

Modeling Site Selection for Roadside Service Area Complexes Using Dynamic Programming and Site Characters

Mahmoud Ameri,

Professor, Department of Civil Engineering, Iran University of Science and Technology, Tehran, I.R.Iran
Ameri@iust.ac.ir,

Iraj Bargegol

PhD Student, Department of Civil Engineering, Iran University of Science and Technology, Tehran, I.R.Iran
Bargegol@yahoo.com

Abstract

Service area in this paper is defined as a place along the a major road where facilities such as rest rooms, restaurants, repair shops, prayer rooms, and so on offer services to the public. The purposes of such an area are to provide a safe place for passengers and drivers to rest and to meet them and their vehicles with basic necessities. Various studies have been performed regarding the location, planning, and designing of service areas in many countries. Some studies have been recently conducted in Iran as well. This paper develops a solution based approach to modeling site selection for service areas along the road sides in the country. It defines the parameters affecting the site selection and modeling of site selection for service areas. Frameworks of formulating different scenarios for locating the service areas are proposed. The frameworks take into account distances between the service areas, their numbers, required facilities in such places, traffic volume and composition, demand for using of the area, and the size of the facilities and the attributes of the land needed. Factors influencing the location of service areas are explained. Finally, a dynamic programming optimization model for solving the multiple attribute decision making problems is introduced.

Key words: *Dynamic programming; Locating; Modeling; Rest Area, Service Area, Multiple Attribute Decision Making.*

Introduction

There is more than 86,000 Km of freeways and major highways across Iran [1]. Numerous service areas exist in these highways. A “service area” in this paper means any roadside facility or businesses that is open to public, is next to a major highway, and has direct access or direct access road to and from the highway¹, offering the passerby a wide variety of goods and services. These range from restaurants and gas stations to worship facilities and rest areas. There is no regulation or planning guidelines in Iran for placement and development of such facilities. It appears they have come into existence based on demand for services and local economic situation and local political action. Some locations in the country totally lack any sort of service providers where at some locations there is an overabundance and concentration of them. Service areas should be established throughout the country based on proper planning techniques considering traffic volumes, roadway class, and local conditions and so on. In some countries these facilities are built along the roadways as service center complexes. A rest area is one type of such an area. According to AASHTO “A safety rest area is a roadside area, with parking facilities separated from the roadway, provided for the travelers to stop and rest for short periods. The area may provide drinking water, restrooms, tables and benches, telephones, information displays, and other facilities for travelers” [2]. This paper identifies the factors influencing the location selection of service areas. A model is developed to help identify the appropriate location. This is a multiple criteria decision making problem. A new optimization techniques using dynamic programming is developed for the solution. First the process of preparing different scenarios is explained. Then the factors affecting the selection are discussed. At the end mathematical relationships and the optimization model are introduced.

¹ Depending on their use, they are called by various names such as safety rest area, travel plaza, truck stop, service station, roadside parking, service plaza, fuel stations, restrooms, tourist information center. Wayside Park, etc.

Literature Review

Travelers on long land trips have certain needs such as food, sanitary facilities, and a place to rest. In ancient Iran these needs were met at a caravansary. Today's traveler has service areas to cater to these needs. In 1950s the emphasis for service areas was on providing parking spaces outside the traveled way [3]. In the sixties attention was paid to maintenance and costs [4] while matters such as drinking water, garbage collection, and sanitary sewage were also paid attention to [5]. In seventies aesthetics and scenic consideration was added to it [6]. It wasn't until eighties when economics of the service areas and privatization were considered [7, 8, and 9]. Location has always been, directly or indirectly, the focus of service area studies in the past decades. In 1950s a location would be selected for a service area where adequate and safe parking area could be provided. Later location was the major consideration regarding drinking water, and sanitation. Eventually other matters such as scenic background, solar power, and so on would be considered when selecting a location for a service area [10, 11]. "Rest Area Spacing and Location" was one of the first papers that specifically dealt with service areas in 1975 [12]. In 1981 Federal Highway Administration published "Safety Rest Area: Planning, Location, Design" [2]. AASHTO addressed rest areas in 2011 edition of the green book [13]. In the same year "AASHTO Guide for the Development of Rest Area on Major Arterial and Freeway" was published [14]. Many studies have addressed the elements affecting the location selection of service areas. None, however, have addresses the relative degree to which these element affect the location selection. The existing literature does not show any studies of how these elements influence one another. This study did not come across any attempts to develop a model concerning location design of service areas. For example, the Highway Design Manual [15] introduces the elements affecting a service area decision as availability of general services (water, sewer, telephone, etc.), topography (slope, flood history, etc.), and scenic view. In Iran some studies have been conducted to develop a comprehensive plan for the location of wayward leisure and service complex centers. The Roadway Transportation and Maintenance Organization's Office of Investment and Monitoring Affairs sponsored it. The comprehensive plan contains only general guidelines for location design of a service area. This includes shape and slope of land, safety from natural dangers, low agricultural production value of the land, and natural scenery. [16] This paper examines the elements affecting the location selection of service areas. It develops a model to help in the selection of appropriate location for service areas.

