IMPLEMENTATION OF THE RESULTING COST MODEL OF ROADS NETWORK IN THE GEOGRAPHIC INFORMATION SYSTEM (GIS)

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Abstract:
After reaching to the primary cost model of the roads network of the country through the analytical hierarchical process in order to bring about an alternative route network for the traditional network which is far from reality since it just uses only length and time parameters for giving value to the routes, now in order to test the new cost model which considers more elements than just time and length parameters, we should implement it in the GIS environment. In this article after a brief explanation about the method of elements determination in this model, the method of implementation will be mostly considered. The Tehran-Mashhad route was selected for testing the resulting models because of its variation. The results said that the answers are according to the real world situation.

1- Introduction:

In Geographic Information Systems (GIS), network analysis is one of the most powerful tools. Selecting optimum paths for inter-cities traveling, transportation vehicles of domestic, directing the bus fleet of tourism corporations and international transportation companies are some examples of network analysis applications. So different parts of the routes network are evaluated considering their distance and required time to pas each part to analyze the optimum route to take. Unfortunately the route analysis through these two variables of time and distance can determine the exact specifications of network and practically results in dissatisfaction of GIS users. In next sections of this paper it will be shown that considering sufficient and suitable variables in selecting routes based on GIS environment will results in better suggestions about the optimum route between Tehran and Mashhad following section introduces the proper effective criteria used in cost model.

2- The Criteria in roads cost:

Basically the main criteria effecting on roads are divided in to three groups of road humane and vehicle factors [Sadeghi –2002] the road criteria include that kinds of factors effecting on the value of a specific part of a route network and determines the characteristics and additional facilities and capabilities of that part an its nearby environment. Considering the variety of criteria in cost modeling these criteria are divided in to three groups of road, vehicle and humane factors (Table 1). Considering the short opportunity of preparing this paper and also the lack of sufficient information the modeling contains only some of the road criterion factors (Table 2)

The traffic rates, safety and security of the road, weather condition and road type are some examples of road criterion factors. The vehicle type and extent and type of fuel of that it use and … are examples of second group of factors which show the influence of vehicle in determination of the optimum route. The last group of factors is dedicated to humane factors including the age and skill of driver, the power of sight and familiarity of driver with car technical affairs.

Among above-mentioned factors the road criterion factors are more general applicable in route finding analysis since the relevant information to this factors are more accessible than other two groups of factors. So in this paper we work on road factors on the other hand the weight of these parameters is also dependent on the vehicles types so the in the mentioned issues in this regard the cars are considered.

Table(1):Criteria are divided in to three groups of road, vehicle and humane factors

Cost model criteria	Example
Road criteria	Traffic, safety, additional facilities, weather condition, route length, geometric specifications, road type, road area, the potential points of collision, animals passing by, accurate driving signals, junctions and deviations, one-way or two-way direction, geographic direction, existent checkpoints
Vehicle criteria	Vehicle type and model, type and extent of fuel, vehicle weight, its shipment the method of tightening of shipment, the tires type, the lights, headlights, indicator lights and …
Humane criteria	Age, experience, fastening seat belts, wearing sight glasses, familiarity with car technical affairs, using road map and education and..

Table (2): the road criterion factors which have been modeled in this research

Criteria	Sub criteria
Length	A main factor which was multiplied to other criteria in the structured model
Traffic	A, B, C, D, E levels of service
Safety	Like highway petrol centers, village and city points, side-road parking lots, z, health and medical treatment services, telecommunication centers
Tourism	Sea, lake and streams, dike, recreation places, jungle, mountain region, ski runs, cultural-historical places, antiques, religious regions, deserts, fishing zones,
Facilities	The fuel stations and public service centers and terminals
Weather condition	Moderate, relatively dry, cold , desert weather condition, warm and relatively dry, warm and humid

3- Cost Modeling:

After the identification and determination of criteria and sub criteria effective on the cost model of the routes, in order to devote values to each part of the routes network after determination of effecting criterion factors on the value devoting process, these determined factors should be weighed and combined in a systematic manner [Sadeghi-2003]. These factors are put to gather in a model called cost model in this research. Since some of these factors are quantitative and some others are qualitative, a method should be used to enable the simultaneous evaluation and combination of both groups of factors. The Analytical Hierarchical Process is one of the most developed methods of multi attribute decision making models because this method enables the hierarchical formulation of matters and has this capability to contain both qualitative and quantitative factors in one single model [Ghodsi Pour, 1999]. This method was developed by a researcher called Thomas L. Saaty based on the method of analyzing complicated fuzzy matters by human brain in 1975 to the extent that many applications for this methods have been suggested by different researchers since that time. This process includes series of judgments, decision-makings and personal evaluations via a logical method.

