Post-Disaster Casualty Logistics Planning for Istanbul

by

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A Thesis Submitted to the

Graduate School of Engineering

in Partial Fulfillment of the Requirements for

the Degree of

Master of Science

in

Industrial Engineering

Koç University

July 2008

Koç University

Graduate School of Sciences and Engineering

This is to certify that I have examined this copy of a master's thesis by

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and have found that it is complete and satisfactory in all respects,
and that any and all revisions required by the final
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To my parents

ABSTRACT

In this thesis, we analyze post-disaster casualty logistics for an expected earthquake for Istanbul using multi-period mixed integer programming (MIP) models. We first present a dynamic casualty transportation model to assess the expected performance of the emergency response system under most likely disaster scenarios. System performance is measured by the total travel and waiting time of casualties over the planning horizon. The MIP model minimizes these objectives subject to the availability of ambulances and emergency care capacity of hospitals in each period. The model results showed that a large percentage of casualties could not be served within reasonable time. Hence, additional service capacity has to be provided by establishing temporary emergency units (TEU) after the disaster. To determine the location of the additional emergency units, a joint casualty transportation and temporary emergency unit location model is proposed. In addition to minimizing the total travel and waiting time of casualties, a TEU set up cost is incorporated into the objective. The system performance was evaluated by solving the model under various scenarios differing in the travel times due to possible road blockage, estimated number of casualties in different districts and different healing rates at the emergency units. The results indicate the location and the size of additional capacity needs.

ÖZET

Bu tezde, İstanbul'da olması muhtemel bir deprem için, afet sonrası yaralı taşıma lojistiği, karışık tamsayı programlama modeli kullanılarak analiz edilmiştir. Dinamik bir yaralı taşıma modeli oluşturularak mevcut acil yardım sistemlerinin durumu beklenen senaryo depremleri altında değerlendirilmiştir. Sistem performansı değerlendirmesi, belirlenen süre içerisinde yaralıların toplam taşınma ve bekleme süreleri kullanılarak yapılmıştır. Karışık tamsayı modeli bu amaçları en küçüklemeye çalışırken, her periyotta, ambulansların bulunabilirliğini ve acil yardım merkezlerinin kapasitelerini de göz önünde bulundurmaktadır. Sonuçlar, mevcut sistemin olası deprem durumunda yetersiz olduğunu ve yüksek oranda yaralının makul sürelerde taşınamadığını göstermiştir. Bu sebeple geçici medikal servislerin kurulması suretiyle ek acil yardım istasyonları sağlanmaya çalışılmıştır. Geçici acil yardım merkezlerinin yerini ve gerekli kapasiteleri belirlemek amacıyla birleşik yaralı taşıma ve geçici acil yardım merkezi kurulum modeli oluşturulmuştur. Yaralıların toplam taşıma ve bekleme sürelerine ek olarak, geçici medikal merkez kurulum maliyeti amaç fonksiyonuna eklenmiştir. Sistem performansı modelin yol kapanmasından kaynaklanan seyahat süresi farklılıkları, değişen yaralı sayıları ve iyileşme oranları esasına dayanan farklı tip senaryolarla çözülmesiyle değerlendirilmiştir. Sonuçlar geçici merkezlerin yerleşimi ve gerekli kapasite miktarlarını göstermektedir.

ACKNOWLEDGMENTS

First and foremost I would like to thank my thesis advisor F. Sibel Salman for her enthusiastic and helpful supervision in all steps of this study. Without her assistance, this thesis would not be possible and I have learned and achieved a lot due to her guidance and help.

Also, I am very grateful to Lerzan Örmeci and Evrim Didem Güneş for taking part in my thesis committee, for critical reading of this thesis and for their valuable suggestions and comments.

I am also very grateful to Tubitak BIDEB Turkish Scientific and Research Council for providing me the scholarship during this study.

I would like to thank all of my friends at Koc University, Ferda, Figen, Pelin, Seray, Uğur, Selim, and Güven for their valuable suggestions and encouragement when I needed. I am very happy to meet such people who possess success, kindness, and fun together and to be part of their friendship. I also want to thank my other friends Fulya, Banu, Şirin, Sinem, Gözde, and Evren for their precious support to encourage me at my hard times.

Also, I would like to thank Dr. Metin Çancı and Duygu Var in Istanbul Metropolitan Planning; Department of Logistics for providing detailed data of Istanbul for the implementation of the model. I am also grateful to Bülent Dik and Murat Yücesoy in Acil Yardım ve Can Kurtarma Müdürlüğü for their guidance and sharing of data.

I am very grateful to my family for being with me in every time and for their endless and supporting love. Without them, any success I achieved would not be possible.

The last but not the least, I especially would like to thank very much to my best friend, my fiancé Muhammet for his valuable and everlasting encouragement and permanent belief in my life. I feel very lucky to spend many good and bad times with him and overcome many obstacles with his endless joy.

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NOMENCLATURE

TEU	Temporary Emergency Units
LSCP	Location Set Covering Problem
MCLP	Maximal Covering Location Problem
MEXCLP	Maximum Expected Covering Location Problem
SQE	Stochastic Queue Median
CALL	Computerized Ambulance Location Logic
DARP	Dial-a-Ride Problem
ACO	Ant Colony Optimization
SMF	Successive Maximum Flow
JICA	Japan International Cooperation Agency
IMM	Istanbul Metropolitan Municipality
MIP	Mixed Integer Programming
VN	Vehicle Number
PH	Private Hospital

Chapter 1

INTRODUCTION

Patient transportation is a crucial logistic problem because of its urgency and the inherent risk of of human life. The problem has been addressed in the Operations Research literature mostly in terms of the deployment and dispatching of emergency medical services. Almost all models proposed were tested with real life data from various cases worldwide. In day-to-day incidents, because the number of patients is not massive, patients are typically taken to the nearest facility and served in first come first served order. When the scale of the incident increases, the situation changes. In a disaster, a massive number of casualties who need immediate care emerges. Since the existing capacity will be most likely insufficient, simple policies may no longer be applicable.

It is well known that natural and human-made disasters have the potential to cause huge damages in large areas in a short time frame. Due to the chaos after the disaster and the high damages, the current emergency medical system may be locked. As part of disaster preparedness, the existing medical system should be assessed and effective emergency logistics plans should be generated. Altay and Green [1] grouped the studies in disaster management under four stages: mitigation, preparedness, response, and recovery. Casualty transportation is one of the critical response activities for which preparations and planning must be carried out before a disaster. Planning is complicated due to uncertainties associated with the disaster. For example, predicting the timing, the magnitude, and the impact of an earthquake is difficult. Any planning activity has to consider the possible disaster scenarios and estimate the circumstances arising in the aftermath of the disaster.

When addressing the post-disaster casualty transportation problem, a number of issues should be considered. Ambulances serve casualties simultaneously without coming to their first stations. This implies that ambulance locations should be tracked over time. The available capacities of the medical units and the number of casualties waiting to be served should be updated over time. When there is no capacity in the nearest emergency medical unit, rather than waiting for service, a casualty may be transported to a hospital out of the regional area of the ambulance. For casualty transportation throughout the disaster situation, typically the first twenty four hours and the following two days are critical, during which the transportation activity continues. A planning horizon consisting of multiple periods is needed to capture the dynamic nature of the operations. In addition to these, the uncertainties in disasters such as the number of casualties and the condition of infrastructure systems should be incorporated with different scenarios to the problem.

In this thesis, we propose two mathematical models for post-disaster casualty transportation logistics. In the first model, we minimize the total travel time of served and total waiting time of unserved casualties over a planning horizon consisting of multiple periods. In each period, the number of casualties, capacity of hospitals and the number of ambulances for each location are updated. In updating the available capacity in a hospital, the number of healed casualties and the new arrivals to the hospital are accounted for. Average transportation time of casualties in each district as well as their waiting times are generated from the model solution. In the second model, TEU are placed at the districts to aid casualties. The objective is to minimize total travel time, total waiting time and total set up cost of new units. The model reveals which regions need the most concentration of such facilities. Model outputs indicate roughly the capacity required at the new units.

We evaluate the casualty transportation by considering the current emergency medical service capacities of hospitals in Istanbul using the transportation model, and then determine the location of necessary additional emergency units to be established after the disaster using the transportation-location model. Istanbul is threatened by a high scale earthquake for the coming years. Input data for our models were generated by using data from the study of JICA [19] that estimated possible earthquake scenarios for Istanbul and the potential damage to be caused by them. For each scenario, the number of casualties in the affected areas were available in the JICA report. The distances between the casualty locations and the hospitals were generated by considering the level of risk around the roads vis-à-vis the probability of blockage of the roads. The models were solved with the data sets for the Asian and the European sides of Istanbul under various parameter values.

The remainder of this thesis is organized as follows. In Chapter 2, an overview of the previous studies about patient transportation, emergency medical service deployment and dispatching, and some studies related to casualty transportation for disaster situation are given. Chapter 3 comprises the casualty transportation problem definition and its mathematical formulation. Chapter 4 explains the data generation, the solution procedure and the results from the transportation model solution. In Chapter 5 the transportation-location problem is modeled. Results from the solution of this model with Istanbul data are reported in Chapter 6. Finally, Chapter 7 presents a summary with concluding remarks.

Chapter 2

LITERATURE REVIEW

When a crash occurs, someone is injured, somewhere is on fire, and even when some elderly people want to go to the hospital for periodic health controls, emergency logistics are needed. Deployment of these services within the region, and dispatching them when a situation occurs carries high importance due to the urgency of the situation. However, in disaster situations emergency logistic activities differ from the daily life incidents in several ways. Because for disaster cases the scale is large, the day-to-day practices may not be applicable. Although the problem structure may change according to the case under consideration, in both cases, the aim is to preserve the lives of as many people as possible.

In the literature, there have been some studies about the emergency medical services for the normal situation. Many of them are related to the deployment of the emergency facilities such as ambulance services. Because the deployment of the ambulances depends on the current situations of the city such as the number of ambulances, possible locations of ambulances, situation of roads etc., many studies depend on real life cases. Generally, for the deployment of these services, three different models have been studied such as Covering, P-Median, and P-Center Models.

The covering models have been widely used to formulate the emergency facility location problems. The location set covering problem (LSCP) was first defined by Toregas et al. [26]. The aim was to minimize locating the number of emergency facilities while covering all demand points. In LSCP, all demand points are needed to be covered although population and demand quantity might be extremely high. Therefore, another model for the maximal covering location problem (MCLP) was developed. Church and Revelle [6] developed the MCLP model trying to maximize the exact coverage of all demand points. In order to incorporate the uncertainty of the emergency situation, some stochastic and probabilistic models were constructed. Daskin [8] formulated the maximum expected covering location problem (MEXCLP). The aim was to maximize the expected value of covering demands, while locating P facilities. He tried to incorporate a probability such that any request from any demand point can be satisfied by at least one server who is free with an estimated parameter (q). In addition to this, queuing models were developed to solve emergency medical service locations problems. The well-known model called the hypercube model was developed by Larson [20]. The model calculated the fractions of servers on network which is steady state busy and deal with the system congestion. The evaluation of the vehicle utilization, average travel time, etc. can be provided by the hypercube model. Mendonça and Morabito [21] tried to minimize the mean response time to patients call by using the hypercube model to evaluate the performance of the system for the Brazilian highway between the cities of Sao Paulo and Rio de Janeiro and they similarly studied on the deployment of the ambulances.

Another important models to solve the location of emergency medical service are P-Median models. In these models, aim is to locate the facilities by evaluating average distance between demand points and the facilities. The P-Median problem was first introduced by Hakimi [15] who tried to locate P number of facilities while minimizing the average distance between demand points and facility locations. Carbone [4] developed a deterministic P-Median which minimizes the travel time of users to medical centers. Also model was improved by him to a chance constrained model because of the uncertainty of users number at demand points. Study about dispatching the ambulances under emergency situations was done by Carson and Batta [5]. They tried to minimize the mean response time to patients call. Scenarios were developed in their model for different demands and with their P-Median model, location of ambulances was achieved dynamically. Serra and Marianov [25] developed a P-Median model considering demand,travel time, or distance uncertainties, scenarios for uncertainty variations and providing facility location by minimizing maximum regret in each scenarios. Queuing model was also incorporated into the P-Median models. Berman et al. [3] constructed stochastic queue median (SQM) model minimizing mean cost of response to demands by dispatching and locating the emergency medical units.

P-Center models which have been used to locate emergency medical services, aims to minimize the worst situation of the system different than the P-Median models. Garfinkel et al. [11] improved an integer programming model by using a binary search technique and some heuristics as solution procedures to locate the emergency units. In another model, Revelle and Hogan [24] tried to minimize the maximum distance of emergency units which are available with α reliability by locating facilities. Congestion of system and server busy probability were taken into consideration. Hochbaum and Pathria [17] considered the stochastic P-Center model minimizing the maximum distance on the network by locating emergency units. Model was developed in multi-period having different costs and distances and 3-approximation algorithm used as solution procedure.

In addition to these, some survey papers about facility location have been published. Owen and Daskin [22] prepared a survey study related to strategic facility location problems. They discussed the formulations of model and some solution approaches by looking at the application areas in industries. Also, Jia et al. [18] gave extended research on the review of medical services facility location and modeling facility location for large-scale situations.

Also, there have been some other studies related to the emergency medical systems. Fitzsimmons [10] developed an analytical model to predict the response time of the actual system and he used CALL (Computerized Ambulance Location Logic) methodology to deploy the ambulances for minimizing the mean response time for the city of Los Angeles. Harewood [16] presented a multi-objective model to locate the emergency ambulances in Barbados. He tried to find good locations with the data of Barbados Emergency Ambulance Service and with the solutions of the model he used the simulation to control the system performance. Haghani et al. [13] developed a mathematical model to make decision in real time dispatching of emergency medical services and used simulation framework integrating real time transportation information with the dispatching applications to test the model for the normal situation. Also, well-known dial-a-ride problem (DARP) is used to transport the patients. Cordeau and Laporte [7] prepared a survey paper about DARP and described that DARP is related to construct routes for vehicles and schedules for n number of users having request for pickup and delivery between service nodes.

Besides casualty transportation, there have been some studies about transportation of commodities in disaster situation. Haghani and Oh [14] formulated a multi-commodity, multi-modal network flow model for disaster relief operations. Aim was to determine the detailed routing and scheduling of the available transportation modes, delivery schedules of the many commodities , and transportation modes' load plans. They proposed two heuristic algorithms with the application of sensitivity analysis for the solution procedure. Ozdamar et al. [23] proposed a model for dispatching commodities to distribution centers. Model was tested on a scenario based on the 1999 Marmara Earthquake. Barbarosoglu and Arda [2] formulated a multi-commodity multi modal network flow model to transport commodities on urban transportation network. In the solution, two stage stochastic programming method was used. Fiedrich et al. [9] proposed a dynamic optimization model for resource allocation after earthquake disasters. Two heuristic methods SA (Simulated Annealing) and TS (Tabu Search) were used as solution procedures.

All studies mentioned above are not related to the disaster cases. Especially for a disaster situation there has been little research on the casualty transportation problem. Yi and Ozdamar [29] emphasized an integrated location-distribution model to support the post-disaster evacuation and logistic applications. In this model, while emergency commodities such as food and medicine are transported to the affected points as soon as possible, it was aimed to transport casualties to the hospitals. The model is designed as a mixed integer multi-commodity network flow model and the vehicles are treated as integer flows rather than binary variables. Although the model was designed as location model, binary variables representing to open TEU are eliminated, because there is no fixed cost and all service levels are balanced due to the care fastness and group and the number of wounded people. The solution method was designed in two stages. In the first stage, the minimization of unsatisfied demand over all commodities and weighted sum of injured people not served at demand locations and temporary and permanent medical services was provided by a mathematical model. Commodities were defined as their people equivalents and shared among all supply nodes. Also, the future demand were adjusted according to current demand. At the second stage, with the data coming from the first stage and an algorithm called 'route', the suitable itinerary for vehicles were found without determining load quantities and after that the schedule of load/unload quantities was assigned to the route of vehicles. The performance of the model was evaluated with a possible earthquake scenario in Istanbul and compared with other proposed model single-stage Vehicle Routing Problem formulation.