Modeling: General Principles

Modeling for location selection of service areas is based on principles of civil engineering, architectures, economics, landscaping, and so on. To determine the factors affecting the location decision construction requirements as well as maintenance and operation should be considered A service area site should be located where there are advantages regarding construction, maintenance, and operation over other sites. National and regional conditions as well as government policies play a decisive role. One of the most important problems in operation of service areas is making them economically plausible. This is a widespread problem and many service areas have had to stop operating because of it. Selection of a site close to tourist attractions could help alleviate part of this problem. The attractions could range from natural, ancient, to religious sites. Figure 1 shows the general steps of modeling for selection of service area locations. This starts by dividing the study region into cells. The size of each cell depends on the area needed for the service center. Based on the each cell's location characteristics a score is assigned to each element affecting the selection of the site. Next, using the proposed relationship between each element a final scored is obtained for each cell. To do this a relative value for each element compared to other elements is needed. The last step involves selecting the optimal location using the model based on the average distance of the centers and the maximum desired distance between two centers. The result is a matrix of solution cells along with the final score of each cell.

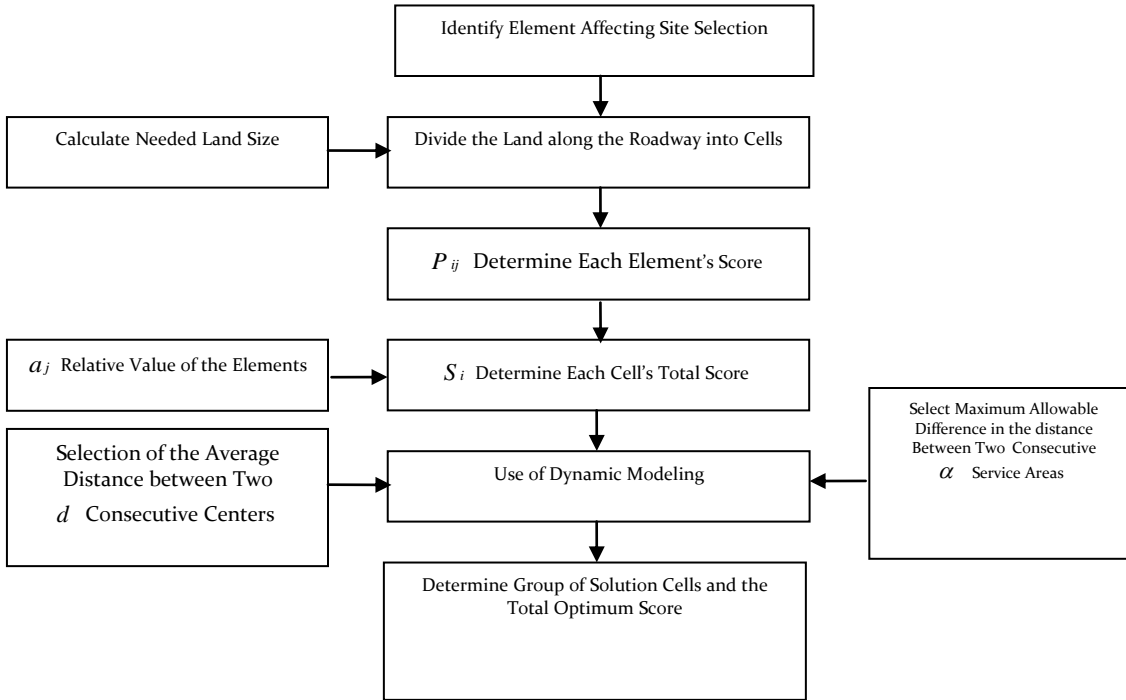


Figure 1: Site Selection Model Flow

According to figure 1, an important step in this model is determining the needed land size for the site. The size depends on the number of service areas along the specific path, available amenities at each, volume and class of vehicles to be serviced, and demand. Figure 2 shown the relationship.

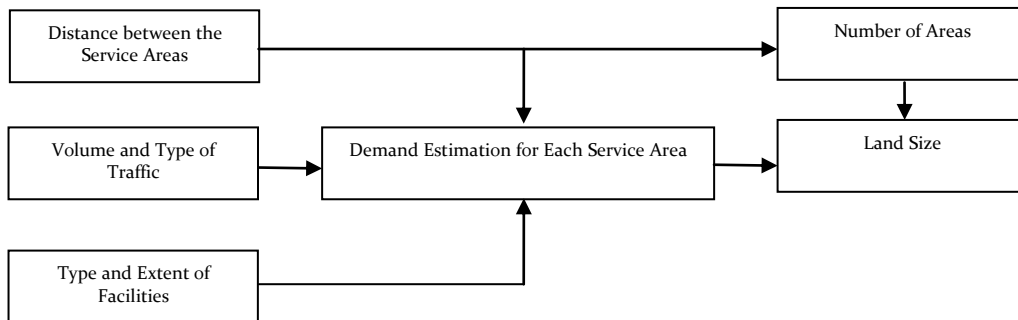


Figure 2: Flow Process of Determining the Required Land Size

Volume and mix of traffic, trip length, passenger mix, type and extent of facilities and quality of services provided at the service areas are factors affecting the demand for use of the areas. First step in this model involves determining the needed land size for the site. Assuming a fixed number of passengers, as the distance between two areas increases there will be a need to increase