FACILITY LOCATION DECISION UNDER DEMAND UNCERTAINTY AND TRAVEL TIME FLUCTUATION

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Abstract: *This study solves the facility location problem of an IT service company whose main problem is to arrive at the customer's site in the shortest time when support is needed. This problem should consider both the demand of the customers and the distance and/or travel time between the customers and the company. Travel times and demand are not constant since they are affected by many factors. Therefore, one should take into account uncertainty. This study formulates the problem by considering the demand as fuzzy and travel time as varying based on different time intervals, which are defined hourly, daily and seasonally. Moreover, we consider the cases of minimum speed, average speed and maximum speed for travel time. We illustrate the application of the proposed framework using data of a company. We compare the proposed framework with the traditional distance based optimization approach and show the advantages of the proposed method.*

Keywords: *transportation-location problem, fuzzy demand, travel time fluctuation.*

1. INTRODUCTION

Considering the previous literature, this study contributes to the literature widely by deciding on the optimal facility location and route selection at the same time. It is based on both uncertainty of the travel time from facility node to the demand node and demand uncertainty. Moreover, the uncertainties are defined hourly, daily and seasonally, which covers all the time intervals that the company provides service in a year. Thus, all possible conditions of traffic and demand variability are taken into account. When the transportation literature is examined, it can be seen that effects of weather conditions have been commonly modeled in the transportation forecasting literature [1], [2] and [3].

Moreover, time of day is treated as a significant factor that represents the level of demand for the transportation services and the traffic situation during different hours of the day [4], [5], [6], and [7]. Similarly, many studies have demonstrated the variation of traffic volume in different days of week and vacation times [2], and [7]. Besides this, the travel time is modeled in 3 levels, i.e. worst, best and most likely, in order to handle the uncertainty better.

For illustration, the proposed approach solves the transportation location problem for a service company which provides information technologies (IT) support for its customers. The problem considers a "one facility and many customers" case. The company's main problem is to arrive at the customer's site in the shortest time when support is needed. Therefore travel time and demand variability should be considered while selecting the optimal facility location and optimal routes from the facility to the customers. The company and the customers are in Istanbul and Istanbul is one of the most crowded cities in Europe with high traffic density, which makes the problem necessary to be solved.

The paper consists of three more sections. The second section introduces the proposed framework while section 3 presents the application of the proposed framework. Conclusion and further research finalize the paper.

2. PROPOSED FRAMEWORK FOR THE TRANSPORTATION-LOCATION PROBLEM UNDER TRAVEL TIME FLUCTUATION AND DEMAND UNCERTAINTY

This study proposes a framework for the transportation-location problem involving travel time and demand uncertainties. The travel time varies for each route based on time, hence it is uncertain. Moreover, the demand of the customer is not known since there is no past data and it is a subject of uncertainty, too. However, it is apparent that it varies based on time intervals for companies that serve their customers on call. In the problem setting that is considered in this study, the number of facilities to be located is one, but the number of customers is more than one. The company serves the customer at their location and when a call from a customer comes to the company, an agent in the company drives to the customer. The customer does not have a constraint about the arriving time; however, the agent should be at the site of the company as soon as possible. The assumption in the problem setting is that, there is no capacity limit and the company always has enough employees to send to the customers for service. When all these facts are considered together, the following framework is proposed to solve the facility location problem:

Step1: Determine alternative facility locations.

Step2: Find the routes that connect the customers to the alternative facilities

Step3: Determine the number of time intervals (r) that will cover all the service hours of the company.

Step4: Find the probabilities of demand from customer i at time interval k
These probabilities show the probability of customer demand. In this study, the case that there is no past data about the customer demand is considered. However, the experts in the company have some experience about the customer demand. Therefore, FRBS supported by expert opinion is used in order to model the data. After constructing FRBS, the demand probabilities corresponding to each time interval k is derived from this system.

Step5: Find the travel time to customer i when route j is selected at time interval k
This information can be found from the traffic data and Geographic Information Systems (GIS).
Step6: Formulate the problem as a mathematical model and solve the problem minimizing the travel time x demand. Find the optimal routes that should be followed at specific time intervals.