Yi and Kumar [28] proposed a similar model as Yi and Ozdamar [29] for the similar problem. In their model, transportation of casualties to medical services and emergency commodities to affected areas were considered. Location part was excluded. The model considers services rates in hospitals for injured people and injured people in affected areas as supply nodes. The model was designed as a mixed integer multi-commodity network flow model and the vehicles were treated as integer flows rather than binary variables. The objective function aimed to minimize the unsatisfied demand over all commodities and weighted sum of injured people not served at demand locations and medical services. Commodities are defined as their people equivalents and shared among all supply nodes. Also, the future demand were adjusted according to current demand. As a solution method, ant colony optimization (ACO) and a successive maximum flow (SMF) algorithms were used. The solution method decomposes into two phases. In the first phase routes for vehicles were constructed and according to the solution of the first phase the multi-commodity dispatch is solved. ACO provides stochastic vehicle paths under the guidance of pheromone trails and SMF dispatches the commodities to different types of vehicle flows. Dispatching schedules coming form SMF updates the pheromone trails. Hence, two sub-problems work with each other in coordination. The performance of ACO meta-heuristic was tested on the random generated data with grid network and the results were compared with the model solution produced by CPLEX.

Another study related to patient transportation in disaster situation was produced by Gong and Batta [12]. They considered the allocation and reallocation of ambulances after disaster occurred. Initially, they tried to allocate the exact ambulance number to each cluster and constructed a mathematical model describing the growing of cluster after disaster. They emphasized methods to calculate the completion time of each cluster according to model and the given the number of ambulances. With two iterative procedures the makespan and the weighted time of total flow were optimized. After the first problem, second problem deals with the ambulance reallocation problem. In second problem, while new clusters take service, ambulances utilization were fulfilled. Objective was to minimize the makespan and also in the reallocation process the distance between clusters were considered. The model was evaluated with the data of earthquake scenario in Northridge, CA.

In our model, we have tried to construct the model in such a way that the model provides a guide to the decision makers about what will be the current situation under some possible scenarios and what are the necessities. At strategic level, it may not be necessary to transport both commodities and wounded people with same vehicle. Hence, the model can be divided into two separate models for commodities and casualties. For the disaster cases, in order to take efficient results, it is very important to simplify the model and work with the extended data. In our model, we considered all of the resources from the real data. Scenarios were incorporated to the model because of the uncertainty in the casualty numbers. Also, due to dynamic structure of the problem, models were developed multi-periodically. The road conditions were taken into consideration for each scenario with some blockage and non-functionality probabilities. As long as there is a capacity to treat a patient, it is easily assumed that the medical materials and personnel can be supplied and these additional supplies can be directed to the temporary units which are closer than the current hospital locations to the affected areas. Also, because there will be huge amount of casualties in various types, some highly equipped vehicles can be used only heavily injured people so that it will not be necessary to split the transportation mode. This study considering important details of the casualty transportation problem aims to give the strategic guide to the decision makers with the evaluation of the medical system. Two mixed integer mathematical models were constructed for the casualty logistics. In both model, the travel time of served and the waiting time of the unserved casualties were minimized. The model was constructed dynamically allowing to update of the situation of resources such as capacities and casualty numbers. This study gives important extension to the existing literature because of the lack of the study about emergency response logistics in disaster situation. With the data of Istanbul based on earthquake scenarios, the current system was evaluated with the models. The main goal of this study is not providing real-time dispatching strategies right after an earthquake for Istanbul. The aim is to evaluate the current medical system of Istanbul with existing emergency medical capacities in hospitals and determine the location and the size of additional units.

Chapter 3

CASUALTY TRANSPORTATION PROBLEM DESCRIPTION AND THE MATHEMATICAL MODEL

The problem that we described in Chapter 2 takes its motivation from the real life problem faced by the locations threatened by the serious disasters. Post-disaster applications especially reaching to the casualties and provide medical treatment are very important activities and efficiency in these operations will certainly decrease the loss of life. Even though the daily emergency service activities are very important, emergency response logistics in disaster situation are more crucial, because of the large amount of effect and damage. Efficient post-disaster application needs some organization and pre-determined disaster management. In this context, aim is to construct a model solving transportation of casualties to emergency medical centers with available ambulances. One of the important properties of the problem is insufficient data depending on difficulty about damage forecast. For example, after an earthquake, injured number of people can change according to the damage and some of the roads can be unusable due to the blockage. In order to provide efficient casualty transportation, different data is generated due to different types of disaster scenarios. Also, the casualty transportation has a dynamic structure allowing the change of the casualty number, ambulance number and capacity of hospitals.

To transport casualties to the available capacities in hospital with available vehicles (ambulances), we constructed mixed integer mathematical model. In our model, while the total travel time of the casualties is minimized, the total waiting time of the unserved people is also minimized. The model is multi-period transportation model which gives important property to the model. The capacities of hospitals, the location of ambulances, and the number of casualties are updated for each period. Capacity of each ambulance was considered as 1. Hence the proposed model is single type casualty and single transportation mode model. Also, because each ambulance can carry a casualty in a period, the number of ambulances traveling in a period represents the number of served casualties. As the capacities of these services, the capacity of emergency services of hospitals were considered. Also, in the updating procedure of hospital capacities, the number of healed casualties were also taken into consideration. In order to achieve this, we incorporated healing rate r into the model. The first location of ambulances were selected as hospitals, because most of the ambulances are located currently in hospitals. Therefore, there are two different location sets. One of them is for the locations of hospitals and ambulances and another one is for the locations of casualties. As a result, with the updated data of hospital capacity, ambulance location, and casualty number in each period, an ambulance locating in the ambulance and hospital location goes to the casualty location and brings him/her to the suitable hospital. The waiting time of the unserved casualties due to the insufficiency of ambulances or hospital capacities are calculated. Waiting time calculated with the α penalty value adjusted according to the length of planning horizon. Also in the model, the transportation of an ambulance between casualty and hospital locations were limited with the value of ρ which is the transportation time limit based on the length of planning horizon.

In the problem, we determine

i. the total number of unserved and served casualties for each location,

ii. the capacities of hospitals and the number of ambulances for each location.

minimizing the sum of

i. the total travel time of served casualties,

ii. total waiting time of unserved casualties.

For the casualty transportation problem that we have described, we give below a mathematical model preceded by its notation.

Sets and parameters

H Set of hospital locations

P Set of patient locations

a Ambulance location $a \in H$

p Patient location $p \in P$

h Hospital location $h \in H$

t Time period $t = 1, ..., T$

τ_{tap} Total travel time of an ambulance from location in a to location in p in period t

σ_{tph} Total travel time of ambulance from a patient location in p to hospital in location h in period t

ρ_t The transportation limit of an ambulance in period t

e_{tap} 1, if $\tau_{tap} \leq \rho$; 0, otherwise

d_{tph} 1, if $\sigma_{tph} \leq \rho$; 0, otherwise

λ_{tp} Number of new casualties arriving in period t and location p

α Penalty value of waiting

r Healing rate of casualties in a period ($0 \leq r < 1$)

State variables

NA_{ta} Number of ambulances in location a in period t

HR_{th} Number of healed casualties for the next period

C_{th} Capacity of hospitals in location h at the beginning of time t

NP_{tp} Number of casualties in each location p at the beginning of time t

LA_{ta} Number of ambulances leaving location a in period t

AA_{th} Number of ambulances arriving to the hospitals in location h in period t

Decision variables

x_{tap} Number of ambulances traveling from a location in a to a location in p in period t

y_{tph} Number of ambulances traveling from a location in p to a hospital in h in period t

NS_{tp} Number of casualties in location p that could not be transported in period t

The Model

Minimize

$$z = \sum_{t=1}^{T} \sum_{a \in H} \sum_{p \in P} \tau_{tap} e_{tap} x_{tap} + \sum_{t=1}^{T} \sum_{p \in P} \sum_{h \in H} \sigma_{tph} d_{tph} y_{tph} + \sum_{t=1}^{T} \sum_{p \in P} \alpha NS_{tp}$$

subject to

$$\sum_{p \in P} e_{tap} x_{tap} \leq NA_{ta}, \qquad \forall a \in H,\ t = 1, ..., T \tag{3.1}$$

$$\sum_{a\in H} e_{tap}x_{tap} + NS_{tp} = NP_{tp}, \qquad \forall p \in P,\ t = 1,...,T \tag{3.2}$$

$$\sum_{p\in P} d_{tph}y_{tph} \leq C_{th}, \qquad \forall h \in H,\ t = 1,...,T \tag{3.3}$$

$$\sum_{p\in P} e_{tap}x_{tap} = LA_{ta}, \qquad \forall a \in H,\ t = 1,...,T \tag{3.4}$$

$$\sum_{p\in P} d_{tph}y_{tph} = AA_{th}, \qquad \forall h \in H,\ t = 1,...,T \tag{3.5}$$

$$NA_{(t+1)a} = NA_{ta} - LA_{ta} + AA_{th}, \qquad \forall a \in H, \forall h \in H, \forall a = \forall h,\ t = 1,...,T \tag{3.6}$$

$$NP_{(t+1)p} = \lambda_{(t+1)p} + NS_{tp}, \qquad \forall p \in P,\ t = 1,...,T \tag{3.7}$$

$$HR_{th} \leq r(C_{1h} - C_{th} + AA_{th}), \qquad \forall h \in H,\ t = 1,...,T \tag{3.8}$$

$$C_{(t+1)h} = C_{th} - AA_{tsh} + HR_{th}, \qquad \forall h \in H,\ t = 1,...,T \tag{3.9}$$

$$\sum_{a\in H} e_{tap}x_{tap} = \sum_{h\in H} d_{tph}y_{tph}, \qquad \forall p \in P,\ t = 1,...,T \tag{3.10}$$

$$x_{tap}, y_{tph} \geq 0\ \ and\ \ integer, \qquad \forall a \in H, \forall p \in P, \forall h \in H,\ t = 1,...,T \tag{3.11}$$

$$HR_{th} \geq 0\ \ and\ \ integer, \qquad \forall h \in H,\ t = 1,...,T \tag{3.12}$$

$$NS_{tp}, C_{th}, NA_{ta}, NP_{tp}, LA_{ta}, AA_{th} \geq 0, \qquad a \in H, \forall p \in P, \forall h \in H,\ t = 1,...,T \tag{3.13}$$

Objective function minimizes total travel time of the served and the total waiting time of the unserved casualties. Here, x_{tap} and y_{tph} represents the number of traveling ambulances and the number of served casualties both. Constraint 3.1 provides that the number of served casualty cannot exceed the number of ambulances. Constraint 3.2 will ensure that the number of served and unserved casualty are equal to the total number of casualties at that period. Constraint 3.3 represents that casualties that will be served can be transported as long as there is a capacity in that hospital. In order to see the leaving ambulances from ambulance location a at the beginning of the period, constraint 3.4 was implemented. Constraint 3.5 represents the number of ambulances coming to the hospitals in each location h at the end of that period. Constraints 3.6, 3.7, and 3.9 provides to update the number of ambulances in each ambulance location a, the number of casualties in each casualty location p, and the capacity of each hospital in each hospital location h respectively. With the help of constraint 3.8, healing rate of the current casualties and capacity update for the hospitals for the next period are obtained. Constraint 3.10 is the flow balance constraint of the ambulances which ensures that the number of ambulances coming to the casualty location and left from that casualty location for each period are equal to each other. Finally, constraints 3.11, 3.12 and 3.13 are nonnegativity constraints for all variables.

Chapter 4

COMPUTATIONAL EXPERIMENTS AND RESULTS FOR THE CASUALTY TRANSPORTATION MODEL

4.1 Data Generation

Generating the data is crucial part of this study. The performance of the model was evaluated with the data of the expected earthquake scenarios of Istanbul. In 30 years, there will be an earthquake having high magnitude with high probability. According to the research of JICA (Japan International Cooperation Agency) [19], there are four possible earthquake scenarios for Istanbul. The European and the Asian sides of Istanbul are considered separately in the case of the damage in the bridges and long travel time. Therefore, all experiments were done for both side of Istanbul separately. Data generation can be divided into 5 different subsections.

4.1.1 Earthquake Scenarios and Casualty Numbers

There are four different earthquake scenarios for Istanbul, which are Model A, B, C, and D respectively. Model A is the most probable and Model C is the worst case scenario. Figure 4.1 describes the length of fault line which will be broken. Because Model C has longer broken line, it has higher damage. There are the data for casualty numbers for these two scenarios in the JICA and IMM (Istanbul Metropolitan Municipality) Report [19], because Model A is similar to Model B, and Model C is similar to Model D. In Table 4.1 these numbers can be seen. These numbers are the total number of casualties of each district. In order to find the casualty numbers for each period, according to the previous behavior of the casualty numbers in disaster situation as the time changes, we assumed an exponential function like in Fig.4.2 and calculated the numbers for each model, district, and period respectively. Total period number is 144. (1 period=30 min., 1 day=48 periods, 3 days=144 periods). We assumed that casualties come for three days after disaster occurs. This means expected number of casualties are calculated for each period in three days.