the size of the service areas to provide for more services. On the other hand with increasing number of service areas, the number of passengers and vehicles attracted to each individual area will decrease and it will require smaller service areas. Demand for each of them will decrease. There should be a setting assigning the maximum desirable distance between two service areas. Distance and the size of areas depend on the local climate, volume of traffic, topography and so on. In mountainous regions it is difficult to find large parcels of land for large service areas. The distance and number of service areas are the first decisions when modeling for location selection.

Land size can be calculated once the demand and extent of facilities are known. The mathematical relationships are shown under the section titled Location Selection Model for Roadside Service Centers. Roadside conditions such as climate, geography, economy, traffic, security and so on can vary drastically at different parts of the country. We need to define several scenarios from distance and facilities point of view (Figure 1) and select the best one amongst them by examining the results. Next step in modeling for location selection is reviewing the site characteristics and assigning a score to each cell along the roadway. Various fields of science are involved. There are also non-quantifiable elements such as aesthetics. These necessitate conferring with and surveying the opinions of the experts as well as the road user. A questionnaire was prepared for this purpose. The questionnaire allows the survey taker to assign a score of 0 to 10 based on the increasing importance of each element. Table 1 shows the result of this survey. It contains the effective factors as well as the relative score and standard deviation of each.

Table 1: List of Effective Factors, Relative Scores, and Standard Deviations

Row	Factors	Relative Value	Standard Deviation
1	Ground Slope	6.595	2.177
2	Soil Type	4.500	3.436
3	Geographical Direction of Hillside	2.607	4.787
4	Quantity of Water	7.310	1.969
5	Prevailing Winds	2.357	4.866
6	Danger of hillside instability	7.095	2.232
7	Risk of Earthquake	8.167	2.252
8	Risk of Floods	7.714	2.355
9	Risk of Snow Avalanche	6.833	2.237
10	Being Away From High Traffic Accident Locations	9.345	2.514
11	Proximity to Population Centers	9.107	2.751
12	Proximity to Tourist Attractions	9.119	2.810
13	Aesthetics	7.048	2.323

Figure 3 shows the results for aesthetics. This is one area where direct quantification is very hard.