A scientist called Tomas L. Saaty in 1975 developed this method on the basis of brain pattern of analysis on complicated fuzzy cases. This is process of judgment, decision-making and personal evaluation through a logical procedure[Satty,1988]. This could be said that this method is dependent on personal imaginations and experiences to hierarchically formulating a matter and on the other hand relates to the logic and conceptions for making the final decisions. Another advantage of the AHP method is that it makes a structure for participation and group cooperation for resolving the problems and making decisions. It also provides a unique, simple and flexible model for resolving a broad range of unstructured problems, which is understandable for everyone. So it uses both systematic approach and detailed analysis to solve sophisticated problems and also realize the relative importance of factors in a model and tries to make a equity between these factors and enables the user to select best alternative suits its special objectives.

Conception of sophisticated events and matters can be come a major problem for human mentality so breaking the major structure of a case into its separate elements through a hierarchical structure can contribute to better perception of human mentality. In these kinds of structures every component is placed in a specific level and is assumed as a sub branch of one or all other elements which are placed in higher levels so the first step in AHP is dedicated to the identification of criteria and the relative position of these criteria (Figure 1). After structuring the tree chart and AHP chart, the same level and relevant criteria are compared with one another. Now in order to combine the criteria cording to above mentioned method of AHP the criteria should be granted suitable weights and compared with each other by specialist experts of AHP.

Since the comparison of the criteria required to specify the type and season of the travels so the modeling was performed through four different divisions (summer – tourism traveling, summer - none tourism traveling, winter – tourism traveling and winter – none tourism traveling)

The modeling is addresses in two levels, the first level's elements are the main criteria and the second level is composed of the sub criteria of each main criterion.
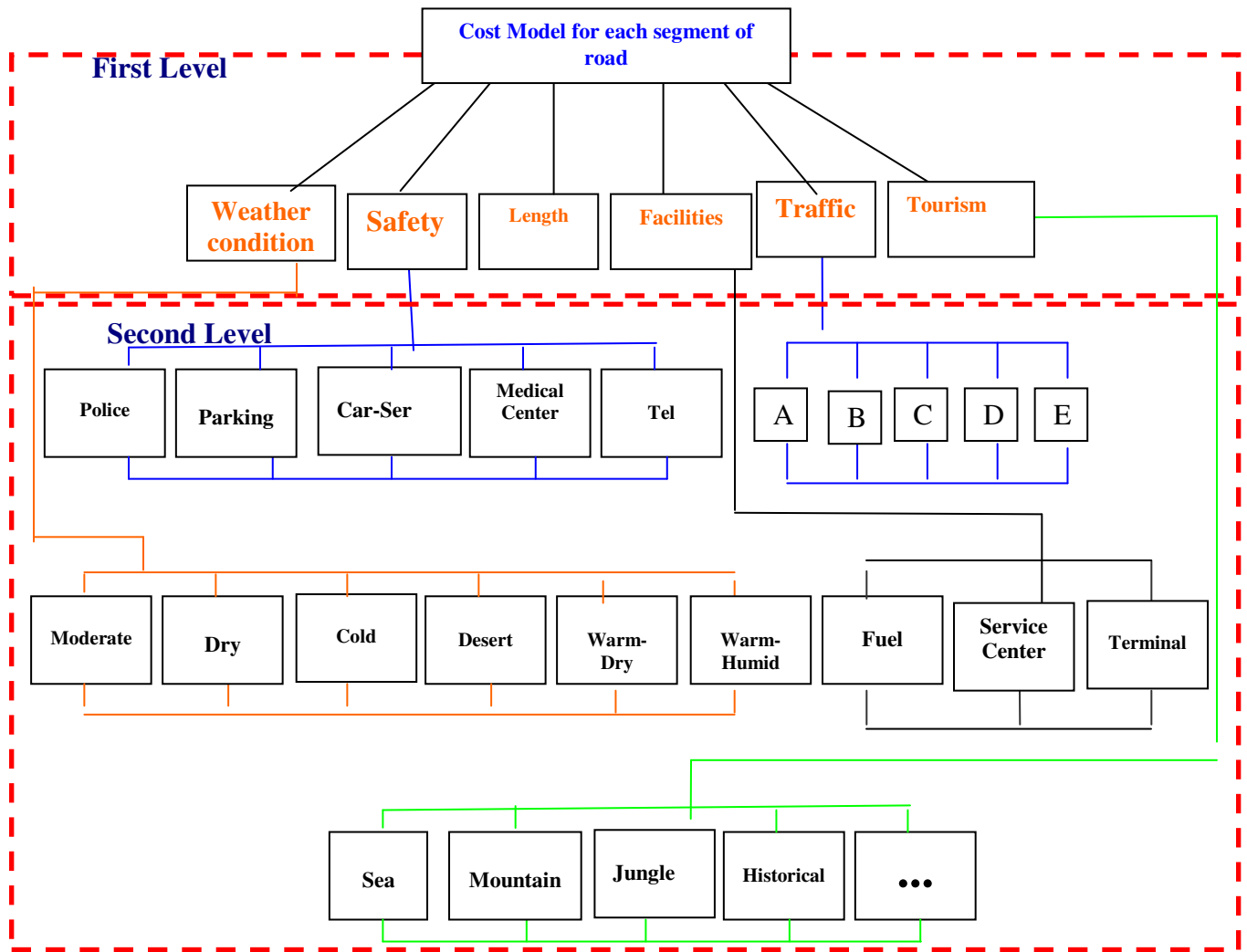
Figure 1 – the AHP diagram of main criteria and sub criteria of interurban cost modeling