Table 4.1: Casualty Numbers of Districts for Model A and Model C

	Casualty Numbers	
Name of District	**Model A**	**Model C**
Adalar	3001	3255
Avcilar	6154	6841
Bahcelievler	7630	8165
Bakirkoy	5735	6310
Bagcilar	6376	7294
Beykoz	646	807
Beyoglu	4914	5482
Besiktas	2108	2547
Buyukcekmece	1661	2010
Bayrampasa	5713	6283
Eminonu	4418	4820
Eyup	3316	3742
Fatih	7873	8245
Gungoren	4959	5750
Gaziosmanpasa	3846	4435
Kadikoy	5196	6127
Kartal	4265	4858
Kagithane	2654	3278
Kucukcekmece	7583	8049
Maltepe	3925	4441
Pendik	4528	5091
Sariyer	585	802
Sisli	2369	3040
Tuzla	2762	3169
Umraniye	2108	2607
Uskudar	2764	3516
Zeytinburnu	6785	7455
Esenler	4610	5365
Catalca	47	65
Silivri	108	1322

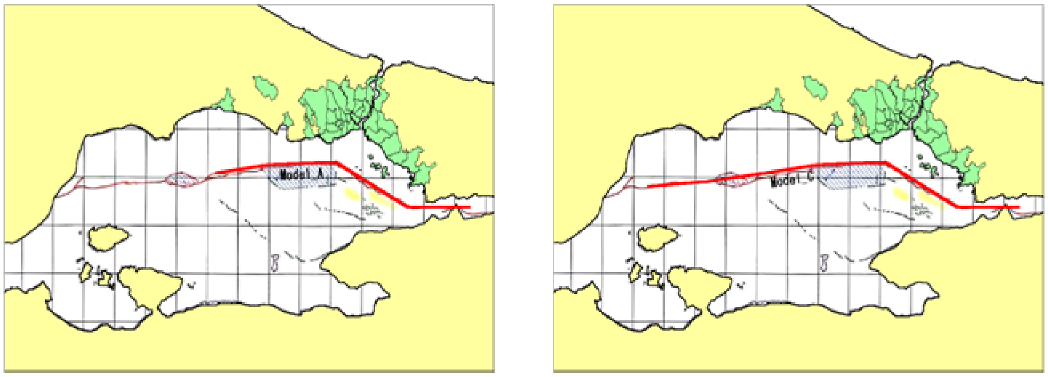

Figure 4.1: Earthquake scenarios for Istanbul Model A and Model C

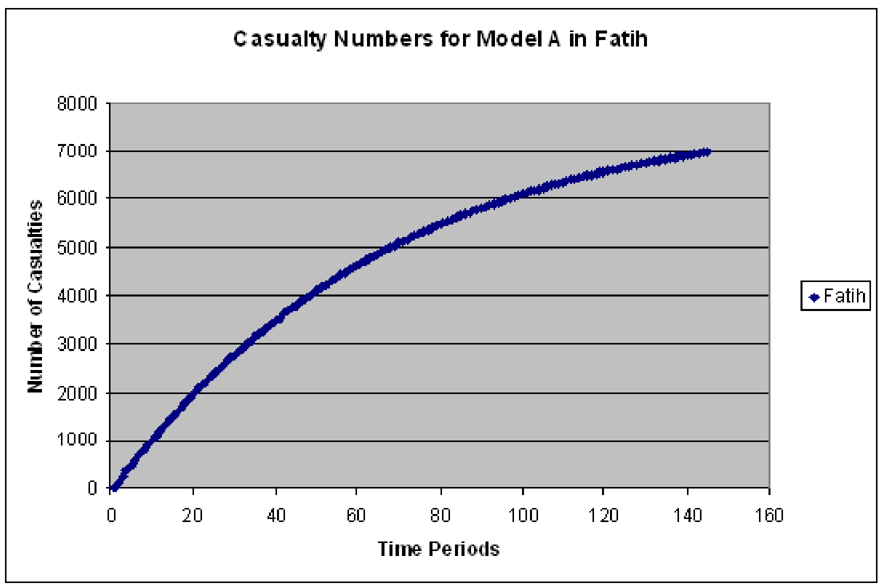

Figure 4.2: Number of Casualties in Fatih for Model A

4.1.2 Ambulance-Hospital and Casualty Locations

As we described in Chapter 3, there are two set locations in our model. All ambulances were located in the hospital locations, because most of them were located in hospitals currently. Therefore, ambulances not located in hospitals currently were assigned to the nearest hospital. To calculate the maximum efficiency of the current system, it was assumed that all hospitals can work properly after the disaster. Also, for another location set, casualty location, in order to obtain meaningful solutions from the model, casualty numbers were divided into the locations in districts. The number of casualty locations in a district are correlated with the expected number of casualties in that district. The districts where the expected number of casualty is between 0 and 2000, 2000 and 4000, 4000 and 5000, 5000 and 7000, and above 7000 will have 2, 3, 4, 5, and 6 casualty locations respectively. The data of the number and the location of public and private ambulances were taken from the Istanbul Metropolitan Municipality Emergency Medical and Lifesaving Service and Istanbul City Health Office and the data of the location and emergency units capacity of public and private hospitals were taken from the Health Ministry. These values are given in the Table A-1. Also, these ambulance-hospital and casualty locations can be seen in the Figures 4.3 and 4.4. With the usage of software Arcmap, the coordinates of ambulances, hospital, and casualty locations are defined as points.

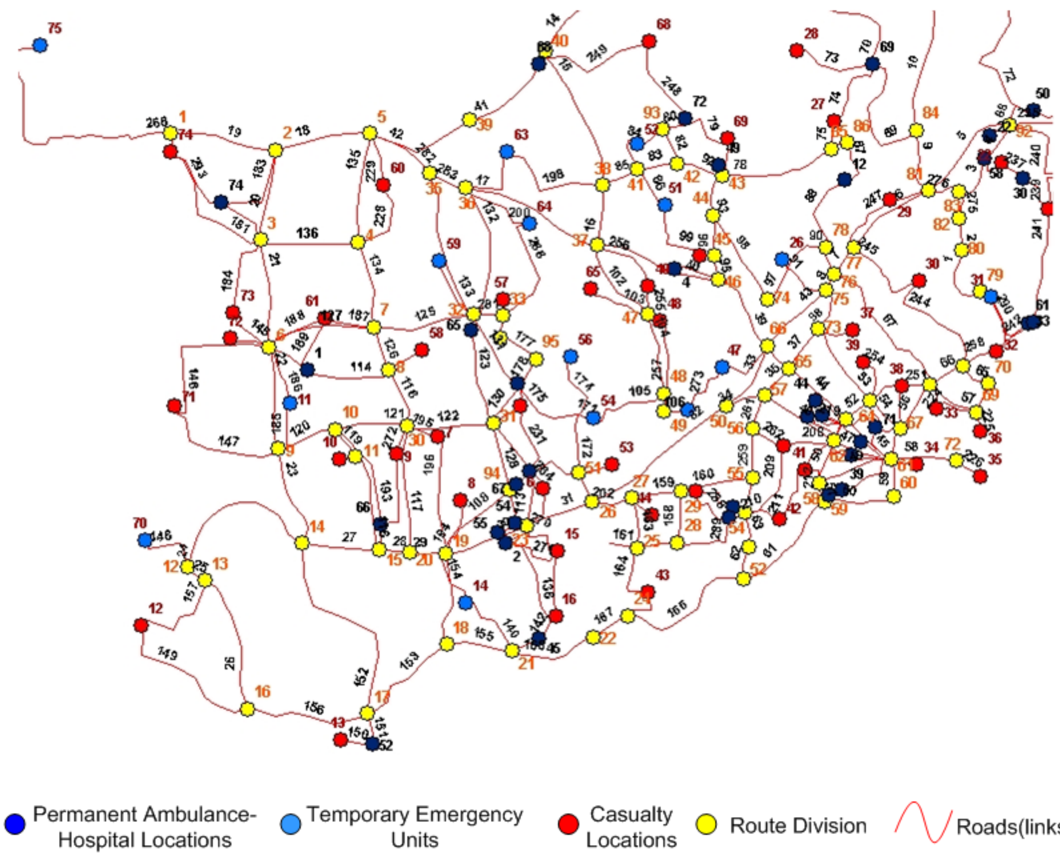

Figure 4.3: The network of the European side containing roads and locations

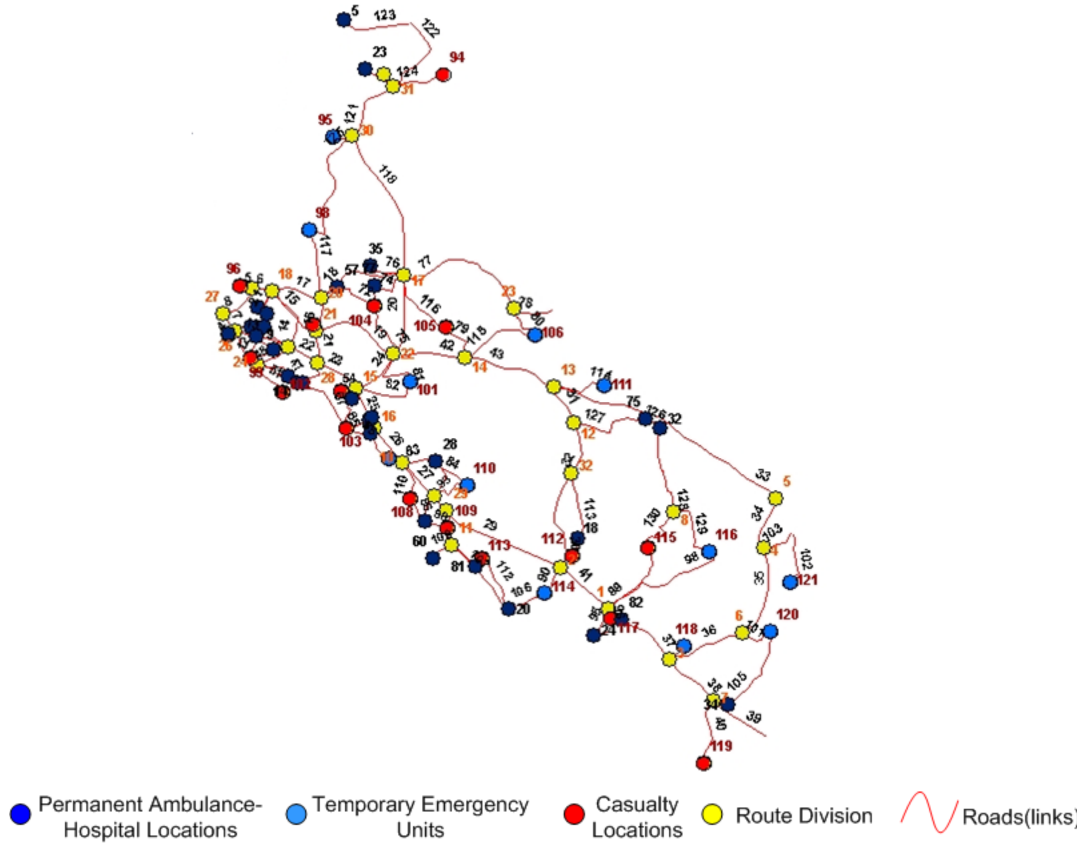

Figure 4.4: The network of the Asian side containing roads and locations

4.1.3 Travel Time Scenarios

The ambulance-hospital and casualty locations are to calculate the travel time of the ambulances. With the plotted real roads between ambulance-hospital locations and casualty locations, the transportation networks were generated. In addition, assuming the average velocity of ambulance was 50 km/h, the average travel time of the ambulance between locations were calculated. The travel time of the ambulance depends on the road situation. Roads can be blocked due to the building collapse onto the roads or bridge and viaduct collapse. Therefore, we divided the roads into three groups such as the roads having the width 2-6 m, 7-15 m, and above 16 m respectively. The blockage probability with the building collapse onto the roads were taken from the JICA Report [19]. For the bridge and viaduct collapse probability, we used the data from Master of Earthquake Plan [27] for the "less risky" and "very risky" bridges and viaducts. Very risky structures were weighted

Table 4.2: Scale used to determine non-functionality probabilities of roads

Link Score	≤ 1	≤ 4	≤ 7	≤ 10	≤ 13	≤ 17
Probability	0.2	0.3	0.4	0.45	0.5	0.55

with 4 points while less risky ones were weighted with 1 point. The number of the less risky and very risky bridges and viaducts for each roads were identified and we determined a weighted score and converted to the non-functionality probabilities of roads. In Figure 4.5 less risky and very risky bridge and viaducts can be seen. The scores and incorporated non-functionality probabilities are in the Table 4.2. In JICA Report [19], the road blockage probability with building collapse had generated in interval and only for Model C. We generated all probabilities for all scenarios (2 Model A scenarios and 2 Model C scenarios) from these intervals and with the combination of road blockage probability with building collapse and non-functionality probabilities of roads due to the damaged bridges and viaducts, we identified the final non-functionality probabilities of roads. With these probabilities and type of roads, we calculated the expected average travel time of an ambulance for earthquake scenarios . The roads having the width 2-6 m, 7-15 m, and above 16 m are the type 3, 2, and 1 respectively. If the road has type 3, 2, and 1, the expected travel time on the road under the circumstances of any road blockages will increase 20 %, 40 %, and 60 % respectively. Types and length of roads and incorporated probability values of roads can be seen in Table A-2. With addition of these probabilities, τ_{tap} and σ_{tph} values increases from Model A1 to Model C2.

4.1.4 Penalty Value of Waiting

This value was represented as α in the model. The penalty value of waiting was set according to the length of a period. The length of period is 30. Therefore, we set this value as 31 in order to allow the casualties to be served within the length of period.

4.1.5 Healing Rate

Another important parameter that we generated is the healing rate. This rate was represented as r in the model and determines the healing rate of casualties being in the hospital

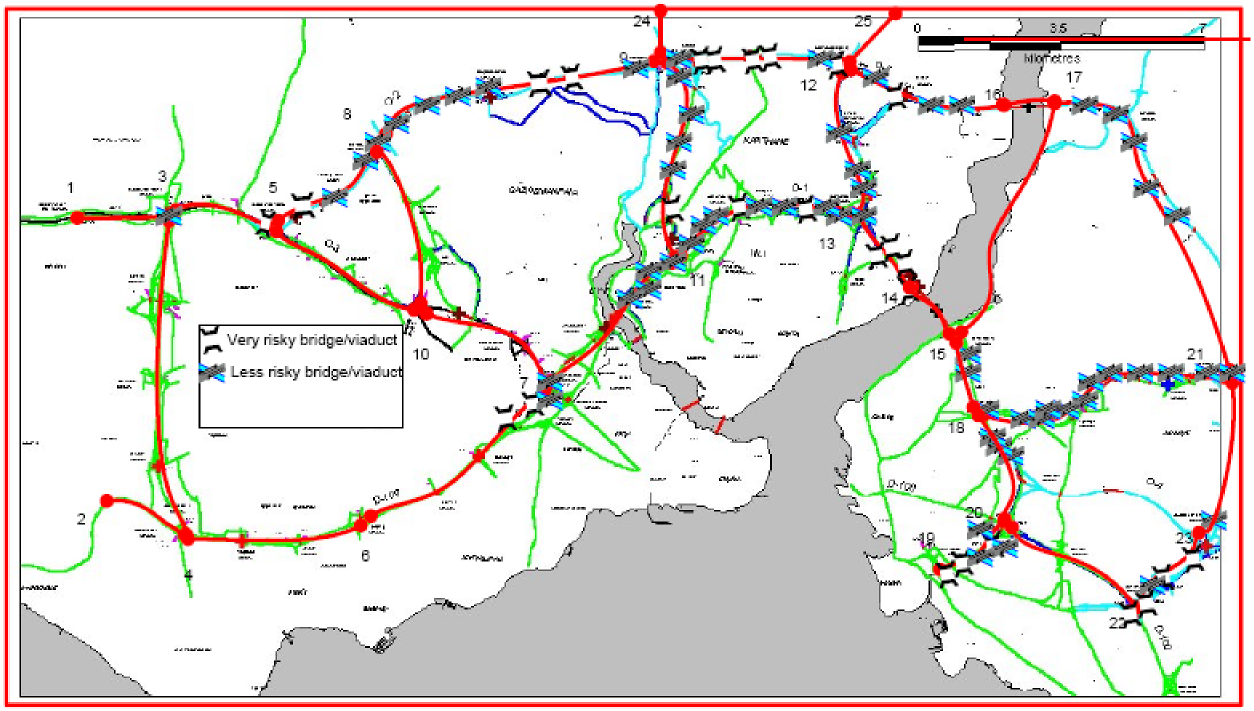

Figure 4.5: The less risky and very risky bridges/viaducts on Istanbul city major highways

at that time. We assumed two ratios as 0.25 and 0.5 for all scenarios in the European and Asian sides. 0.25 and 0.5 represents that the number of healed person is the 25 and 50 percent of the casualties in that hospital and in that period. These ratios provides new hospital capacities for the next period.

4.2 Computational Results

In the data generation and solution procedure, we used some packages.

Arcmap It is a well-known geographical tool working on GIS (Geographical Information System and Mapping). Arcmap is the product of ESRI®. We used this package in order to construct a real network for Istanbul metropolitan city between the ambulance-hospital and casualty locations with real roads.

MATLAB 7.0 Expected travel time between the locations under some probabilities were calculated by using Matlab environment.

