facilities	0.054	0.081
CR02	traffic combination	0.016	0.141	CR18	land topography		NA
CR03	design speed	0.014	0.135	CR19	bed soil conditions		NA
CR04	service level	0.012	0.141	CR20	ease of maintenance	0.043	2.900
CR05	travel time	0.014	0.222	CR21	longitudinal slope		NA
CR06	traffic capacity	0.024	0.123	CR22	domestic experience	0.099	0.160
CR07	left turn rate	0.024	3.700	CR23	property value of land	0.027	0.536
CR08	pedestrian facilities	0.002	0.170	CR24	construction cost	0.063	0.236
CR09	compliance with other plans	0.003	0.166	CR25	maintenance cost	0.030	0.236
CR10	integrity of interchange shape	0.011	0.237	CR26	fuel consumption reduction	0.008	0.311
CR11	distance to near interchanges	0.077	0.085	CR27	land required to construct	0.014	4.000
CR12	interferences' conditions		NA	CR28	crash reduction estimated	0.109	3.700
CR13	multi-level adaptation		NA	CR29	accident severity reduction	0.034	0.524
CR14	land use type	0.128	0.497	CR30	noise pollution reduction	0.088	0.530
CR15	required facilities relocation	0.015	0.535	CR31	air pollution reduction	0.055	0.501
CR16	blockage of local streets		NA				

* SP = Single Point interchange, the selected interchange based on the scores.

After exploring the effect of each factor for selecting the form of interchange, the best form of interchange must be found for the existing intersection under study. Equation (1) is used for rating where P_i is the score of the interchange, a_{xi} is the score obtained according to factor x and finally, b_x is the final score for intersection x. It is obvious that the higher score will determine the most appropriate interchange. For example, the score for single-point interchange is determined as follows by equation (2);

$$P_i = \sum a_{xi} b_x \quad (1)$$

$$P_s = (0.128 \times 0.497) + (0.109 \times 3.7) + \cdots + (0.0023 \times 0.170) = 0.95 \quad (2)$$

Applying the same procedure, $P_D = 0.93, P_s = 0.95, P_c = 0.80, P_{Dc} = 0.91$ where P_D, P_S, P_C, P_{DC} are the scores obtained for diamond, single point, cloverleaf, and full directional, respectively. The above procedure made for all nominated interchanges and results shown in Table 5 which determines the best score belongs to the single point interchange shown in bold at the last row.

Table 5: final scores obtained by each type of interchange

Expert	Diamond	Single Point	Cloverleaf	Directional
1	0.853	0.936	0.639	0.801
2	0.901	0.876	0.702	0.804
3	0.794	0.865	0.733	0.830
4	0.891	0.906	0.644	0.841
5	0.815	0.921	0.653	0.749
Average	**0.851**	**0.901**	**0.674**	**0.805**

5. Validation

In order to validate the proposed procedure, a five-expert team composing of three traffic consultants, a construction project manager, and a decision support system consultant, were asked to look at the factors that are nominated as influencing factors on the selection of interchange type and inspect the results again. They set their scores based on four pre-defined attributes of usefulness, efficiency, satisfaction, and applicability of the model proposed by Mohammadi (2016). The nominated experts access the procedure and rate that following the above criteria. As shown in Figure 4, the score of all factors is above 50%, which means that the procedure meets the desired requirements. As shown the rate of received scores for the above-mentioned attributes are 0.91, 0.75, 0.82, and 0.72, respectively for satisfaction, applicability, usefulness, and efficiency.

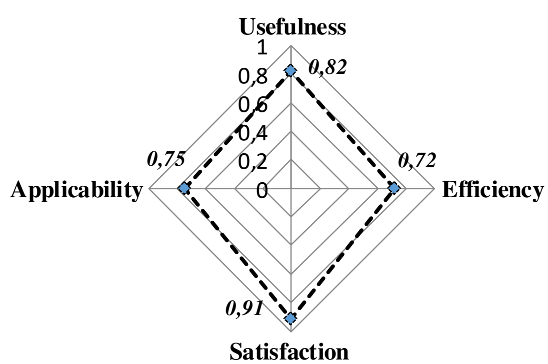

Figure 4: Average score for single point interchange

6. Summary and conclusion

In this study the influencing factors for selecting the type of interchange that had been previously introduced by researchers in other studies explored by the Delphi method manipulating the experts' opinions. The card sorting technique was then used to cluster the factors into main categories. The clustering procedure has also resulted to extract 31 factors out of 36 explored as the leading factors. The inter-relationships of factors have been analyzed by Dematel and the effect of inter-relationships known as super-matrix has been powered by six times to prioritize the aforementioned factors. Factors have been initially ranked and sent back to the experts for reconsideration. By combining the experts' opinions on the degree of importance of each factor in each interchange type and considering them for the case study of Sanaat square in the Iranian capital city of Tehran, the results obtained and validated to reveal the most appropriate interchange for the case study is Single Point type and the procedure is also capable to perform for other intersections. Moreover, this study shows that the six factors with the most considerable influence on the selection of interchange type are respectively land use, crash reduction, the domestic experience of construction, noise pollution reduction, distance to adjacent interchange, and construction cost. While the present study focuses on the urban intersections, further research may lead to study rural intersections where the factors may be different from what has been ranked by experts' opinions.

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