- First level Modeling: after preparing a comparative table of criteria and sub criteria of the model and collecting the cost model experts points of view about the first level, two formulas were achieved:

After the paired comparison of criteria in four different statuses in first level this general formula for cost model is achieved:

$$f = \sum_{i=1}^{n} \left(K_i \, X_i\right)$$

2

In this formula f is the primary cost model of the roads excluding the length criterion, n is the quantity of effective criteria in cost model of the roads and Xi shows the effective criteria to cost model and K is a constant coefficient determined by experts of cost modeling.

The relative preference of one part to another part cost model is resulted from the quantitative result of F in above-mentioned formula. In other word that part is selected after cost model analysis, which has the highest value in all studied parts of routes network. Also the part with the shortest length is selected so the lengths of the route and F function have reverse relationship with each other. At last this general formula is offered as the general cost model:

$$F = \sum_{i=1}^{n} \left(\frac{K_i \, X_i}{L_i}\right)$$

3

The important point in these kinds of modeling is that the coefficients in the formula are normalized it means that the aggregate of these coefficients is equal to 1.

The four different phenomena of the general cost model (formula 3) are mentioned bellow:

Summer – tourism traveling: in summer – tourism traveling status considering the high importance of sightseeing attractions criterion (F2), this criterion is granted the highest value in the model (formula 4), also another important case in tourism traveling is the extent of traffic in the roads so considering this case the next highest value is granted to traffic criterion (F3). In order to investigate the accuracy of granted values to different criteria and testing this issue that what would happen if one or more of criteria will be excluded from the model we will work it out in sensitivity analysis section.

$$F_{ST} = \frac{1}{L_i}(0.149\,F_1 + 0.296\,F_2 + 0.193\,F_3 + 0.175\,F_4 + 0.187\,F_5)$$ 4

In this offered formula $\mathbf{F_{ST}}$[1] 、 $\mathbf{F_{SNT}}$[2] 、 $\mathbf{F_{WT}}$[3]

$\mathbf{F_{WNT}}$[4] are cost model of summer – tourism, summer none tourism, winter tourism and winter none tourism traveling respectively. Also note that F1 is the criterion of weather condition, F2 shows the sightseeing attraction, F3 is the criterion of traffic, F4 stands for safety and F5 is the criterion of facilities, Li is the length of every part of the route. The F1 to F5 parameters are not constant but they are functions of their specific sub criteria which will be reviewed in next sections

Summer – none tourism traveling: in this kind of traveling since the sightseeing attractions have the least importance for the travelers the granted value two this criterion is 0. And since the traffic rate is very important for the traveler in this kind of traveling and he wants to get to the destination as soon as possible this criterion (F3) is the most important criteria in this specific model.