Table 4.3: GAMS/Cplex options in the first mathematical model

Option	Explanation	Value
`ITERLIM`	Simplex algorithm iteration limit applied per node of the searched three	5,000,000
`RESLIM`	Solution time limit for MIP solver	1 hour
`OPTCR`	Relative optimality criterion for a MIP problem	0.001

GAMS 11.0.0 It is well-known optimization tool containing many different solvers to solve different types of problem. Because our problem is MIP, we used CPLEX engine (CPLEX is the product of ILOG INC.)

All codes have been written in GAMS 22.5 tool and used the MIP solver CPLEX 11.0.0, compiled and executed on a 3.00 GHz Intel Xeon®server with 4 GB RAM. In GAMS models, the accuracy obtained by the Cplex solver is controlled with a number of options. Relative optimality criterion `OPTCR` can be set for the MIP model to determine when the solver should terminate its branch-and-bound procedure. `OPTCR` is defined as the ratio$(|\texttt{BP-BF}|)/(1.0e-10+|\texttt{BF}|)$ where `BF` is the best lower bound found so far in case of minimization and `BP` is the best objective function value of the current best integer solution found so far. If the this value drops under the specified `OPTCR` value, procedure terminates. If this criteria is not fulfilled, program continue to work until the `RESLIM` or `ITERLIM` criterion are satisfied. Final gap are recorded. Options used in our GAMS models are explained in Table 4.3. Computational experiments were done for all generated data. An instance was generated for every combination of the following parameters:

- the European side/the Asian side.
- Healing rate (0.25, 0.5).
- Period 144 (Consecutive runs, One shot - relaxed model with gaps).
- Earthquake scenarios (2- Model A's, 2- Model C's - different casualty numbers in A and C (distribution over the districts) and travel times differing in 1 and 2 of Model A and C).

Also there are some fixed parameters at the beginning:

- Hospital locations: the European side 34 locations and the Asian side 31 locations.
- Patient locations: the European side 61 locations and the Asian side 28 locations.
- Hospital capacities.
- Ambulance numbers.
- Number of new casualties in each locations in each period and in each scenario.

All results for the first model are in Tables from B-1 to B-12 in Appendix B. The number of unserved and total casualties and the percentage of unserved casualties were reported. The ambulance usage percentages were also calculated for each scenarios in the European and Asian sides. One of the examples of the table is below. This Table 4.4 represents the results about the Asian side when healing rate is 0.25 and for Model A1. For each district in the Asian side, total number of casualties and unserved casualties were calculated. Percentage of unserved casualties according to total casualties were also reported for each district at the last column. Although we took 3 consecutive runs for the periods between 1-48, 48-96, and 96-144 respectively, the results were given after the last period (at the end of three days). According to all instances, we evaluated the solutions and system performance. Integer solutions were compared with the result of relaxed model solutions based on optimality gap. Relaxed models were defined as the relaxation of x, and y variables. HR variables were not relaxed because healing rate gives the fractional value to the capacity and the capacity update mechanism would not work same as integer model if HR variables were also relaxed. Hence, the optimality gap was defined between integer and these relaxed solutions. Also, in some of the solutions, especially in early times of periods, because many casualties are not transported, total waiting time is very high in the objective function. This is because of the low value of transportation time while high value of penalty value of waiting. This may lead to be ignored total travel time in the objective. However, because codes were compiled for 1 hour, this situation was eliminated by finding good solutions.

Table 4.4: Computational results (No. of unserved and coming casualties and % of unserved casualties) for Model A1 for the Asian side when healing rate=0.25

Model A1	**Asian Side, Healing Rate=0.25**							
No of Casualties	**Beykoz**	**Uskudar**	**Kadikoy**	**Umraniye**	**Maltepe**	**Kartal**	**Pendik**	**Tuzla**
Unserved	1.9	4.2	10.8	4.9	23.0	26.1	21.8	17.4
Total	4.9	18.5	34.4	14.5	26.1	28.2	29.9	18.5
%(Unserved)	38.2	22.8	31.2	33.7	88.1	92.6	72.8	94.5

4.2.1 Results for the European side when healing rate is 0.25

Tables B-1,B-2, and B-8 are related to the results for the European side side with 0.25 healing rate. Tables B-1and B-2 represent the number of unserved and total casualties. Generally, most of the casualties could not be transported in districts for each scenario. The reason was the lack of the hospital capacity, because ambulance usage percentage is below 50 % which means about half of the ambulances cannot be used because of the hospital capacity limit. Because there are many casualties in the casualty locations, only the casualties who are near to the hospitals were served. Unserved percentages of some districts were extremely low with respect to others such as Sisli and Fatih, because they have more hospital capacities than other districts. Also, because the healing rate is extremely low, capacity cannot be updated for the next period. The other limit affecting the unserved percentage is travel time limit of ambulances. Ambulances can only go to the locations within 15 minutes, the length for both casualty and hospital locations. Therefore, the districts which is far to the hospitals and have little hospital capacities have more unserved casualties such as Esenler and Kucukcekmece. In Table B-8, we calculated the average travel time of served and average waiting time of the unserved casualties. Because of the capacity limit, every model have about the same number of served casualties. Only in Model A1, 1 person was transported more, this can be because of the travel time limit. All time values were given in minute/person. Because of the capacity limit of hospitals, travel times are low and waiting times are extremely high. Model A1 and A2 have the same number of casualties with different high τ_{tap} and σ_{tph} values. Hence, Average travel and waiting times in Model A1 are lower than Model A2 which is similar in Model C1 and C2. Also, although Model C1 and Model C2 have high τ_{tap} and σ_{tph} values than Model A1 and Model A2, they have less average travel and waiting time values for each casualty. When the number of casualties increases in Model C1 and C2, because there are available capacities in the nearest hospital, many of these casualties are transported to this nearest hospital. However, in Model A1 and A2, all casualties in a location are transported to the nearest hospital, and there is still available capacity in that hospital, and casualties from other locations are transported to this hospital. While this lead to the increase in the average travel time for Model A1 and A2, the number of served casualty percentage is lower than Model C1 and Model C2. Average waiting times are also lower than Model A1 and Model A2, but the total number of unserved casualties are high in Model C1 and Model C2. Model tries to minimize also the total number of unserved casualties. Therefore, there are more unserved casualties with less average waiting time in Model C's. This can be seen from the high unserved percentages of Model C's. Another important property of the solutions is solution quality. We generated another model in order to evaluate our model. In this model only the x, and y integer variables were relaxed. HR variable was not relaxed, because it would change the hospital capacities. The healing rate of the current casualties in a hospital gave the fractional capacity upload to the hospitals for the next period. If we took it as fractional value, capacity would not be the same as integer model. Therefore, it was not relaxed. According to the relaxed solutions, optimality gaps are extremely low.

4.2.2 Results for the European side when healing rate is 0.5

Tables B-3,B-4, and B-9 are related to the results for the European side with 0.5 healing rate. The solutions are similar to the solutions when the healing rate is 0.25. Because of the capacity expansion, the unserved percentage was decreased in some other additional districts such as Eminonu, Beyoglu, and Gaziosmanpasa. However, some districts have the same high percentages such as Esenler and Kucukcekmece because of the the travel time limit and the lack of capacity. Even though the number of served casualties are the same for all scenarios, the unserved percentages are different in also between Model A's and Model C's due to the different travel times. The current system of Istanbul the European side is not sufficient by means of the hospital capacity and ambulance (here ambulance usage is extremely good, but not 100 %) even if the healing rate is high (0.5). It is necessary to have some additional units for resources in order to increase efficiency. By means of the solution quality, results are also have very tight gaps with the relaxed solutions.

4.2.3 Results for the Asian side when healing rate is 0.25

The Asian side has different network structure than the European side. Accommodation in the European side is more complicated. Hence, the worst affect will be in the European side. In the Asian side, travel times are a little high and locations are spread in the large area. This directly affected the results. Table B-5 represents the results for the unserved and total casualty numbers and B-10 are related to the results of system performance for the Asian side with 0.25 healing rate. Because of the reason of damages in Bosphorus Bridges, and the travel time limit, we neglected the casualty transportation between continents. Results of the Asian side are more acceptable than the European side results, because the unserved percentage is below 50 % except some districts. Because of the transportation network, travel times are little higher in the Asian side. Similarly, Model A1 has 1 additional casualty transported. Ambulance cannot work with its full capacity, because of the lack of hospital capacity. Optimality gaps with relaxed solutions are acceptable also.

4.2.4 Results for the Asian side when healing rate is 0.5

Tables B-6 and B-11 are related to the results of total number of casualties and unserved casualties and performance of the model respectively for the Asian side with 0.5 healing rate. The unserved percentage values are very good except Kartal and Tuzla. Many of the casualties were transported. This increased the ambulance usage percentage and travel time also. Performance of the solutions by means of the solution gaps are sufficient. In order to get higher efficiency, it is also necessary to increase the ambulance number and hospital capacity to the certain point.

It can be seen from the results that the model gives the proper solutions in acceptable times and acceptable optimal gaps and help to evaluate the current system. The results shows that the current system of Istanbul is not sufficient under the possible earthquake scenarios to serve many of the casualties. In order to increase efficiency, it is necessary to have some additional resources and it is necessary to have some strategic plans to achieve this.

Chapter 5

CASUALTY TRANSPORTATION AND TEMPORARY EMERGENCY UNIT LOCATION PROBLEM DESCRIPTION AND MATHEMATICAL MODEL

According the results of the first model, the current system capacities are insufficient. Determining necessary capacities and locations for the temporary emergency services will be very helpful for the tactical decisions. For the disaster situation, pre-determined capacities can be useful by means of the preparation. TEU can be located right after the disaster actually, but adjusting the demand is the long period organization. The current resources such as medical equipments and personnel have to be considered. Calculating necessary capacities and preparation for the possible disasters will cause certainly lower response time to the casualties and decrease the affect of the disaster. Possible additional units can be located either in the same location of the current hospitals or in some other suitable areas such as schools, parks etc. According to minimization of the response time to casualty demands, decisions to open new units will be given. In addition to this, one solution which may be obtained from these four scenarios with some other solution techniques cannot be sufficient for this problem. For the first model, it is very helpful to obtain the total travel time and waiting time of served and unserved casualties for each different scenarios. This will give an idea about the results of possible scenarios. For the second problem also, it will be useful to show the situation for each scenario. This will give an idea about the strategic plan to decision makers by looking at the each possible scenario result. Instead of making decision ourselves, showing all of the cases can create better strategic solutions. For this purpose, we extended the first model to transportation-location model. In this model, we aimed to decide where to locate the TEU and what are their capacities under some decisions.

In the problem, we determine

i. the total number of unserved and served casualties for each location,

ii. the capacities of permanent emergency units and the number of ambulances for each location.

iii. the location and capacities of TEU

minimizing the sum of

i. the total travel time of served casualties,

ii. total waiting time of unserved casualties.

iii. total set-up cost of TEU

For the casualty transportation and TEU location problem that we have described, we give below a mathematical model preceded by its notation.

Sets and parameters

H	Set of emergency unit locations (permanent and temporary)
I	Set of permanent emergency unit locations $I \subset H$
J	Set of temporary emergency unit locations $J \subset H$
P	Set of casualty locations
a	Vehicle location $a \in H$
p	Patient location $p \in P$
h	Permanent and temporary emergency unit location $h \in H$
i	Permanent emergency unit location $i \in I$
j	Temporary emergency unit location $j \in J$
t	Time period $t = 1, ..., T$
τ_{tap}	Total travel time of a vehicle from location in a to location in p in period t
σ_{tph}	Total travel time of vehicle from a patient location in p to hospital in location h in period t
ρ	The transportation limit of a vehicle
e_{tap}	1, if $\tau_{tap} \leq \rho$; 0, otherwise
d_{tph}	1, if $\sigma_{tph} \leq \rho$; 0, otherwise
λ_{tp}	Number of new casualties arriving in period t and location p
α	Penalty value of waiting
r	Healing rate of casualties in a period ($0 \leq r < 1$)
β	Priority for the usage of the permanent emergency units ($0 < \beta < 1$)

ϑ Set-up cost of temporary emergency units ($\vartheta < \alpha$)

${C^*}_j$ The capacity of temporary emergency unit in j

γ Total number of possible open emergency units

η Number of possible open emergency unit in each j location

State variables

NA_{ta} Number of vehicles in location a in period t

HR_{th} Number of healed casualties for the next period

C_{th} Capacity of emergency units in location h at the beginning of time t

NP_{tp} Number of casualties in each location p at the beginning of time t

LA_{ta} Number of vehicles leaving location a in period t

AA_{th} Number of vehicles arriving to the hospitals in location h in period t in travel

Decision variables

x_{tap} Number of ambulances traveling from a location in a to a location in p in period t

y_{tph} Number of ambulances traveling from a location in p to a hospital in h in period t

NS_{tp} Number of casualties in location p that could not be transported in period t

l_j Number of temporary emergency unit to open in location j

The Model

Minimize

$$z = \sum_{t=1}^{T}\sum_{a\in I}\sum_{p\in P}\beta\tau_{tap}e_{tap}x_{tap} + \sum_{t=1}^{T}\sum_{p\in P}\sum_{h\in I}\beta\sigma_{tph}d_{tph}y_{tph} + \sum_{t=1}^{T}\sum_{a\in J}\sum_{p\in P}\tau_{tap}e_{tap}x_{tap} +$$

$$\sum_{t=1}^{T}\sum_{p\in P}\sum_{h\in J}\sigma_{tph}d_{tph}y_{tph} + \sum_{t=1}^{T}\sum_{p\in P}\alpha NS_{tp} + \sum_{jinJ}\vartheta {C^*}_j l_j$$

subject to

$$\sum_{p\in P} e_{tap}x_{tap} \leq NA_{ta}, \qquad \forall a \in H,\ t = 1, ..., T \tag{5.1}$$

$$\sum_{a\in H} e_{tap}x_{tap} + NS_{tp} = NP_{tp}, \qquad \forall p \in P,\ t = 1, ..., T \tag{5.2}$$

$$\sum_{p\in P} d_{tph}y_{tph} \leq C_{th}, \qquad \forall h \in H,\ t = 1,...,T \tag{5.3}$$

$$\sum_{p\in P} e_{tap}x_{tap} = LA_{ta}, \qquad \forall a \in H,\ t = 1,...,T \tag{5.4}$$

$$\sum_{p\in P} d_{tph}y_{tph} = AA_{th}, \qquad \forall h \in H,\ t = 1,...,T \tag{5.5}$$

$$NA_{(t+1)a} = NA_{ta} - LA_{ta} + AA_{th}, \qquad \forall a \in H, \forall h \in H, \forall a = \forall h,\ t = 1,...,T \tag{5.6}$$

$$NP_{(t+1)p} = \lambda_{(t+1)p} + NS_{tp}, \qquad \forall p \in P,\ t = 1,...,T \tag{5.7}$$

$$HR_{th} \leq r(C_{1h} - C_{th} + AA_{th}), \qquad \forall h \in H,\ t = 1,...,T \tag{5.8}$$

$$C_{(t+1)h} = C_{th} - AA_{tsh} + HR_{th} \qquad \forall h \in H,\ t = 1,...,T \tag{5.9}$$

$$C_{(1)h} = C_{1i} + {C^*}_j l_j \qquad \forall h \in H, \forall i \in I, \forall h \in I = \forall i \in I, \forall j \in J, \forall h \in J = \forall j \in J\ t = 1,...,T \tag{5.10}$$

$$\sum_{j\in J} l_j \leq \gamma \tag{5.11}$$

$$l_j \leq \eta \qquad \forall j \in J \tag{5.12}$$

$$\sum_{a\in H} e_{tap}x_{tap} = \sum_{h\in H} d_{tph}y_{tph}, \qquad \forall p \in P,\ t = 1,...,T \tag{5.13}$$

$$x_{tap}, y_{tph}, l_j \geq 0 \ \ and \ \ integer, \qquad \forall a \in H, \forall p \in P, \forall h \in H,\ t = 1,...,T \tag{5.14}$$

$$HR_{th} \geq 0 \ \ and \ \ integer, \qquad \forall h \in H,\ t = 1,...,T \tag{5.15}$$

$$NS_{tp}, C_{th}, NA_{ta}, NP_{tp}, LA_{ta}, AA_{th} \geq 0, \qquad a \in H, \forall p \in P, \forall h \in H,\ t = 1,...,T \tag{5.16}$$

In this model, the objective function minimizes the total travel time of served and waiting time of the unserved casualties similarly. We incorporated β value for the permanent emergency unit set to provide the usage priority of these emergency units. Selecting this value lower than 1, we decreased the travel time to these units and obtained the priority of transporting to these units. We add new sets such as I and J. These sets represent the permanent emergency units and TEU sets respectively. Both of them are the subset of set H. Also, we added new setup cost to open TEU. We incorporated ϑ value which is smaller than α penalty value. With this parameter we aimed to prevent opening the slack capacities.