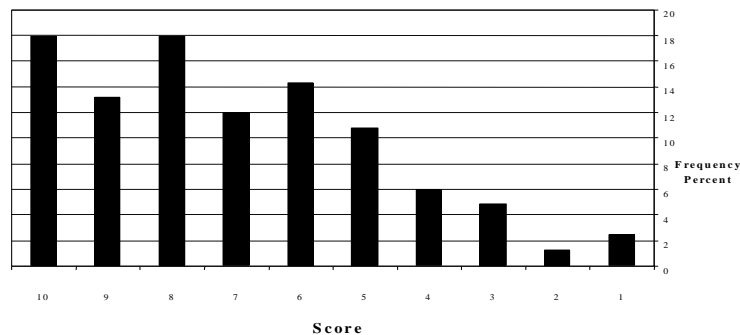


Figure 3: Frequency Percent of Aesthetics Score

Items 1, 2, and 3 are related to the important physical properties of the area. Number 4 relates to the availability of the resources in that area. Numbers 5 through 9 reflect natural dangers. Number 10 is related to traffic hazards. Numbers 11, 12, and 13 involve qualitative measures. It is important to note that natural and regional attractions Number 11, 12,13 scored more than 25 percent in Relative Value. It probably shows a change in the way people and experts view service areas as they are putting more emphasis on attractions and qualitative measures. In reality this view means that attention to attractive elements and it will prepare the background for economical use of service areas. Developing a service area in an un-attractive area with no other tourist attractions in the vicinity might eventually end up with the closure of that facility. Table 1 shows what the road users and the experts considered important. There are other factors that are important and can be similarly addressed. These factors are matters such as possibility of providing electricity, phone service, and so on, which could vary according to each location. As it was mentioned before the factors affecting the selection of a location are numerous. Some are quantitative while others are qualitative. To be able to investigate the influence of each factor there is a need to prepare a uniform measuring scale. This uniform scale will be used to convert various factors into a more comparable value. To avoid a very length paper the writers show using of the uniform scaling methodology for just two factors. These are the hillside instability and prevailing winds. Hillside instability happens when the conditions become such that the forces keeping a certain landmass in place become smaller than the forces that try to move or slide that mass. This could happen at small and slow scale such as falling rocks to large scale such as massive landslides. Land mass could fall, creep, slide, or move in a particular manner. Factors affecting hillside instability are surface waters, underground waters, geological characteristics, shear resistance of soil aggregate, slope, altitude, loading, and earthquake. [17, 18] Safety factor of safety of hillside is defines as the ratio of resisting forces over forces causing movement or pushing forces. Safety factor of 1 means stability of slope (limiting balance). Slightest increase in pushing forces makes the hillside instable. If there are people living down slope from hillside the safety factor should be at least 1.5. The danger of slope failure is estimated based on the potential severity and the probability of occurrence. Slope failure ranking is in form of no danger, low danger, medium danger, and high danger. The failures can also be classified with respect to the risk they would pose to engineered structures and human activities as no risk, low risk, medium risk, high risk, and very high risk [17, 18]. On this basis, it is recommended that roadway routs be as far away as possible from high risk and very high risk points. Avoiding the lower risk areas is also appropriate. In the present paper regarding the qualitative and quantitative factors, the mode is presented in Table 2. These principles are also true for roadside facilities built to serve the road user. Discussion on how to stabilize the slope and similar problems are out of the scope of this paper even though they were paid attention too in the studies presented here. According to this classification the locations with unsuitable characteristics are omitted from the candidate list.