Evry "X" criterion can be a separate "F" cost model

[1] **Summer tourism**

[2] **Summer None tourism**

[3] **Winter tourism**

[4] **Winter None tourism**

$$F_{SNT} = \frac{1}{L_i}(0.007\,F_1 + 0.0\,F_2 + 0.961\,F_3 + 0.019\,F_4 + 0.013\,F_5) \qquad 5$$

Winter – tourism traveling: in this cost model (formula 6) since this is a tourism traveling the sightseeing attraction (F2) and traffic criteria (F3) are the most important criteria and the weather condition criterion (F1) has relatively high importance.

$$F_{WT} = \frac{1}{L_i}(0.195\,F_1 + 0.234\,F_2 + 0.214\,F_3 + 0.179\,F_4 + 0.179\,F_5) \qquad 6$$

Winter – none tourism traveling: the traffic criterion is the most important factor (F3) while the granted value to the sightseeing attraction factor is "0" since it has no importance for the user.

$$F_{WNT} = \frac{1}{L_i}(0.040\,F_1 + 0.0\,F_2 + 0.901\,F_3 + 0.032\,F_4 + 0.027\,F_5) \qquad 7$$

- Second level Modeling: After the paired comparison of criteria in four different statuses in Second levels this general formula and tables for cost model is achieved (Table 3).

Table (3): The cost modeling of sub-criteria.

Tables and Formulas of Sub Criteria	Criteria

Table of Weather's Sub-Criteria in summer. — **F₁** Weather condition Criteria

Cold	Moderate	Dry & Cold	Warm & Humid	Dry & Warm	Desert
0.378	0.275	0.128	0.096	0.079	0.045

Table of Weather's Sub-Criteria in winter.

Cold	Moderate	Dry & Cold	Warm & Humid	Dry & Warm	Desert
0.029	0.308	0.301	0.231	0.049	0.083

Level of service for traffic criteria — **F₃** Traffic Criteria

Level of service	A	B	C	D	E
Coefficients	0.505	0.267	0.127	0.074	0.027

F4 Safety Criteria

$$F_4 = (0.088\,X_1 + 0.088\,X_2 + 0.033\,X_3 + 0.406\,X_4 + 0.298\,X_5 + 0.069\,X_6 + 0.017\,X_7)$$

X₁police, X₂ Like highway petrol centers ، X₃، village and city points، X₄ side-road parking lots، X₅، car service centers، X₆ medical treatment services, X7 telecommunication centers.

F5 Facilities Criteria

$$F_5 = (0.134\,W_1 + 0.093\,W_2 + 0.773\,W_3)$$

W₁ public service centers، W₂ terminals ، W₃ fuel stations.

4- Cost Model Test:

In this section the above-developed models are to be tested. So first of all we should specify the route, which we want to test the cost model on, and then we will precede to select optimum route through application of the cost model and evaluate the result against the reality.

5- Implementation in the GIS environment:

To modulate the sub criteria, first of all the method of implementation should be determined so that from the resulting answers, the effect zone of each criterion could be achieved so the dual comparison of each zone, as an element, could be possible through AHP method. To implement the sub criteria two different phenomena could be considered. The first one includes the sub criteria of two main criteria of traffic and weather condition that both have integrated and none differentiable effect zone for example the temperate weather condition and or service level A. The second one includes the sub criteria of three main criteria of security, tourism, and facilities that all have multiple and none differentiable effect zones. For example the sub criterion of Police, which is divided into two effect zones of useful and useless. For the second phenomenon there are three methods of differentiating the effect zones, buffering method,

average quantity of kilometers and the special method. The effect zone of each sub criterion is determined through its overlapping and intersection with each route part. In the following sections the methods of the second phenomenon are addressed.