We set it smaller than α because serving is more important than open temporary units. ϑ value affect the objective function with the total capacities of new open TEU. The hospital set was converted into two different subsets. H represents the total emergency unit set in this new model, I and J is the set of permanent and temporary emergency unit locations respectively. In order to increase the system efficiency, some other vehicles such as automobile instead of ambulances were considered. Similarly, because the vehicle capacity is 1, the number of traveling vehicles represents the number of served casualties in this model also. We limited the capacities of TEU with ${C^*}_j$ parameter. ${C^*}_j$ with γ value representing total number of possible open emergency units provides total temporary capacity limit of all locations. In addition to this, ${C^*}_j$ with η value representing the number of possible open emergency unit in each j location limits total temporary capacity for each j location.

All of the constraint except some constraints such as Constraints 5.10, 5.11,and 5.13 are the same. Constraint 5.10 represents the capacity at the first period. The capacity at first period cannot exceed the permanent and selected TEU capacities. Constraint 5.11 is for the limit of total opened TEU in all locations. γ represents this number. Finally, Constraint 5.13 provides the limit to the number of opened emergency units for each location.

Chapter 6

COMPUTATIONAL EXPERIMENTS AND RESULTS FOR THE CASUALTY TRANSPORTATION AND TEMPORARY EMERGENCY UNIT LOCATION MODEL

Solving the first and second model is hard because of the dynamic structure and the healing rate. Without periods and healing rate (assumption of all casualties will not be in hospital in next period) model transforms to a network flow problem. We have three integer variables which are x, y, and HR. x represents the ambulances going from ambulance location to casualty location while y represents the ambulances going from the casualty location to the hospital location. HR gives the number of healed casualties for that period. When x and y integer variables are both relaxed, even in small example with multi-period and healing rate, the fractional solution is obtained. It can be seen from the simple small example below. As it was explained before, because it changed the capacities, HR variables were not relaxed. With this example described in the Figures 6.1, 6.2, and 6.3, it was proven that the relaxation of the x, y variables does not give the integral solutions. The Figures 6.4, 6.5, and 6.6 represents the solution when all variables are integer. The total number of unserved casualties are the same in relaxed and integer problems. Therefore, objective values are different because of the travel time of served casualties. For three periods transportation time of relaxed solution and integer solution are 8.129 and 8.245 minutes respectively. In the relaxed solution, fractional number of casualties were transported. Sending fractional number of casualties affects directly the number of healed people for the next period and this will cause the least travel time of served casualties. For this example, because hospital capacities are sufficient for three periods, the number of ambulances are important to transport more casualties. In this example, we aimed to show the difference between the relaxed and integer solution and importance of the healing rate. However because of the structure of the model, the relaxation of only x variable gave the same result with integer solution. Therefore, Figures 6.4, 6.5, and 6.6 are the results of the model when

x variables are relaxed at the same time. It was explained in the following Proposition 6.1 and Proof 6.1.

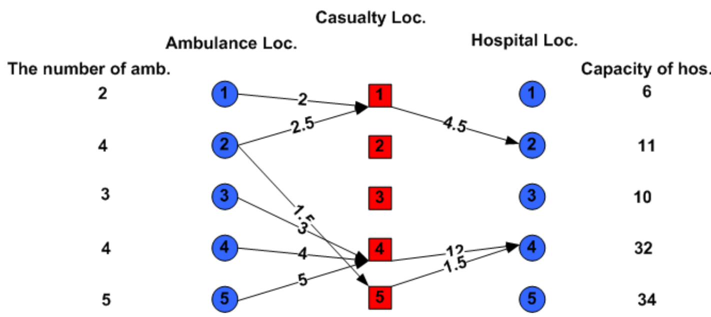

Figure 6.1: Solution of the first period when x and y are relaxed

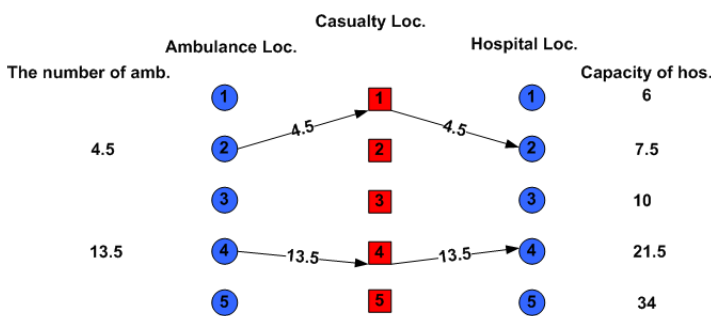

Figure 6.2: Solution of the second period when x and y are relaxed

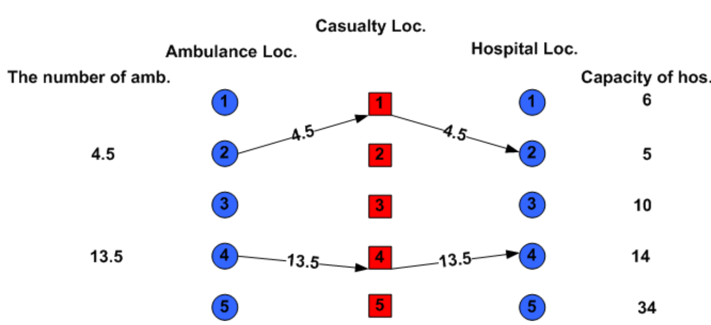

Figure 6.3: Solution of the third period when x and y are relaxed

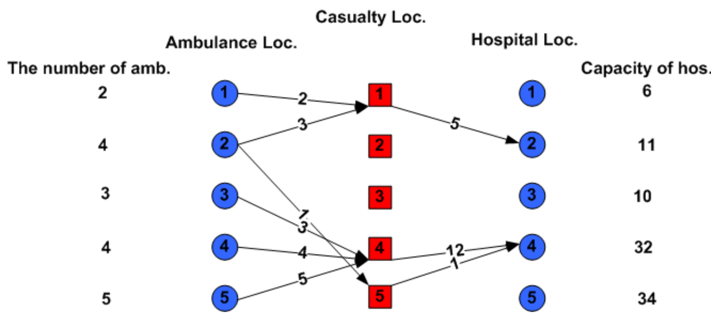

Figure 6.4: Solution of the first period when all variables are integer or only x is relaxed

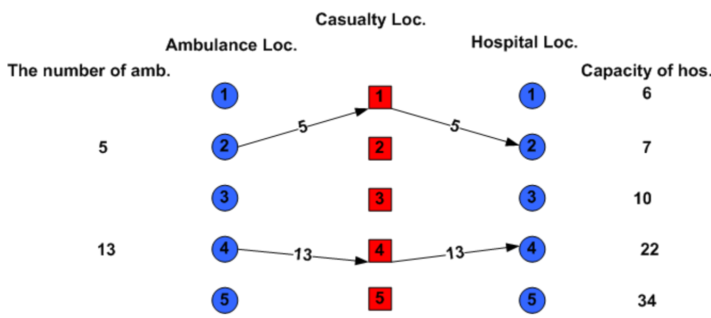

Figure 6.5: Solution of the second period when all variables are integer or only x is relaxed

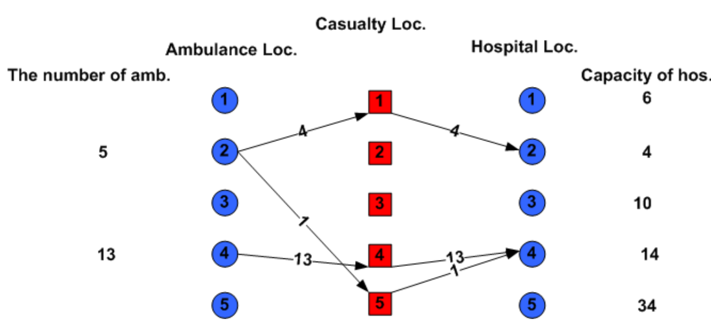

Figure 6.6: Solution of the third period when all variables are integer or only x is relaxed

Proposition 6.1 : If the model depends on the periods and healing rate affected directly by the variable y, the relaxation of only the variable x will always give integer solutions.

Proof 6.1 : Intuitively, the important part of the model affecting the integral solutions are the second part which is the part of the casualty transportation from the casualty location to the hospital location. The capacities are always integer at the beginning and the fractional value of healing rate will not affect the integrality of the capacities (because healing rate variable was set always as integer). When y variables are relaxed, this will affect the number of healed casualties and the hospital capacity for the next period. When y values are forced to be integer, x values cannot take any factional value, because it will try to send as many ambulances as possible to the casualty location if there are ambulances and the capacity of hospitals are available. Therefore, not only for this example and for this instance, but also for the model, the relaxation of x values will not affect the integral solutions.

With the help of this Proposition , in the second model x variables were relaxed. The relaxation of x variables could not be used in the first model in order to increase the number of period instead of solving the model in three steps, because the optimality gap with relaxed solutions could not be decreased in reasonable time. Therefore, we did not relax the x variables in the first model and solve the model in three steps in reasonable time with reasonable optimality gap.

6.1 Data Generation

The second model and its data were generated according to the solutions of the first model. From the transportation model solution, in order to increase the efficiency of the system and serve many people, it was definitely necessary to locate new emergency units and increase the number of vehicles.

It is certain that the second model is harder than the first model. Hence, in order to solve the model, we decreased the number of locations to a certain point especially for the European side. Also, we solved the model for the first 24 periods (12 hours). For the location problem, because the decision of opening the emergency unit is given at the beginning of the periods, the number of periods is not much effective on location decision. Also, the highest number of casualties are in the first periods and because of the exponential function, the number of casualties are decreasing as the periods pass. Hence, if these casualties in the first periods are transported, the casualties who will come for the next periods will be served certainly. In addition to this, because all locations have the same exponential function for casualties, increasing the number of periods will not affect the location decision.

For the European side, the number of permanent ambulance and hospital locations was decreased to 16. Some of the hospitals which are near to each other were assumed as one point and their capacities were added them together and the average value of travel times to casualty locations was considered as travel times. For example, 4, 6, 12, 13, 14, 19, 29, 30 are called location 1, ambulance and hospital locations 2, 20, 21, 22, 27 are called location 2, ambulance and hospital locations 11, 34 are called location 3, Because 1, 33, 25, 32, 26, 15, 3, 31, 16, 5, 28 ambulance and hospital locations are not close to any other locations, we called them location 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, and 14 respectively, ambulance and hospital locations 7, 8, 9, 17, 18, 23 are called location 15, and finally 10, 24 ambulance and hospital locations are called location 16.

In addition to this, we decreased the number of casualty locations. According to results of the transportation model, we extracted one of the casualty location having the least unserved casualty number for each district. In addition, the number of temporary emergency units was selected according to the unserved percentages of districts. Therefore, in Sisli, Fatih, Eminonu and Gaziosmanpasa districts, the location of temporary units was not allowed. The districts having unserved percentages above 90 % was decided to have 2 possible temporary units to locate while others have 1. Selection of these locations for each district was done also according to the number of unserved casualties. The casualty location having more unserved casualties in that district was selected as potential TEU. Under these assumptions, while Zeytinburnu , Bayrampasa, Gungoren, Esenler, and Kucukcekmece have 2 possible locations, Bahcelievler, Bakirkoy, Eyup, Beyoglu, and Bagcilar have 1 possible location. Consequently, for the European side, there are 31 emergency locations (16 permanent, 15 temporary) and 47 casualty locations.

For the Asian side because data is acceptably small, it was not necessary to decrease the number of locations. According to percentages of the unserved casualties which were the solutions of the transportation model, it was assumed that while Maltepe, Kartal, Pendik, and Tuzla have 2 possible locations, Beykoz, Uskudar, Kadikoy, and Umraniye have 1 possible location for temporary emergency units. Also, the number of casualty locations was not decreased. Therefore, for the Asian side, there are 43 emergency unit locations (31 permanent, 12 temporary) and 28 casualty locations. All these temporary units can be seen in Figures 4.3 and 4.4. The number of locations an some parameters are in the Table 6.1

Table 6.1: Number of locations and value of some parameters for second model

	The European side	**The Asian side**
Number of permanent emergency unit locations	16	31
Number of temporary emergency unit locations	15	12
Number of casualty locations	47	28
Total locations	78	71
β	0.5	0.5
α	0.52	0.52
ϑ	0.4	0.4

and the number of TEU for each district is in the Table 6.2.

In the experiments of the second model, the healing rate was considered as 0.25. β representing the priority for the usage of the permanent emergency units was set to 0.5. With this value it was aimed to give a priority to the permanent emergency units. ϑ representing setup cost for each new open capacity was set as 0.4 which is smaller than α value. Table 6.1 gives these values also.

The solution performance were evaluated with the relaxed solution and optimality gap were calculated according to (integer sol.-relaxed sol.)*100/relaxed sol. formula.

As we explained before, with the second model, we aimed to describe the necessities of each locations decide where to locate the additional units in order to increase system efficiency. However, this is not an easy issue, because the uncertainty in the disaster situation affects the response plan. In the solution of the second model, some cases are generated in order to obtain better solutions and emphasize the necessities under the circumstances of the uncertainties adding new resources to the current system.

Case 1

In this case, the constraints 5.11 and 5.13 were eliminated and the $C^*{}_j$ was set to the large number. Vehicle number was set as the 5 times of the ambulance number in the first model for the European side and 3 times of the ambulance number in the first model for

Table 6.2: Number of temporary locations for each districts

the European side	**Number of temporary emergency units**
B.evler	1
Bakirkoy	1
Sisli	-
Eyup	1
Beyoglu	1
Eminonu	-
Fatih	-
Z.burnu	2
B.pasa	2
Gungoren	2
Bagcilar	1
Esenler	1
G.opasa	-
K.cekmece	1
the Asian side	
Beykoz	1
Uskudar	1
Kadikoy	1
Umraniye	1
Maltepe	2
Kartal	2
Pendik	2
Tuzla	2

Table 6.3: Data set for second model

	$C^*{}_j$	η	γ	**VN**
the European side				
Case 1	BN	-	-	1020
Case 2				
1	100	4	20	816
2	100	4	25	1020
3	100	4	30	1020
4	100	4	30	1224
the Asian side				
Case 1	BN	-	-	378
Case 2				
1	100	3	6	252
2	100	3	8	378
3	100	3	10	378

VN=Vehicle Number, BN=Big Number

the Asian side. With this case, it was aimed to see what is the necessity capacities for each possible location.