Table 2: Classification of Hillside Slopes and It's Score

CLASS	DESCRIPTION	SCORE
Class 1	No Danger, Low Danger, or Low Cost Correction Possible	1
Class 2	Medium Danger, high, and very high if there are cost effective measures to control the hillside and the danger	0
Not Suitable	Medium Danger, high, and very high if there are no cost effective measures to control the hillside and the danger	-

Another factor is the prevailing winds. Prevailing winds are the winds which most frequently blow from a specific direction at a specific geographic location [19]. Usually the nuisance and incident attributed to wind are measured in “Beaufort Scale”. Table 3 shows the details of classification based on Beaufort Scale and the manifestation of trouble and incident causing of wind.

Table 3: Classification based on manifestation of wind nuisance & incident causing, in Beaufort Scale [19]

Speed (km/hr)	Manifestation	Beaufort Scale
Greater than 11.9	Pedestrians feel uncomfortable at covered passage ways	Greater than 2
Greater than 19.4	People sitting in open areas feel uncomfortable	Greater than 3
Greater than 28.4	Pedestrian, especially the elderly, feel uncomfortable walking	Greater than 4
Greater than 33.3	Elderly bicyclists loose balance	Greater than 5
Greater than 44.1	Children and the elderly walking around buildings loose their balance	Greater than 6
Greater than 55.8	Adults (young and middle age) loose their balance while walking	Greater than 7

Based on the nuisance manifestations mentioned in Table 3, and based on the policies considered in this paper, wind affect classification is recommended as shown on Table 4.

Table 4: Prevailing wind effects and score

Class	Beaufort Scale	Speed (km/hr)	Score
Class 1	Less than 4	Less than 19.4	1
Class 2	Less than 6	Between 19.4 up to 44.3	0.5
Class 3	Less than 7	Between 44.3 up to 55.8	0
Unsuitable	Greater or equal to 7	Bigger or equal to 55.8	-

Location Selection Model for Roadside Service Areas

Roadside land is divided into cells. Each cell is analyzed separately based on the ranking criteria introduced for measuring the suitability of that cell for a service area. Cell sizes depend on the distance between service areas scenario and the topography. In this section mathematical relationships are used to analyze some of the parameters mentioned earlier. The mathematical methodology to obtain a combined score for each cell, and the model for finding the optimum location follow. Available parking size to accommodate various types of vehicles is one of the most important factors affecting the volume of attracted traffic. The relationships shown below can be used to estimate the amount of attracted traffic.

$$DDHV = AADT \times k \times D \quad (1)$$

$$S_l = S_L \times \frac{l}{L} \quad (2)$$

$$N = AADT \times k \times D \times S_l \times PF \quad (3)$$

$$N_p = \frac{AADT \times k \times D \times S_l}{T} \quad (4)$$

Where:

DDHV = Design directional hourly volume

AADT = annual average daily traffic

k =ration of peak hour volume to *AADT*

D =ratio of peak direction volume (*D* =1 for undivided highways or if service area serves both directions)

L =total route length

l =average distance between two consecutive service areas

S_L =percent attracted traffic to all service area along the total route length

S_i =percent attracted to each complex (which is proportional to average distance between two areas compared to the whole route distance)

N =peak hour number of vehicles attracted to each complex

T =design hour parking turn over

N_p =needed parking space for various types of vehicles during peak hours

P_i =percent of type i vehicles

The following equation shows the number of type i vehicles. Using average occupancy numbers, size of needed facilities can be estimated.

$$N_i = \frac{AADT \times k \times D \times S_i}{T} \times P_i \quad (5)$$

$$P = \sum_{i=1}^o (N_i A_i) \quad (6)$$

N_i =design hour number of parking spaces needed for type i vehicles.

o n=number of various classes of vehicles permitted to use the service area².

A_i =average occupancy of class i vehicle.

P =number of vehicle occupants using the service area during the design hour.

Determination of the average numbers for Iran needs extensive data collection, which has already started. Required number of service areas depends on the distance between two cities and the distance between two consecutive service areas. It is obtained by using the following equation.

$$n = \left\langle \frac{L}{d} \right\rangle - 1 \text{ s. where } \left\langle \frac{L}{d} \right\rangle \text{ is the rounded up value } \frac{L}{d}. \quad (7)$$

This assumes no service areas next to the cities. If for reasons such as security or providing certain services, service areas are built next to the cities, then the following will apply.

$$n = \left\langle \frac{L}{d} \right\rangle + 1 \quad (8)$$

n =Number of service areas required along the

L =Distance between the two cities measured along the route in km.

d =Average distance between two consecutive service areas.