- **The Buffering Method:** this method is used for those kinds of sub criteria, which have low density near the inter-city roads. In this method, two effect zones, one in the buffer which gets a "1" coefficient and the other one out of the buffer which gets a zero coefficient, are specified. These methods are divided in to three different groups according to the type of sub criteria (i.e. point, linear and or superficial), Buffer, linear buffer and superficial buffer. The buffer, linear buffer and superficial buffer are used respectively for sub criteria which are in the form of point, linear and superficial. In these methods an approximate effect zone is needed. These approximate effect zones are firstly addressed in this theses and reaching to more accurate estimates needs further researches to be done in this regard which is out of the context of the current research. In the security criterion, point buffers with approximate length of 20 and 10 kilometers are considered for the sub criteria of toll-houses, urban areas and villages and also for the main criterion of tourism with approximate length of 5, 2, 2, 2 and 2 kilometers are considered for the sub criteria of Ski jumps, amusement places, traditional cultural and historical places antique-artificial places and religious places respectively. In the tourism main criterion an equal effect vectors of 1 kilometer were considered for both rivers and pisciculture areas as the sub criteria. In the tourism main criteria a superficial buffer with the vectors of 10 and 5 kilometers length were respectively considered for lakes and dikes all above issues are assumed as two areas

- **Exceptions in Buffering Method:** Implementation of the sub criterion of road police stations through point buffer with a effect vector of 20 kilometers length, is a little different from the toll-house and urban areas. Because all of the road parts are under control of the road police but this control area of road police could be divided in to two areas of effective control activity and normal activity so that finally two cost values of 0.875 and 0.125 were resulted. (Figure 2)
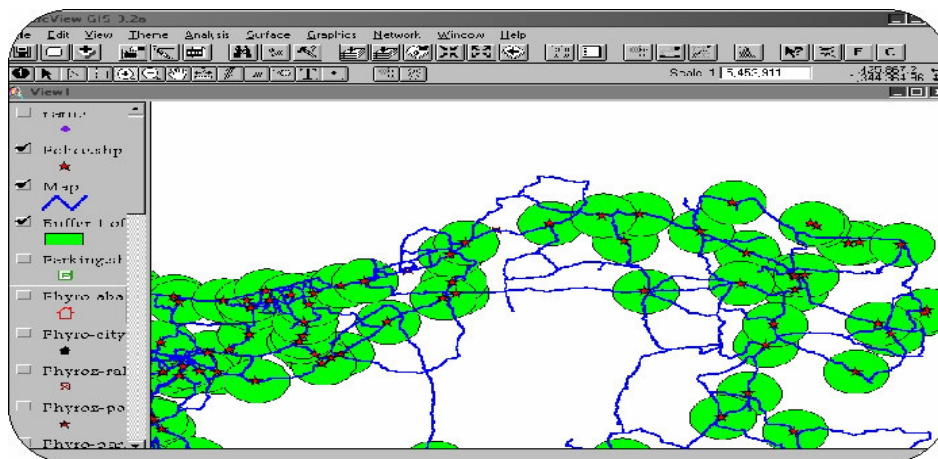

Figure 2: inter-city road police stations in the useful area of activity (a effective vector of 20 kilometers length)

The effect zones of sea after buffer analysis in this theses based on GIS environment were determined as follows: A) very sightseeing areas: this zone was determined through definition of a superficial buffer with an estimated vector of 25 kilometers from the seaside which includes most of the tourist attracting northern cities and places of the country influenced with sea. B) Average sightseeing effect zone: this zone includes the roads, which are located in an area 25 to 70 kilometers far from seaside (figures 3 and 4). C) None sightseeing effect zone: this zone includes the roads, which are located in distances farther than 70 kilometers from the seaside. The results of modeling are presented in table (4).