Case 2

In this case, the model was solved under different types of γ values representing the total number of open temporary units in all locations and the number of vehicles. $C^*{}_j$ values were fixed as 100. For the European side η value was set to 4. This γ and η values are directly related to the total capacity of emergency units. γ*100 will be the limit of total capacity of temporary unit while η*100 is the capacity limit for each possible location. While the total number of open temporary units are 20, 25, 30, and 35, the corresponding vehicle number was selected as 4 times, 5 times, 5 times and 6 times of of the ambulance number in the first model for the European side respectively. Similarly, for the Asian side η value was set 3. While the total number of open temporary units are 6,8 and 10, the corresponding vehicle number was selected as 2 times, 3 times, and 3 times of of the ambulance number in the first model for the European side respectively. In this case, it was aimed to see the system performance under some restriction of the opening new units. All these values about these cases can be seen in Table 6.3.

6.2 Computational Results

Similarly to the first model, all codes have been written in GAMS 22.5 tool and used the MIP solver CPLEX 11.0.0, compiled and executed on a 3.00 GHz Intel Xeon®server with 4 GB RAM. Options that we explained in the first model was remained same for the second model solutions 4.3. In order to compare the solution of the first and second model, we collected the results for the first 24 periods from the first model. As we explained before, we worked with 24 periods for the second model. For the location model it will not cause much change in the final solution when we increase the number of periods. Because in all periods, the number of casualties in each district will show same attitude as the periods increase (because all districts works according to the same exponential function). Also, the highest number of casualties were reached in the first 24 periods. As an example, we executed the Model A1 for the Asian side when VN=378 and γ=10, and we obtained the same results by means of the new opening temporary units.

6.2.1 Results for the European Side

Case 1

With the addition of new units, all casualties were transported in Model A1 and Model A2. Only small amount of casualties in Model C1 and C2 could not be served due the the lack of vehicle number. From that point, it was concluded that not only the increase in capacities cause to reach more people, but also the number of vehicles will directly affect the number of served casualties. In order to serve many people, it is necessary to adjust the capacities and vehicle numbers. From the solution of the first model, it can be seen that the number of served casualties were increased and the average travel time of a served casualty increased, because the casualties can be transported to the remote places where the temporary services are located. Similar to the first model results, because Model A1 has lower travel time values, it has better objective than Model A2 which is the same in Model C1 and C2. The performance of the solutions were evaluated with the relaxed model and the optimal gap was calculated. All results have 0.00 value which is extremely tight C-17.

For Model A1 and A2, we could not give the average waiting time of unserved casualties because of there are not any unserved casualties at the end of 24th period. For such solutions, we calculated the maximum waiting time of one person in intermediate periods.

Table 6.4: Maximum waiting time of some models under the circumstances of no unserved casualties at the last period

Max. Waiting time	
the European side	
Model A1	
Case 1	372
VN=1224,γ=35	31
Model A2	
Case 1	372
VN=1224,γ=35	0
the Asian side	
Model A1	
Case 1	189
Model A2	
Case 1	189

All these values are given in the Table 6.4.

The capacity requirements show similar attitude in all scenarios. While some of the locations are highly used such as Beyoglu, 1st location of Gungoren, Bakirkoy, Bahcelievler, and Bagcilar (above 300 capacity requirements), other locations have less capacity requirements. Therefore, it is certain that new capacities will be located in these locations even if there is a limitation in total capacities such as Case 2 results. Necessary capacities were reported in Tables C-2, C-4, C-6, and C-8 for Model A1, A2, C1, and C2 respectively.

The percentages of unserved casualties were reported in Tables C-1, C-3, C-5, and C-7 for Model A1, A2, C1, and C2 respectively. Because all casualties were transported in Model A1 and Model A2, the unserved casualty percentages are at the lowest level. In Model C1 and Model C2, although all districts have acceptable unserved percentages, in contrast to the first model results, Fatih and Eminonu have the worst results because we located temporary emergency units in some other places where the permanent emergency units have been already insufficient.

Case 2

In these cases, with different capacity limits for each location, we aimed to see the behavior of the system. In the European side, because there are more casualties, we applied 4 different data sets. As we assumed before, the locations where needs more capacities in Case 1, were selected as new temporary locations. As the VN and γ values increase, the capacities are increased in these locations. Also, as the VN and γ values increase, the unused location number decrease. Generally, for Model A1, A2, and C1, 1st location of Zeytinburnu, Esenler and Kucukcekmece and 2nd location of Bayrampasa are the least used locations, while for Model C2, 2nd location of Bayrampasa and 1st location of Esenler are the least. These locations are rarely used in scenarios which shows that the location of new unit there are not as necessary as locating in other locations. These values can be seen from the Tables C-2, C-4, C-6, and C-8 for Model A1, A1, C1, and C2 respectively.

The percentages of unserved casualties behaves differently in each data set and scenario. Because there is no priority for districts, solutions can change for different scenarios. For example, the percentages of unserved casualties decreased when the VN and γ were reached to the highest level. Beyoglu, Fatih, and Zeytinburnu for Model A1, Beyoglu, Zeytinburnu, and Kucukcekmece for Model A2, Fatih, Zeytinburnu, and Kucukcekmece for Model C1, and Beyoglu, and Zeytinburnu for Model C2 have least unserved percentages at the fourth data set. These results can be seen from the Tables C-1, C-3, C-5, and C-7 for Model A1, A2, C1, and C2 respectively.

The performance of the solutions were reported in Tables C-17. All results have good optimality gaps even though the objective function values decrease as the VN and γ values increase. Average travel times increase as the VN and γ values increase. Generally, average waiting time increases because the number of unserved casualties decreases. Similar to the first model results average travel and waiting time of Model C1 and C2 values are lower than Model A1 and A2. When the number of casualties increases in the locations where many casualties are transported from there, additional casualties are transported from these locations certainly instead of other distant casualty locations. Therefore Model C1 and C2 have the least average travel time values. In addition, although average waiting time is lower in Model C1 and C2, the number of unserved casualty numbers are higher and total average waiting time is much larger that Model A1 and Model A2.

Generally, from the solutions, it can be said that the fist location of Gungoren, Beyoglu, Bakirkoy, the second location of Zeytinburnu, Bagcilar and Bahcelievler have high priority to locate additional units. In Figure 6.7, the location priority was defined with the color of the points. While the red points have the high priority, yellow ones have the lowest.

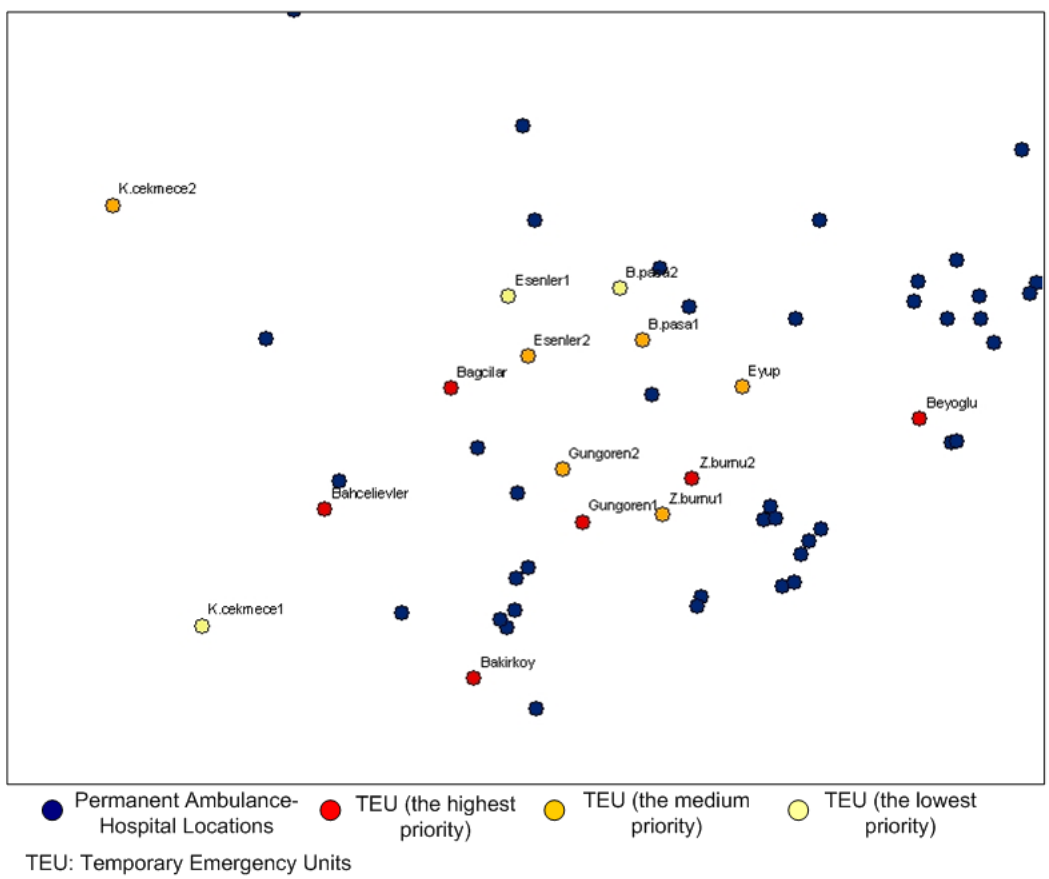

Figure 6.7: The location priorities of TEU in the European side

6.2.2 Results for the Asian Side

Case 1

Capacities of TEU are spread equally generally to all locations. However, some locations have little less capacity necessities such as Beykoz, Umraniye, 1st location of Kartal and Tuzla with respect to other locations. This is because of the network structure of the Asian side. The locations are distant from each other, so in order to increase the efficiency, every temporary location need to have some capacity which is not low to ignore. Tables C-10, C-12, C-14, and C-16 represent these results.

In Tables C-9, C-11, C-13, and C-15 reported the results of unserved percentages of casualties. While all casualties in Model A1 and A2 are served, except some casualties in Kadikoy and Pendik, many casualties in Model C1 and C2 were served.

Solutions have 0.00 gap with respect to relaxed solutions similar to the European results C-17.

Case 2

When there is a limitation on the capacities, model behaves similarly in each scenario. For example, in each data set, temporary units were not located in Beykoz, Umraniye, and Tuzla (except some data sets). Maltepe, Kartal, Pendik, Uskudar are highly preferable locations in order to increase the temporary capacities. Increase in the number of casualties did not cause extreme changes in the solutions between Model A and C by means of the location of units. However, it is easy to see that even though the the third data set (VN=378, γ=10) is sufficient for scenarios A1 and A2, it is necessary to add small amount of additional capacities in order to serve all casualties in Model C1 and C2. These results are shown in the Tables C-10, C-12, C-14, and C-16.

When it is looked the Tables C-9, C-11, C-13, and C-15, the results change for each data set can be realized. In model A1, Uskudar and Kadikoy casualty percentages were decreased at the first data sets. In Model A2, same situation is valid for Uskudar and Maltepe districts. This results are directly related the capacities of temporary units. The more capacity the locations have, the more casualty will be served from there. While Kadikoy has more capacities in most of the data sets in Model A1, Maltepe has more capacities in Model A2. In Model C1, at the first data set, Maltepe and Kartal have least casualty percentages. In later data sets, Umraniye and Maltepe have the less values. Model C2 does not gives the stable results. At the the third data set, Umraniye and Maltepe have the least unserved casualty percentages similar to Model C1.

Optimal gaps are acceptable, even though in the the third instance set Model A1 and Model A2 gives 4.66 and 5.33 relative gaps which is higher with respect to other solutions. However, objective function values decrease when the capacities increase. It is normal and acceptable to have this amount of gap. Results are in the Table C-18.

According to results, while incorporated instances are sufficient for scenarios A1 and A2 even if in Case 1 and the the third instance sets in Case 2, this does not work for scenarios C1 and C2. Some certain locations in the European side such as Beyoglu, Gungoren, Bakirkoy, Bagcilar, and Zeytinburnu and in the Asian side such as Uskudar, Maltepe, Kartal and Pendik are very important districts in the case of location for new units. This was proven with first case and in the steps of decreasing limit VN and γ in the second case. The solution of Model A1 and A2 provides lower limit of additional capacities to the decision makers. In order to transport more casualties it is necessary to have extra capacities mostly in these location that we described above.

Generally, from the solutions, it can be said that Maltepe, the second location of Kartal and Pendik, and Uskudar have high priority to locate additional units. In Figure 6.8, the location priority was defined with the color of the points. While the red points have the high priority, yellow ones have the lowest.

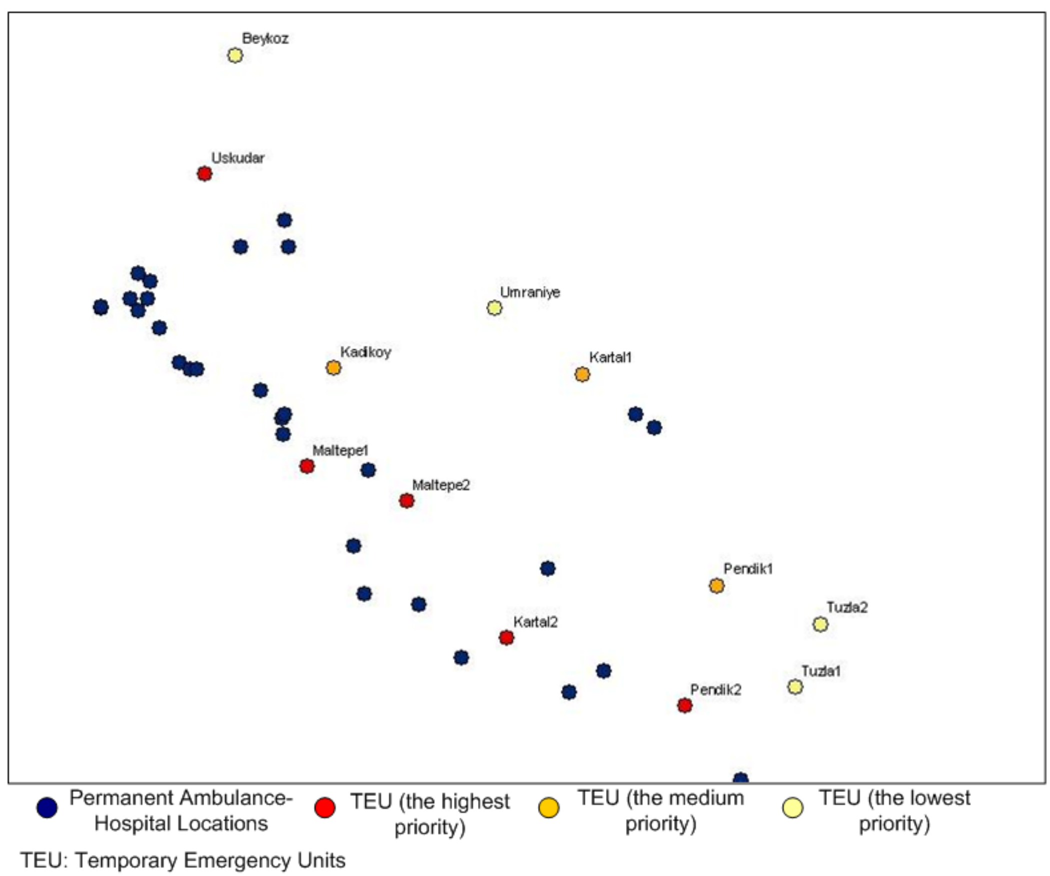

Figure 6.8: The location priorities of TEU in the Asian side

Chapter 7

CONCLUSIONS

In this thesis, we have studied multi-period casualty logistic problems for post-disaster activities. The problems that we have been dealing with take their motivations from the real life problems faced by the locations threatened by disasters, especially earthquakes. Our aim is to analyze the current system and capacities, and give some strategic decisions to the current system in order to increase the efficiency by constructing reasonable model. Two mixed integer mathematical model were constructed. The first model is multi-period casualty transportation model. In this model, objective is to minimize the total travel time of served and total waiting time of unserved casualties with subject to updated number of casualties, ambulances, and hospital capacities in each period. The second model is the multi-period casualty transportation and temporary emergency unit location model. Also, in this model, total travel times of served and total waiting time of unserved casualties are minimized. The set up cost were incorporated into the objective additionally in order to decrease the slack capacities to be open. In the second model, two types of hospital locations were considered; permanent and TEU locations. While permanent locations represent the current capacities, the aim is to determine the possible locations and capacities of additional temporary emergency units.