By recognizing the elements, which affect the location selection, and assigning a relative weight to each element, it will be possible to come up with the total relative weight or score for each cell.

² In Iran and some other countries certain service areas only admit certain class of vehicles.

The weight or score of each element in each cell depends on the land size in the scenario. As the land size changes other elements might surface. For instance, suppose three scenarios with areas of 1, 3, and 5 acres are possible. The 1 acre scenario has the right slope. As the size increases to 3 acres some earth work is needed to obtain acceptable slopes. The 5 acres scenario will need additional improvements to stabilize the land mass. Each of these elements will have their own favorable or less favorable scaling in each scenario. Gains added by increase in land area might be offset by other requirements.

Total weight of score for each cell is obtained by the following relationship:

$$S_i = \sum_{j=1}^m a_j P_{ij} \quad (9)$$

Where:

S_i = Total score for cell i ,

P_{ij} = The j^{th} element's effect in cell i ,

a_j = Relative value of j^{th} element obtained from Table 1.

m = Number of elements affecting the location selection.

This paper uses compensatory method for Multiple Attribute Decision Making (MADM). In this method passing scores between selection criteria in each cell is allowed. [20]

In this section, the goal from modeling is to locate places for service areas so that the mean distance between the service areas are observed and the total score for the selected cells are maximized. This is written as the following equation:

$$\text{Max } Z = \sum_{j=1}^m S_j X_j \quad (10)$$

With the limitations of:

$$d_{i+1} - d_i \leq (1 + \alpha)d \quad (11)$$

$$d_{i+1} - d_i \geq (1 - \alpha)d \quad (12)$$

$$X_j : \text{ zero or 1 variable . (13)}$$

Where:

Z = Summation of total score obtained from selecting n cells along the routes for location of complex center

m = Number of cell considered for location along the route

n = Number of needed complexes along the route

S_j = Total score for each cell j

X_j = Equals 1 if selected and equals zero if not selected

d = Average determined distance between two consecutive complexes

d_i =Distance of complex number i complex from the origin

α =maximum allowable difference in distance between to consecutive complexes ($0 \leq \alpha \leq 1$)

This model is an optimization model. Considering the goal of “finding locations for service area by keeping the required distances but maximizing the total score of all the selected cells”, the variables dependent on the goals and the limits are not of the same type. Solving this problem with normal optimization methods will be extremely hard and only dynamic programming could offer a solution. Dynamic programming model is a mathematical programming technique, which makes solving problems involving a series of multiple decision making stages possible. [21]. First stage involves selecting the first cell amongst all cells. Second stage selects the second location considering the first selection. This continues until the n th location is selected based on the optimum location for the $n - 1$ location. This can be translated into a mathematical form shown as follows:

$$Z_1^*(\beta_1, X_1) = \text{Max} \{S_1(\beta_1, X_1)\} \tag{14}$$

$$Z_2^*(\beta_2, X_2) = \text{Max} \{S_2(\beta_2, X_2) + Z_1^*(\beta_1, X_1)\} \tag{15}$$

$$Z_i^*(\beta_i, X_i) = \text{Max} \{S_i(\beta_i, X_i) + Z_{i-1}^*(\beta_{i-1}, X_{i-1})\} \tag{16}$$

Where:

i =Stage number

n =Number of Decision making stages in dynamic programming (number of needed complexes)

β_i =Dependent representing the situation or being included in the decision making stage of the i th complex.

X_i =Decision making variable in i th stage considering the situation β_i

$S_i(\beta_i, X_i)$ =Benefit of the total score of the stage i considering the decision X_i and situation β_i

$Z_i^*(\beta_i, X_i)$ = Optimum goal dependent or sum of total optimum scores of the selected cells for location of a complex to stage i considering decision X_i and situation β_i

The decision making method and stages of modeling is shown on figure 4. Backward Process model is used.