Table (4): the effect coefficient of three affect zones of the sub criteria the main criterion of tourism-religious places

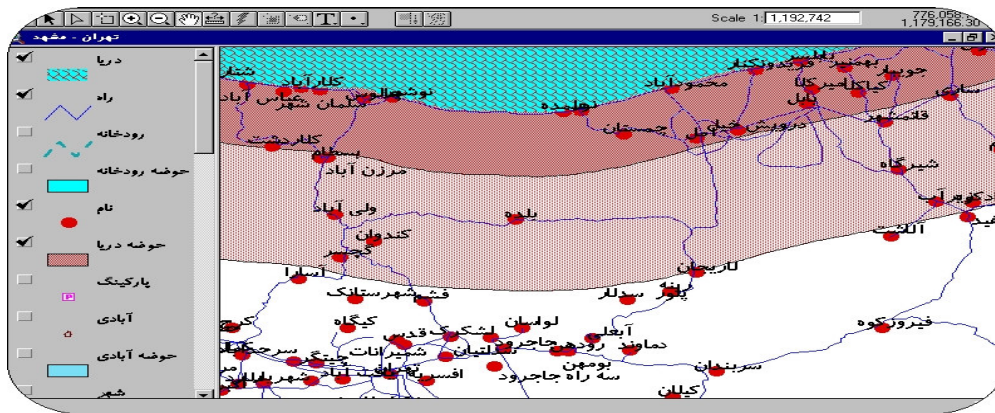| Very sightseeing zone	Semi sightseeing zone	None sightseeing zone
0.743	0.194	0.063

Figure 3 Illustration of the 25 and 75-kilometer zones and its involving cities
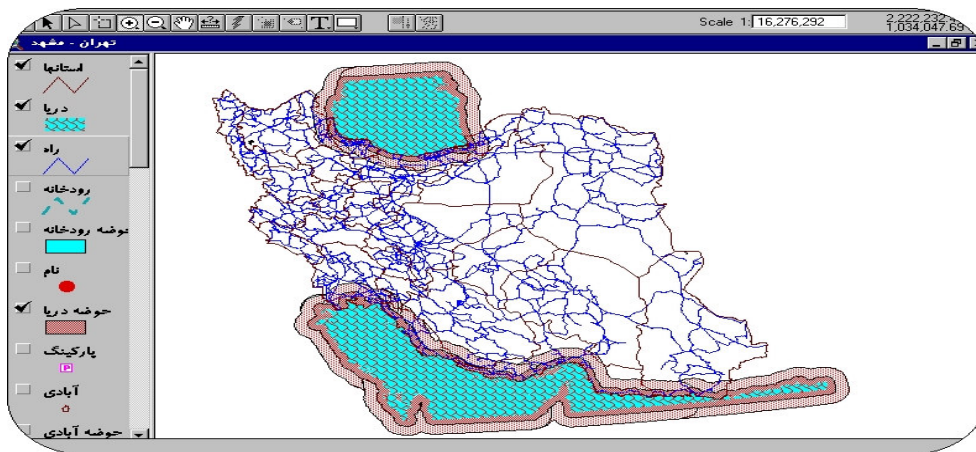

Figure 4: Illustrations of the superficial buffers have 25 and 75-kilometer zones near country's seas.