Given that there are n customers, m routes, r time intervals, and u alternative facilities, the problem can be formulated as an integer programming model by the following equation set (1):

$$\min \sum_{l=1}^{u} \sum_{i=1}^{n} \sum_{j=1}^{m} \sum_{k=1}^{r} \left(p_{ik} * t_{iklj} * y_{iklj} \right) \tag{1}$$

subject to

$$\sum_{j=1}^{m} y_{iklj} = 1 \quad \forall_i \, \forall_k \, \forall_l \,, \; \sum_{l=1}^{u} z_l = 1 \,, \; y_{iklj} \leq z_l \quad \forall_l, \qquad y_{iklj}, z_l \in \{0, 1\} \tag{2}$$

where

p_{ik}: probability of getting a call from customer i at time interval k

t_{iklj}: travel time to customer i at time interval k from facility l when route j is selected

y_{iklj} : binary variable which denotes whether route j is selected in order to go to customer i from facility l at time interval k

z_l : binary variable which denotes whether facility l is selected

The first constraint in the model ensures that only one route is selected from facility l to customer i at time interval k. The second constraint is to make sure that only one alternative facility is selected. The above mathematical model can be solved optimally by using integer programming solution techniques.

Step7: Compare the results with the distance based approach where traffic density is not considered.

3. APPLICATION OF THE PROPOSED FRAMEWORK

The illustration of the proposed framework is performed for an information technologies (IT) support company in Istanbul.

Step1: The alternative facility locations are determined by the experts in the company. The alternative facilities are selected by considering available office locations, the closeness to the customers, commercial areas, and closeness to the main transportation roads. There are 3 alternative facility locations, two of the alternative locations are in the Asian side of Istanbul and one is in the European side of the Istanbul. Two of them are chosen from the Asian side since most of the customers are there.

Step2: The company has six customers and there are 43 alternative routes in total that connect the 3 alternative facility locations to the 6 customers. Since Istanbul is a city that connects two continents (namely, Europe and Asia), the customers and alternative facility locations are on both side of the city, and there are two bridges that connect the two continents, there are several alternative routes for each combination.

Step3: Determine the number of time intervals (r) that will cover all the service hours of the company.

The number of these time intervals is determined as 160, which covers all the days in a week, all hourly time intervals in a day and all seasons in a year. There are five weekdays, 8 hourly time intervals that the company serves (10.00-11.00, 11.00-12.00, 12.00-13.00, 13.00-14.00, 14.00-15.00, 15.00-16.00, 16.00-17.00, 17.00-18.00) and 4 seasons. Hence the combination results in 160 different time intervals. The aim was to cover all possible time intervals since the traffic conditions differ substantially among weekdays, hours in a day and weathers. For instance, during rush hours, traffic is really crowded in Istanbul. Moreover, in winter the severity increases due to increased number of accidents and necessity of driving slow.

Step4: FRBS is used to find the demand probabilities. In order to identify the variables in the FRBS and to fuzzify the variables, experts are consulted. The fuzzy inference system offered by MATLAB 7.6.0 fuzzy logic toolbox is used in this study. Using the IF-THEN rules, the probability of getting a service demand at a specific time interval is estimated based on the input variables of weather condition, day of week and time of day. The determined variables have effects on both the demand of the customers and traffic conditions. The experts state that demand of the customer varies across day of week and time of day. It also varies with seasons since in summer, most of the people are on vacation and demand decreases relatively.

In the fuzzification step, the membership functions of the input variables are defined using expert opinion. Time of the day is represented by the linguistic variables of early, mid and late. Early is standing for the beginning of the week and late for the end of the week (weekend is not considered since the company does not work at weekends). Demand is also related to the time of the day so the discrete hours of the day have been defined by four levels of linguistic variables namely early, mid, late and very late. Finally, the numerical value of "probability of getting a call from the company" has been used as the demand level, which is the output of the model. Demand levels are represented by the very low, low, medium, high and very high terms. Using the rule-based system, demand probability derivation is achieved and used in the optimization model. In the literature, triangular and trapezoidal fuzzy numbers are frequently utilized for fuzzy applications. In this study, both triangular and trapezoidal fuzzy numbers are used to consider the fuzziness of the decision elements. The membership functions are defined by the experts working in the company. Functions of one of the input variables and output variable are given in Figure 1.