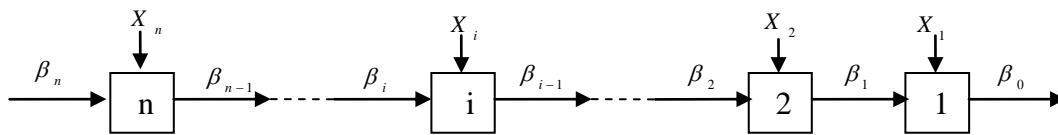


Figure 4: Diagram Showing the Decision Making Process and Stages of Dynamic Programming

The above model is for locating service areas along one route. Normally the service areas are located along major highways and freeways [14]. Figure 5 shows some situations where service areas are considered for an area.

selected then the next cells with 5, 6, and 7 distances from that could be candidates for next selection. (In the proposed model of this paper the maximum allowable percent difference between two consecutive service areas ($0 \leq \alpha \leq 1$) is used for this purpose).The above description is shown as tree decision making network in Figure 8. This figure includes the information for solving the model. Any combination of cells between point A and B on the tree diagram is a possible solution. For example a solution for the above route includes cells A, 5, 10, 15, 20, 25, B. Solving the problem by dynamic programming and given the problems requirements and data, the combination of cells A, 5, 10, 15, 21, 26, B with total score of 299 is the final solution.

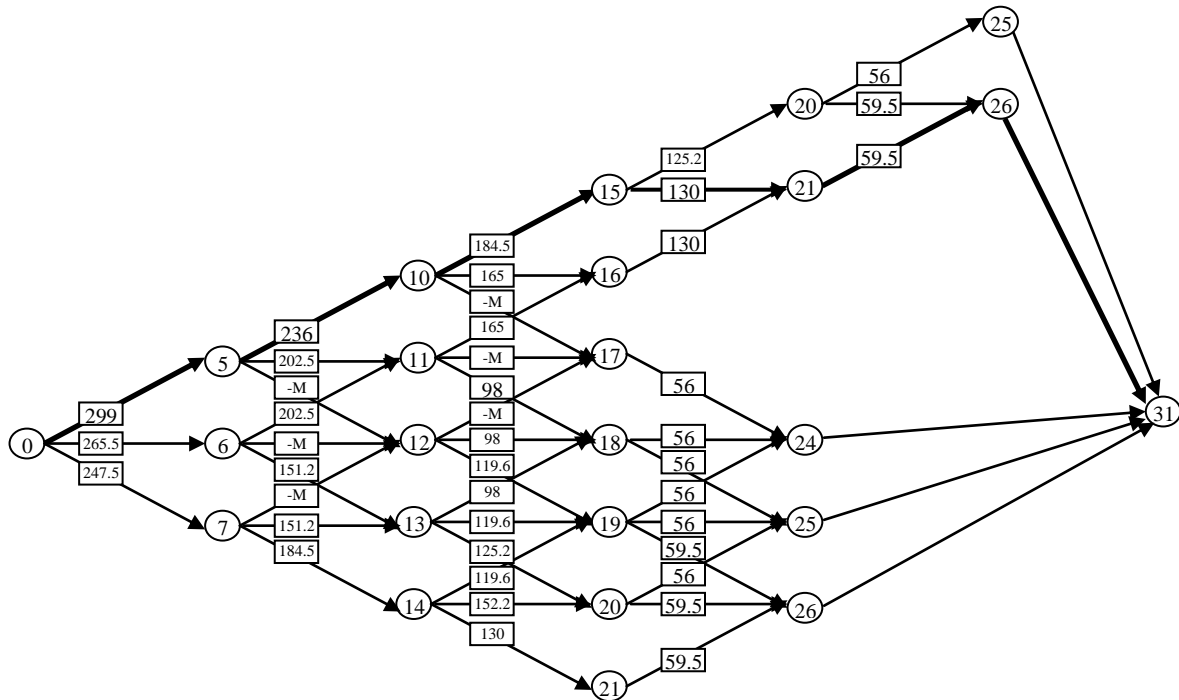


Figure 8: Decision Network and Roadside Cell Information in a Dynamic Programming Model