- **Average quantity of kilometers:** This method is used for those kinds of sub criteria, which have high density near inter-city roads. In this method the average quantity of sub criteria according to the distances between them based on kilometers are calculated. In these kinds of sub criteria using the buffering method could result in wrong answers. An explanation about this issue is presented bellow. In figure 5 it is supposed that both routes of AEB and ADB are similar in distance and other criteria. The square-formed points show a criterion (for example service departments) and the effect zones of these criteria are shown with circle buffers. This could be found out from figure 5 that the expansion of the effect zones of that certain criterion in both routes of AEB and ADB is similar since the buffer zone in both routes covers all the route parts, so the great quantity of special criterion in the ADB route could not be modulated. So this result could be achieved that if the quantities of criteria are that much that the buffer zones of them overlap each other, the buffer method could not be used.
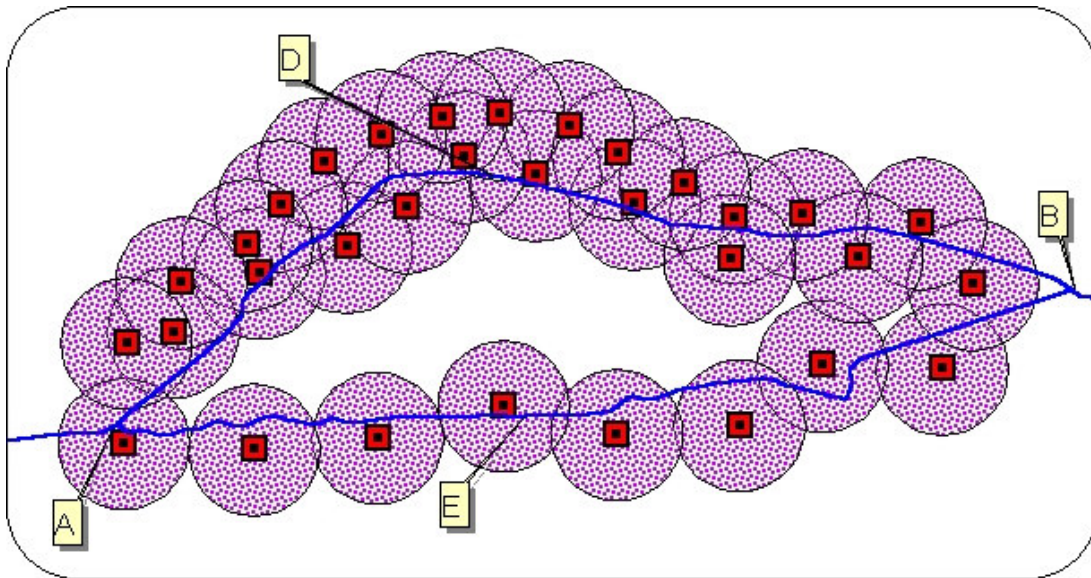
Figure 5: weakness of buffer method in the condition of near inter-city roads sub criteria multiplicity

There must be a way to answer to this question "how much is the distance between two respective criteria based on kilometers?" for this reason the method that is suggested in this theses is presented in formula 8.

$$K_x = \frac{L}{n_x}$$

8

In this formula Kx show that how much is the distance between two existing criterion "x" , L shows the length of each route part, nx shows the quantity of the criterion "x" in each route part.

After the calculation, the Kx relevant to each route part should be determined in a way that shows that in which part this criterion works well, in which one it works in an average level and finally in which one it

has an improper performance, after dividing the Kx zones for the mentioned criterion, the AHP method is implemented and the weight of each zone is determined. This issue that weather this zone division has been done properly and what is the best status, itself needs further deep and careful investigations. The criteria, which follow this method, are as follows. For the sub criteria of security criterion, sub criteria of marginal parking lots, service departments, mechanical and technical assistant departments, health and clinical service departments and telecommunication departments and sub criteria of service and terminal departments from the main criterion of facilities, the average quantity of kilometers method was applied. Zones and relevant coefficients to each zone are calculated and presented in tables 5,6,7,8,9,and 10.

Table 5: the coefficients of sub criteria of marginal parking lots, security criterion C= 0.04

Zone	Kp < 2 (good)	2< Kp < 10 (average)	Kp > 10 Weak
Weight	0.589	0.357	0.054

Table (6): The coefficients of sub criteria of service department and technical and mechanical services, security criterion

Zone	Kc < 3 (good)	3 < Kc < 20 (average)	Kc> 20 (weak)
Weight	0.542	0.396	0.062

Table(7): The coefficients of sub criteria of health and clinical services, security criterion

Zone	Kh < 20 (good)	20< Kh < 70 (average)	Kh> 70 (weak)
Weight	0.735	0.178	0.087

Table (8): The coefficients of sub criterion of telecommunication departments, security criterion

Zone	Kc < 30 (good)	30 < Kc < 100 (average)	Kc > 100 (weak)
Weight	0.577	0.324	0.081

Table (9): The coefficients of sub criterion of service departments, Facilities criterion

Zone	KSe < 20 (good)	20 < KSe < 80 (Average)	KSe > 80 (weak)
Weight	0.717	0.203	0.080

Table(10): The coefficients of sub criterion of terminals, facilities criterion

Zone	KTe < 50 (good)	50 < KTe < 100 (average)	KTe> 100 (weak)
Weight	0.250	0.750	0

6- Conclusion:

The brand-new method of cost model implementation was performed successfully in this research and showed that giving value to parts of inter-city roads on the basis of time and length in route finding analysis mostly bring about results that are opposed of real world conditions, so new criteria for giving value to road parts were identified and the final results of this study showed that answers comply with real world events.

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