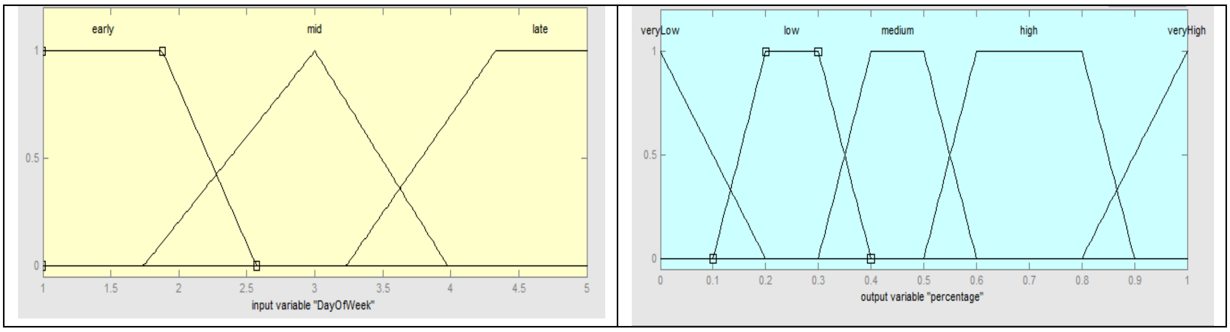

Figure 1. Membership functions of one input variable: day of week (on the left) , and output variable: demand level (on the right).

The rules are defined for each customer and for each season (summer, fall, winter, spring). The main difference among these customers is that, the demand level is never very high for Customer 4. After constructing FRBS, the demand probabilities corresponding to each time interval k for each customer are derived from this system.

Step5: We find the travel times for each route at time different time intervals from the past traffic data of Istanbul Metropolitan Municipality. We consider the cases of minimum, average and maximum travel time for each route in order to make a sensitivity analysis. Hence, we can make the decisions under the worst case, best case and the most likely case.

Step6: Having the above explanations and motivation, we use the travel time data (taken from Istanbul Metropolitan Municipality for last three years) and demand data (from FRBS) to solve the mathematical model. For all the scenarios, the results show that AF_3 (Alternative Facility 3) has the minimum objective function value (best scenario: 87. 4 most likely scenario: 95.9, worst scenario: 111.2). In fact it is expected to select either AF_2 or AF_3, since they are roughly in the middle of all the customers. The resulting optimal routes for AF_3 are shown in Figure 2. The explanations about the optimal routes at different time intervals from AF_3 to the customers are given below.