We solved our models by using CPLEX 11.0.0 engine by using branch-and-bound algorithm. All codes have been written in GAMS 22.5 environment. The solution time was set to 1 hour in options to take the reasonable optimal gaps with lower bound in branch-and-bound procedure. With the possible scenarios determined by the study of JICA for Istanbul, we generated data for these scenarios and set the casualty numbers. Also, the road blockage and bridge and viaduct collapse probabilities were generated for the road non-functionality probabilities. This provides the calculation of expected travel time between locations under these probabilities for each scenario. Real number of ambulances, and hospital capacities and locations were taken from Istanbul Metropolitan Municipality and Health Ministry. The real network of Istanbul considering ambulance and hospital locations and generated casualty locations were generated by using geographical packages Arcmap with real coordinates. For the first model, the European side has 95 (34 ambulance-hospital, 61 casualty locations) locations and 293 roads, the Asian side has 59 locations and 131 roads. The model was aimed to be solved for 144 periods. Each period was assumed 30 minutes and 144 periods represents the first 3-days of the beginning of casualty transportation. From the solution of the first model, especially for the European side which have more casualties according to possible scenarios many casualties will not be served with the current resources. Eminonu, Fatih, Sisli and Gaziosmanpasa have the least unserved casualty percentages among all districts in the European side. Even if the healing rate increases to 0.5, the unserved percentages are still high. The Asian side results are more acceptable. Beykoz, Uskudar, Kadikoy, and Umraniye has the least unserved percentages. In all solutions, while the travel times of the served casualties are extremely low, the waiting time of unserved casualties are high. This is because of the lack of hospital capacity. Also, the ambulance usage percentages did not reach 100 % because of the same reason. Average travel times and waiting times for each person for Model A1 and Model A2 gives higher values than Model C1 and C2, even though Model C1 and C2 have higher travel times. This is because of the increase in the casualty numbers in the location nearer to the hospitals. This will certainly lead the travel time decrease. Also, average waiting time per person is low in Model C1, and C2. Actually, total average waiting time of casualties is the main point. Not only the average waiting time per person explains the situation, but also, it is necessary to consider the total number of unserved casualties. From this point of view, Model C1 and C2 are not better than A1 and A2. Performance of the solutions was evaluated with the relaxed solution. In this solution we relaxed all variables except HR variables because it affects the capacities and the number of served casualties with the fractional parameter r. All gaps are below 0.01 except the Model A1 and Model A2 results in the Asian side when healing ratio is 0.5. These are also below 2 which is acceptable for that objective values.

Second model data was generated according to results of the first model. In the second model we solved the model for the first 12 hours (24 periods). This will not affect the location decision because every casualty location have the same exponential function for casualty numbers and in the first 24 periods, maximum number of casualties come out from the affected areas. If these casualties can be served, certainly in the next periods, others can be transported. Possible temporary locations were selected according to the unserved percentages for each district. The districts having high unserved percentages have 2 possible TEU while others have one. Because the European side data is extremely large, we decreased the number of location of hospitals and casualties. The Asian side data is sufficient to solve the second model with the addition of temporary units. Because the uncertainty in disaster and disaster response activities, we generated some cases in order to evaluate the results. In the first case, there was no limitation on opening temporary units and capacities. In the European side, some of the districts had much higher temporary capacities than others such as Beyoglu, the first location of Gungoren, the second location of Zeytinburnu, Bakirkoy, Bagcilar and Bahcelievler. However, some locations had so low capacities that it is not necessary to locate a unit here. These locations are the first location of Esenler and Kucukcekmece and the second location of Bayrampasa for Model A1 and A2 and C2, the first location of Esenler and Kucukcekmece for Model C1. Similarly in the Asian side, generally, Maltepe, the second location of Kartal, Uskudar and Pendik have higher priority to locate the temporary units. From Model A1 to Model C2, necessities have changed due the the increase in the travel times and the number of casualties. With the usage of different scenarios, different sides of disasters can be predicted and upper and lower bounds of the capacity necessities are determined. In the first case, it was concluded that even if the capacities are sufficient, the number of vehicles are also needed to be sufficient. For Model C1 and C2 for the European and Asian sides incorporated vehicle number should be exceeded. The first location of vehicles are not important in the European side because all locations are reachable in time limit. However, the first location of vehicles are important in the Asian side. Because it was so hard to predict the number of vehicles for each location, we increased the number of vehicles in the same location of ambulances in the first model. In second case, under some possible restrictions in the system, the location and capacities of new units were calculated. Similarly, for Model C1 and C2 for both side, vehicle number were insufficient. Beside this, in the last data sets of both side for Model A1 and Model A2, all casualties were transported. Similar to the first case, the locations having more necessary capacities in Case 1, was selected as temporary locations in Case 2 also. When VN and γ increase, the additional capacities were located in these locations. Also, with different scenarios, upper and lower bound of the system capacities were determined. The performance of the solutions were evaluated with the gap between relaxed solutions. All results except results for some instances are extremely good. However, because the objective function values decrease, it is normal to have high gap between the solutions. With incorporated instances the capacities which are sufficient for Model A1 and A2 are not sufficient for Model C1 and C2. Some extra temporary capacities are needed for the mostly used locations. When additional capacities are added while travel times increase, the average waiting time of total casualties decreased. This is a strategic level decision to make preparation for a disaster under the scenarios. However, solutions shows that it is certainly necessary to locate the temporary units to determined locations in Beyoglu, Gungoren, Bakirkoy, Bagcilar, and Zeytinburnu for the European side and Uskudar, Maltepe, Kartal and Pendik for the Asian side highest possible capacities or at least with determined capacities in results. For Model A and C general priorities of locations of temporary units were determined.

In this thesis, we aimed to generate a model that is suitable with real life problems and gives reasonable results and extension to the decision makers. Considering the problem of Istanbul, we have tried to evaluate the current system with the first model and the data of emergency medical capacities in hospitals and give strategic decisions about where to locate the temporary emergency units and how many capacities are needed in order to decrease the number of unserved casualties. With different scenarios, we have tried to see the scale of the disaster and evaluate the system under these scenarios. This gives an idea to the decision makers about the best and worst case of the data sets under some assumptions. This thesis makes a very important contribution to the existing literature because human life is very important and planning post-disaster activities will certainly decrease the loss of life and the damage of the disaster.

BIBLIOGRAPHY

[1] N. Altay and W. Green III. Or/ms research in disaster operations management. *European Journal of Operational Research*, 175:475–493, 2006.

[2] G. Barbarosoglu and Y. Arda. A two-stage stochasting programming framework for transportation planning in disaster response. *Journal of the Operational Research Society*, 55:43–53, 2004.

[3] O. Berman, R. Larson, and S. Chiu. Optimal server location on a network operating as an m/g/1 queue. *Operations Research*, 33:746–771, 1985.

[4] R. Carbone. Public facility location under stochastic demand. *INFOR*, 12, 1974.

[5] Y. Carson and R. Batta. Locating an ambulance on the amherst campus of the state university of new york at buffalo. *Interfaces*, 20:43–49, 1990.

[6] R. Church and C. Revelle. The maximal covering location problem. *Papers of Regional Science Association*, 32:101–118, 1974.

[7] J. F. Cordeau and L. G. The dial-a-ride problem: models and algorithms. *Ann. Oper. Res.*, 153:29–46, 2007.

[8] M. Daskin. The maximal expected covering location model:formulation, properties, and heuristic solution. *Transportation Science*, 17(1):48–70, 1971.

[9] A. Fiedrich, F. Gehbauer, and U. Rickers. Optimized resource allocation for emergency response after earthquake disasters. *Safety Science*, 35:41–57, 2000.

[10] J. A. Fitzsimmons. A methodology for emergency ambulance deployment. *Mngt Sci*, 19:627–636, 1973.

[11] R. Garfinkel, A. W. Neebe, and M. R. Rao. The m-center problem:minimax facility location. *Management Science*, 23:1133–1142, 1977.

[12] Q. Gong and R. Batta. Allocation and reallocation of ambulances to casualty clusters in a disaster relief operation. *IEE Transactions*, 39:1:27–39, 2007.

[13] A. Haghani, H. Huijun, and T. Qiang. A methodology for emergency ambulance deployment. *Transportation Research Board*, 2003.

[14] A. Haghani and S. Oh. Formulation and solution of a multi-commodity, multi-modal network flow model for disaster relief operations. *Transportation Research*, 30(3):231–250, 1996.

[15] S. Hakimi. Optimum locations of switching centers and the absolute centers and medians of a graph. *Operations Research*, 12:450–459, 1964.

[16] S. I. Harewood. Emergency ambulance deployment in barbados: a multi-objective approach. *J. Opl. Res. Soc.*, 53:183–192, 2002.

[17] D. Hochbaum and A. Pathria. Locating centers in a dynamically changing network and related problems. *Location Science*, 6:243–256, 1998.

[18] H. Jia, F. Ordóñez, and M. Dessouky. A modeling framework for facility location of medical services for large-scale emergencies. *IEE Transactions*, 39:41–55, 2007.

[19] J. I. C. A. (JICA) and I. M. M. (IMM). The study on a disaster prevention / mitigation basic plan in Istanbul including microzonation in the Republic of Turkey. Technical Report Volume V, Istanbul Great Municipality (IGM), September 2002.

[20] R. Larson. A hypercube queuing model for facility location and redistricting in urban emergency services. *Computers and Operations Research*, 1:67–95, 1974.

[21] F. C. Mendonca and R. Morabito. Analysing emergency medical service ambulance deployment on a brazilian highway using the hypercube model. *J. Opl. Res. Soc.*, 52:261–270, 2001.

[22] H. Owen and M. Daskin. Strategic facility location:a review. *European Journal of Operational Research*, 111:423–447, 1998.

[23] L. Ozdamar, E. Ekinci, and B. Kucukyazici. Emergency logistics planning in natural disasters. *Annals of Operations Research*, 129:217–245, 2004.

[24] C. Revelle and H. K. The maximum reliability location problem and α-reliable p-center problem: Derivatives of the probabilistic location set covering problem. *Annals of Operations Research*, 23:192–200, 1989.

[25] D. Serra and V. Marianov. The p-median problem in a changing network:the case of barcelona. *Location Science*, 4, 1999.

[26] C. Toregas, R. Swain, and L. Bergman. The location of emergency service facility. *Operations Research*, 19:1363–1373, 1971.

[27] B. Üniversitesi, I. T. Üniversitesi, O. D. T. Üniversitesi, and Y. T. Üniversitesi. Istanbul icin deprem master planı. Technical report, Istanbul Büyükşehir Belediyesi Planlama ve Imar Dairesi Zemin ve Deprem Inceleme Müdürlüğü, Temmuz 2003.

[28] W. Yi and A. Kumar. Ant colony optimization for disaster relief operations. *Transportation Research*, 43:660–672, 2007.

[29] W. Yi and L. Ozdamar. A dynamic logistics coordination model for evacuation and support in disaster response activities. *European Journal of Operational Research*, 179:1177–1193, 2007.

Appendix A

RELATED DATA FOR MODEL

Table A-1: Capacity of emergency services and number of ambulances in each ambulance-hospital location

Hospital No	Hospital Name	Capacity of Emergency Services	Number of Ambulances
1	Bagcilar EAH	15	6
2	Bakirkoy Dr. Sadi Konuk EAH	25	13
4	Bayrampasa Sagmalcilar DH	6	5
5	Beykoz DH	6	2
9	Dr.Siyami Ersek Gogus EAH	11	4
10	Istanbul EAH	22	6
12	Eyup DH	16	5
13	Fatih Sultan Mehmet EAH	10	3
14	Goztepe EAH	32	4
15	Haseki EAH	39	7
16	Haydarpasa Numune EAH	34	5
18	Kartal Dr. Lutfi Kirdar EAH	0	6
19	Kartal Kosuyolu Yuksek Ihtisas ve EAH	11	3
20	Kartal Yavuz Selim DH	25	6
22	Okmeydani EAH	41	11
23	Pasabahce DH	8	1
24	Pendik DH	8	8
28	Sureyyapasa Gogus Kalp ve Damar CH	12	10
30	Sisli DH	2	5
31	Sisli Etfal EAH	16	13
32	Tacirler Egitim Vakfi Sultanbeyli DH	6	5
33	Taksim EAH	6	4
34	Tuzla DH	4	10
35	Umraniye EAH	9	5
36	Uskudar DH	3	4
37	Validebag Ogretmenler DH	5	3
38	Yedikule Gogus H. Ve Gogus C	8	6
39	I.U. Cerrahpasa Tip Fak.H	30	7
40	I.U. Istanbul Tip Fak.H	30	3

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Table A-1 – continued from previous page

Hospital No	**Hospital Name**	**Capacity of Emergency Services**	**Number of Ambulances**
41	Yeditepe Uni. Tip Fak. H	10	2
42	Maltepe Uni. Tip Fak. H	10	8
44	Vakif Gureba EAH	10	5
45	O.Acibadem Bakirkoy H	8	8
46	O.Acibadem H	8	2
47	O.Acibadem Kozyatagi H	8	2
49	O.Avrupa Safak H	8	8
50	O.Sisli Florance Nightingale H	10	6
51	O.Goztepe H	5	2
52	O.Istanbul International H	5	9
53	O.Istanbul Vatan H	5	3
54	Ozel John.F Kennedy H	5	3
55	O.Medical Park Bahcelievler H	5	3
56	O.Medicana Hospitals Bahcelievler H	5	3
57	O.Medicana Hospitals Camlica H	5	3
58	O.Memorial H	5	5
60	O.Sema H	5	4
61	O.Universal Hospitals(Alman)	5	2
62	O.Universal Hospital	5	2
63	O.Yeni Isvicre H	5	1
65	P.H	8	9
66	P.H	8	3
67	P.H	10	3
69	P.H	2	6
70	P.H.	10	3
71	P.H	10	3
72	P.H	10	8
73	P.H	6	4
74	P.H	4	16
75	P.H	2	2
77	P.H	6	5
78	P.H	8	3
79	P.H	14	2
80	P.H	6	2
81	P.H	12	3
82	P.H	6	7

P.H=Private Hospital

Table A-2: Types and Length of Roads and Non-functionality probabilities of roads for each scenarios in the European side