Conclusion

This paper is an effort for identifying the elements affecting location selection of roadside service areas and modeling the location selection. Based on the result of this study it is possible to consider a set of affecting elements for scoring of each cell. These elements could relate to physical characteristics, resources, support services, natural and traffic hazards, and natural and regional attractions, etc. Quantification of the affecting elements and the ability to compare each cell is another result of this study. The optimization model presented here makes it possible to investigate the outcome of constructing a service area before any construction activity takes place. This study, from the point of view of precise recognition and scoring the elements and using a mathematical model, is the first of its kind in Iran for location selection of service areas. The proposed mathematical model used in this study is of no precedence worldwide. Recognizing the possibility of using dynamic programming, has provided for a wide set of tools for modeling the location selection of roadside service areas. This model can easily accommodate any new condition without having to substantially change the type of the model or its general form. As an example of new conditions we can refer to the conditions relating to any of the effective location selection elements mentioned (Table 1) or conditions regarding the physical dimensions of each of the service complexes. It would be extremely difficult to model the location selection of service areas with other modeling techniques. This is due to the fact that there are many variables and limitations that affect the goal variable. The proposed model has a very high ability to define the problem and solve it and this is another concurrence to the ability of dynamic programming to solve very complex programs so that we can convert them to consecutive decision makings.

References

1. Iran Statistical Center, Official Results of Census of Populations and Houses of Iran, 2011.
2. Minnesota and Dept. of Transportation. , 2004. "Report to the LEGISLATURE on the Minnesota Department of Transportation Rest Area Program".
3. Gordon, G. B. (1952), "Parking Turnout and Rest Areas", Highway Research Board.
4. Cardone, S. M. (1965), "Maintenance Cost of Rest Areas in Michigan", Highway Research Record.
5. Johnson, R. L. (1967), "Report on Rest Area Water Systems for Interstate Highway", Iowa State Highway Commission, USA.
6. Adams, D; Reiersen, J (1981), "Safety Rest Areas; Planning, Location, and Design", Transportation Research Record.
7. Phillips, A. W. M.; Perfater, M. A. (1991), "Opportunities for the Privatization of Virginia's Rest Areas and Welcome Centers. Final Report", Report Number: VTRC 91-R27.
8. Kress, E. N.; Dornbusch, D. M. (1991),"Commercialization of Rest Areas in California", Transportation Research Record.
9. AASHTO (1991), "Final Report of the AAHTO Standing Committee on Highways Task Force on Commercialization of Interstate Highway Rest Areas"
10. Transportation Research Board (1986), "Proceedings of the 1986 mid-year Meeting of the Landscape and Environmental Design Committee (AzA05) of the Transportation Research Board, San Diego, California.
11. Rock-BA; Vliet-GC (1986), "Evaluation of Energy Sources for Roadside Rest Areas. Interim Report", Texas University, Austin, Center for Transportation Research, Austin, TX, 78712, USA; Texas State Department of Highways & Public Transp, Transportation Planning Division.
12. Werner, A. (1975), "Rest Area Spacing and Location", Proceedings Western Association of Canadian Highway Officials.
13. American Association of State Highway and Transportation (2011), A policy on Geometric Design of Highways and Streets, 6th ed., Washington DC.
14. American Association of State Highway and Transportation (2007), "AASHTO Guide for the Development of Rest Area on Major Arterial and Freeway, 3th ed., Washington DC.
15. Caltrans, (2012), Highway Design Manual, California State Department of transportation.
16. Road Maintenance and Transportation Organization, Office of investment and supervision of operation of Iran (2000), Final Report "comprehensive plan for locating service centers".
17. Memarian, H. (2013), "Geological and Geotechnical Engineering", the sixth edition, Tehran University Press.
18. Harris, Charles W. and Nicholas T. Dines (1998), "Time Saver for Landscape Architecture", 2nd, McGraw-Hill Publishing Company, New York.
19. Razjuyan, Mahmoud (2008), "Peace under the Protection of the Wind", Second Edition, Shahid Beheshti University Press.
20. Asgharpour, MJ (2008), "Multiple Criteria Decision Making", Fifth Edition, Tehran University Press.
21. Asgharpour, MJ (2011), "Dynamic Programming", Fourth Edition, Tehran University Press.