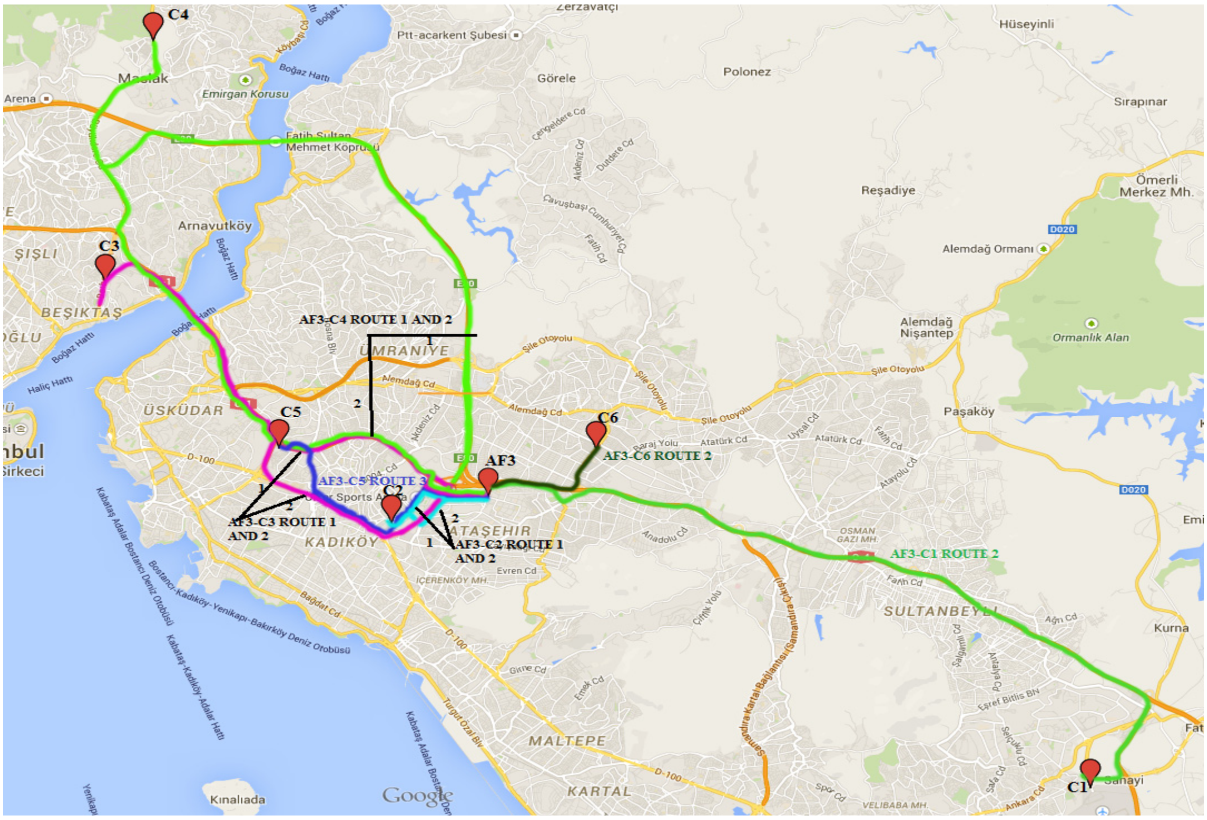

Figure 2. Alternative routes from alternative facility 3 (AF-3) to customers

From AF_3 to C_1 (Customer 1), the advantageous route is route 2 in all time intervals and in all scenarios while the optimal route from AF_3 to C_2 is route 1 in all time intervals for all scenarios. However, for the best scenario for AF_3 and C_2, in summer route 1 and route 2 have the same values which yield to alternative solutions for this season. This result is due to the fact that most of the people are on vacation in summer and the roads are less busy, so travel times on the routes are close to each other.

For the worst scenario, the optimal route from AF_3 to C_3 in spring and in winter is route 2 in the middle hours of the day, but in other time intervals, route 1 is optimal. However, in summer in all time intervals route 1 is optimal. In fall, it is advantageous to use route 2 in late hours of day. However, for the best and most likely scenarios, the optimal route is route 1 in all time intervals.

For all scenarios, the results show that in spring from AF_3 to C_4, the advantageous route is route 1 in the middle hours of the day while it is route 2 in other time intervals. The optimal route is usually route 2 in summer for all scenarios. For the worst scenario, for fall and winter, it is difficult to make a generalization since the optimal route changes among days and hours. However, for the best and most likely scenarios, in fall and winter the optimal route is route 2.

For all time intervals and for all scenarios, the optimal route from AF_3 to C_5 is route 3. Therefore independent from being pessimistic or optimistic, the driver can select route 3 at all times. Again for all time intervals and for all scenarios, the optimal route from AF_3 to C_6 is route 2.

Step7: When we solve the problem by using solely the distances instead of travel times (as in the traditional approach), we find that again AF_3 is the optimal location. We see that the optimal route for C_1 is route 2, for C_2 it is route 1. These results are similar to the results in the proposed approach. However, for the best case and for summer sometimes using route 2 is also advantageous for C_2 in the proposed approach. For C_3, the shortest distance belongs to route

1. In the proposed approach the optimal routes were selected as route 1 and route 2 for different time intervals. The proposed approach shows the optimal routes for C_4 are sometimes route 1 and sometimes route 2. However, route 2 is shorter than route 1. In fact these two routes use different bridges that connect the Asian side and European side of Istanbul, and since the first bridge that is used in route 2 is usually busier, it is sometimes advantageous to use the other route (route 1). The shortest routes are the same as the optimal ones in the proposed approach for customer 5 and 6.

4. CONCLUSION AND FURTHER RESEARCH

The results revealed in the study show that the optimal route and facility location decisions are time dependent. It is also seen that travel time volatility and uncertainty has a significant effect on the route selections. This study contributes the facility location problem with the selection of optimal routes for different time intervals simultaneously. The results show that, time dependent traffic conditions significantly affect the optimal route decision and uncertain demand is also an important factor. Additionally, FRBS is seen as a useful technique for the demand prediction. Moreover, the optimal routes change for different time intervals for different scenarios and the optimal facility location is robust to these scenarios.

Best, worst and most likely scenarios are considered in this study in order to address the uncertainty and fluctuation. In the best scenario, the travel time on a route at that specific time interval is the minimum realized travel time in the real dataset. In the worst scenario it is the maximum and in the most likely scenario it is the average.

Nowadays, technology offers us the availability of traffic data, therefore we should make use of it more. This study is an attempt to achieve this, by using the past data on the traffic conditions on different routes in a very big and highly-populated city, namely Istanbul. Further research can be carried for many locations to many customers case. The implementation is limited in this article and it can be solved for a bigger case in order to see significant results. Moreover, the study can be widened by adding the return routes, too.

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