Road Number	**Road Type**	**Road Length**	**A1**	**A2**	**C1**	**C2**
1	1	1230.17	0.00025	0.00050	0.00075	0.001
2	1	591.80	0.00025	0.00050	0.00075	0.001
3	1	948.35	0.00025	0.00050	0.00075	0.001
4	1	775.27	0.00025	0.00050	0.00075	0.001
5	1	2029.97	0.40015	0.40030	0.40045	0.401
6	1	1840.77	0.30088	0.30105	0.30123	0.301
7	1	592.38	0.00125	0.00150	0.00175	0.002
8	1	294.46	0.00125	0.00150	0.00175	0.002
9	1	1228.81	0.30018	0.30035	0.30053	0.301
10	1	3280.13	0.30025	0.30050	0.30075	0.301
11	1	1691.76	0.00025	0.00050	0.00075	0.001
12	1	2484.78	0.45179	0.45193	0.45206	0.452
13	1	1225.92	0.20020	0.20040	0.20060	0.201
14	1	3347.56	0.30018	0.30035	0.30053	0.301
15	1	2769.78	0.00025	0.00050	0.00075	0.001
16	1	1122.02	0.00025	0.00050	0.00075	0.001
17	1	2773.88	0.00025	0.00050	0.00075	0.001
18	1	1759.91	0.00125	0.00150	0.00175	0.002
19	1	2022.85	0.00025	0.00050	0.00075	0.001
20	1	1740.73	0.20020	0.20040	0.20060	0.201
21	1	2037.37	0.00025	0.00050	0.00075	0.001
22	1	1988.89	0.00025	0.00050	0.00075	0.001
23	1	1889.73	0.00025	0.00050	0.00075	0.001
24	1	3277.95	0.00025	0.00050	0.00075	0.001
25	1	399.29	0.00225	0.00250	0.00275	0.003
26	3	2623.37	0.62500	0.75000	0.87500	1.000
27	1	1393.91	0.00025	0.00050	0.00075	0.001
28	1	559.74	0.00025	0.00050	0.00075	0.001
29	1	645.51	0.00125	0.00150	0.00175	0.002
30	1	1665.90	0.00325	0.00350	0.00375	0.004
31	1	1259.47	0.00025	0.00050	0.00075	0.001
32	1	3067.68	0.00125	0.00150	0.00175	0.002
33	1	1377.10	0.45124	0.45138	0.45151	0.452
34	1	860.96	0.00125	0.00150	0.00175	0.002
35	1	696.94	0.00225	0.00250	0.00275	0.003
36	1	536.77	0.00225	0.00250	0.00275	0.003
37	1	870.76	0.30325	0.30350	0.30375	0.304
38	1	814.78	0.00325	0.00350	0.00375	0.004

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Table A-2 – continued from previous page

Road Number	Road Type	Road Length	A1	A2	C1	C2
39	1	1672.39	0.00025	0.00050	0.00075	0.001
40	1	2433.66	0.00025	0.00050	0.00075	0.001
41	1	1941.49	0.20550	0.20700	0.20850	0.210
42	1	2118.08	0.40015	0.40030	0.40045	0.401
43	1	1530.39	0.00025	0.00050	0.00075	0.001
44	1	1390.43	0.00025	0.00050	0.00075	0.001
45	1	1022.75	0.00125	0.00150	0.00175	0.002
46	1	1489.37	0.00325	0.00350	0.00375	0.004
47	1	1084.60	0.00550	0.00700	0.00850	0.010
48	2	463.08	0.00550	0.00700	0.00850	0.010
49	2	1206.59	0.35000	0.40000	0.45000	0.500
50	2	803.16	0.35000	0.40000	0.45000	0.500
51	2	317.13	0.35000	0.40000	0.45000	0.500
52	3	568.42	0.35000	0.40000	0.45000	0.500
53	1	1643.00	0.00225	0.00250	0.00275	0.003
54	1	760.33	0.00550	0.00700	0.00850	0.010
55	1	575.21	0.00225	0.00250	0.00275	0.003
56	1	1010.29	0.00025	0.00050	0.00075	0.001
57	3	976.34	0.62500	0.75000	0.87500	1.000
58	1	1145.98	0.00550	0.00700	0.00850	0.010
59	1	686.04	0.25750	0.50500	0.75250	1.000
60	1	1397.80	0.00025	0.00050	0.00075	0.001
61	1	2191.28	0.25750	0.50500	0.75250	1.000
62	2	586.14	0.12500	0.15000	0.17500	0.200
63	2	604.56	0.62500	0.75000	0.87500	1.000
64	1	552.63	0.00325	0.00350	0.00375	0.004
65	1	649.19	0.00025	0.00050	0.00075	0.001
66	1	646.38	0.00550	0.00700	0.00850	0.010
67	2	2922.48	0.35000	0.40000	0.45000	0.500
68	1	826.45	0.00025	0.00050	0.00075	0.001
69	2	2634.41	0.01250	0.02500	0.03750	0.050
70	2	3339.46	0.01250	0.02500	0.03750	0.050
71	3	1481.64	0.62500	0.75000	0.87500	1.000
72	3	3183.71	0.62500	0.75000	0.87500	1.000
73	3	1575.12	0.62500	0.75000	0.87500	1.000
74	3	1483.52	0.62500	0.75000	0.87500	1.000
75	3	488.91	0.62500	0.75000	0.87500	1.000
76	2	350.05	0.01250	0.02500	0.03750	0.050
77	3	180.11	0.62500	0.75000	0.87500	1.000
78	2	2179.76	0.06250	0.07500	0.08750	0.100

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Table A-2 – continued from previous page

Road Number	Road Type	Road Length	A1	A2	C1	C2
79	3	1129.47	0.62500	0.75000	0.87500	1.000
80	3	535.94	0.62500	0.75000	0.87500	1.000
81	3	538.99	0.62500	0.75000	0.87500	1.000
82	1	671.29	0.00025	0.00050	0.00075	0.001
83	2	748.44	0.12500	0.15000	0.17500	0.200
84	3	781.86	0.62500	0.75000	0.87500	1.000
85	2	717.18	0.06250	0.07500	0.08750	0.100
86	2	753.22	0.06250	0.07500	0.08750	0.100
87	2	876.93	0.01250	0.02500	0.03750	0.050
88	2	1583.71	0.06250	0.07500	0.08750	0.100
89	1	487.78	0.00025	0.00050	0.00075	0.001
90	3	1013.68	0.62500	0.75000	0.87500	1.000
91	3	1092.40	0.62500	0.75000	0.87500	1.000
92	2	867.31	0.12500	0.15000	0.17500	0.200
93	3	854.76	0.62500	0.75000	0.87500	1.000
94	3	211.38	0.62500	0.75000	0.87500	1.000
95	3	444.37	0.62500	0.75000	0.87500	1.000
96	3	727.46	0.62500	0.75000	0.87500	1.000
97	2	914.00	0.12500	0.15000	0.17500	0.200
98	1	1898.11	0.00025	0.00050	0.00075	0.001
99	2	1422.92	0.22500	0.25000	0.27500	0.300
100	3	853.58	0.62500	0.75000	0.87500	1.000
101	3	233.40	0.62500	0.75000	0.87500	1.000
102	1	1660.11	0.00225	0.00250	0.00275	0.003
103	3	1163.64	0.62500	0.75000	0.87500	1.000
104	1	1509.74	0.00125	0.00150	0.00175	0.002
105	3	1592.81	0.62500	0.75000	0.87500	1.000
106	3	425.42	0.62500	0.75000	0.87500	1.000
107	1	308.88	0.00125	0.00150	0.00175	0.002
108	1	1731.40	0.00025	0.00050	0.00075	0.001
109	1	131.99	0.00225	0.00250	0.00275	0.003
110	1	567.57	0.00225	0.00250	0.00275	0.003
111	1	116.85	0.00225	0.00250	0.00275	0.003
112	1	312.94	0.00225	0.00250	0.00275	0.003
113	2	979.22	0.12500	0.15000	0.17500	0.200
114	2	1518.15	0.06250	0.07500	0.08750	0.100
115	2	679.81	0.01250	0.02500	0.03750	0.050
116	3	1018.19	0.62500	0.75000	0.87500	1.000
117	2	2426.68	0.62500	0.75000	0.87500	1.000
118	2	1819.42	0.22500	0.25000	0.27500	0.300

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Table A-2 – continued from previous page

Road Number	Road Type	Road Length	A1	A2	C1	C2
119	2	559.51	0.22500	0.25000	0.27500	0.300
120	2	1111.92	0.06250	0.07500	0.08750	0.100
121	2	1384.32	0.06250	0.07500	0.08750	0.100
122	1	1464.54	0.00025	0.00050	0.00075	0.001
123	2	1607.26	0.12500	0.15000	0.17500	0.200
124	2	155.62	0.12500	0.15000	0.17500	0.200
125	2	1812.96	0.12500	0.15000	0.17500	0.200
126	2	760.82	0.06250	0.07500	0.08750	0.100
127	2	1920.05	0.01250	0.02500	0.03750	0.050
128	3	1192.23	0.62500	0.75000	0.87500	1.000
129	2	1049.56	0.62500	0.75000	0.87500	1.000
130	2	732.74	0.35000	0.40000	0.45000	0.500
131	2	1541.86	0.62500	0.75000	0.87500	1.000
132	2	2426.71	0.06250	0.07500	0.08750	0.100
133	2	2823.46	0.06250	0.07500	0.08750	0.100
134	2	1581.41	0.01250	0.02500	0.03750	0.050
135	2	1932.54	0.01250	0.02500	0.03750	0.050
136	2	1718.51	0.01250	0.02500	0.03750	0.050
137	3	430.66	0.62500	0.75000	0.87500	1.000
138	3	1672.88	0.62500	0.75000	0.87500	1.000
139	1	1005.30	0.00125	0.00150	0.00175	0.002
140	1	1360.27	0.00025	0.00050	0.00075	0.001
141	3	478.72	0.62500	0.75000	0.87500	1.000
142	3	439.15	0.62500	0.75000	0.87500	1.000
143	3	1137.45	0.62500	0.75000	0.87500	1.000
144	3	625.92	0.62500	0.75000	0.87500	1.000
145	3	922.69	0.62500	0.75000	0.87500	1.000
146	3	3215.53	0.62500	0.75000	0.87500	1.000
147	3	2425.34	0.62500	0.75000	0.87500	1.000
148	3	1275.15	0.62500	0.75000	0.87500	1.000
149	3	2940.23	0.62500	0.75000	0.87500	1.000
150	3	559.51	0.12500	0.15000	0.17500	0.200
151	3	458.56	0.22500	0.25000	0.27500	0.300
152	1	3940.55	0.00025	0.00050	0.00075	0.001
153	1	2019.03	0.00125	0.00150	0.00175	0.002
154	1	1719.35	0.00025	0.00050	0.00075	0.001
155	1	1208.73	0.00025	0.00050	0.00075	0.001
156	1	2253.51	0.00225	0.00250	0.00275	0.003
157	3	1789.93	0.62500	0.75000	0.87500	1.000
158	2	973.77	0.62500	0.75000	0.87500	1.000

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Table A-2 – continued from previous page

Road Number	Road Type	Road Length	A1	A2	C1	C2
159	2	1019.26	0.62500	0.75000	0.87500	1.000
160	2	1348.66	0.22500	0.25000	0.27500	0.300
161	2	491.70	0.06250	0.07500	0.08750	0.100
162	3	707.37	0.62500	0.75000	0.87500	1.000
163	2	939.36	0.62500	0.75000	0.87500	1.000
164	2	1153.16	0.62500	0.75000	0.87500	1.000
165	3	790.47	0.62500	0.75000	0.87500	1.000
166	1	2752.32	0.00025	0.00050	0.00075	0.001
167	1	723.05	0.00225	0.00250	0.00275	0.003
168	1	1591.84	0.00325	0.00350	0.00375	0.004
169	1	600.85	0.00125	0.00150	0.00175	0.002
170	3	979.91	0.35000	0.40000	0.45000	0.500
171	3	271.08	0.62500	0.75000	0.87500	1.000
172	1	1097.29	0.00125	0.00150	0.00175	0.002
173	3	545.50	0.62500	0.75000	0.87500	1.000
174	3	1268.61	0.62500	0.75000	0.87500	1.000
175	1	1375.22	0.00125	0.00150	0.00175	0.002
176	2	325.29	0.12500	0.15000	0.17500	0.200
177	2	726.19	0.12500	0.15000	0.17500	0.200
178	2	523.66	0.22500	0.25000	0.27500	0.300
179	3	1067.44	0.35000	0.40000	0.45000	0.500
180	3	341.88	0.62500	0.75000	0.87500	1.000
181	3	2607.59	0.62500	0.75000	0.87500	1.000
182	3	1023.24	0.62500	0.75000	0.87500	1.000
183	3	1804.48	0.62500	0.75000	0.87500	1.000
184	3	1633.16	0.62500	0.75000	0.87500	1.000
185	3	980.30	0.12500	0.15000	0.17500	0.200
186	3	1064.15	0.22500	0.25000	0.27500	0.300
187	2	920.92	0.01250	0.02500	0.03750	0.050
188	2	1096.44	0.01250	0.02500	0.03750	0.050
189	3	1053.66	0.62500	0.75000	0.87500	1.000
190	3	676.90	0.62500	0.75000	0.87500	1.000
191	3	1618.60	0.62500	0.75000	0.87500	1.000
192	3	473.37	0.62500	0.75000	0.87500	1.000
193	2	2103.26	0.22500	0.25000	0.27500	0.300
194	3	1048.68	0.62500	0.75000	0.87500	1.000
195	3	566.49	0.35000	0.40000	0.45000	0.500
196	3	2098.73	0.62500	0.75000	0.87500	1.000
197	3	1217.38	0.62500	0.75000	0.87500	1.000
198	3	2195.41	0.62500	0.75000	0.87500	1.000

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Table A-2 – continued from previous page

Road Number	Road Type	Road Length	A1	A2	C1	C2
199	3	1368.83	0.62500	0.75000	0.87500	1.000
200	3	1510.51	0.35000	0.40000	0.45000	0.500
201	3	427.70	0.62500	0.75000	0.87500	1.000
202	2	731.45	0.06250	0.07500	0.08750	0.100
203	3	1074.96	0.62500	0.75000	0.87500	1.000
204	3	142.23	0.62500	0.75000	0.87500	1.000
205	3	405.07	0.62500	0.75000	0.87500	1.000
206	3	229.64	0.62500	0.75000	0.87500	1.000
207	3	724.41	0.62500	0.75000	0.87500	1.000
208	3	781.94	0.62500	0.75000	0.87500	1.000
209	3	1607.33	0.62500	0.75000	0.87500	1.000
210	3	642.35	0.62500	0.75000	0.87500	1.000
211	3	1231.39	0.62500	0.75000	0.87500	1.000
212	3	495.74	0.62500	0.75000	0.87500	1.000
213	3	617.62	0.62500	0.75000	0.87500	1.000
214	3	795.17	0.62500	0.75000	0.87500	1.000
215	3	525.29	0.62500	0.75000	0.87500	1.000
216	3	461.94	0.62500	0.75000	0.87500	1.000
217	3	437.79	0.62500	0.75000	0.87500	1.000
218	3	679.81	0.62500	0.75000	0.87500	1.000
219	3	866.47	0.62500	0.75000	0.87500	1.000
220	3	743.88	0.62500	0.75000	0.87500	1.000
221	3	706.48	0.62500	0.75000	0.87500	1.000
222	3	340.39	0.62500	0.75000	0.87500	1.000
223	3	428.21	0.62500	0.75000	0.87500	1.000
224	1	849.50	0.00550	0.00700	0.00850	0.010
225	3	369.71	0.62500	0.75000	0.87500	1.000
226	3	496.84	0.62500	0.75000	0.87500	1.000
227	3	453.69	0.62500	0.75000	0.87500	1.000
228	3	1495.85	0.62500	0.75000	0.87500	1.000
229	3	951.41	0.62500	0.75000	0.87500	1.000
230	3	329.78	0.62500	0.75000	0.87500	1.000
231	3	1263.48	0.62500	0.75000	0.87500	1.000
232	3	512.15	0.62500	0.75000	0.87500	1.000
233	3	291.96	0.62500	0.75000	0.87500	1.000
234	3	1192.40	0.22500	0.25000	0.27500	0.300
235	3	1946.58	0.22500	0.25000	0.27500	0.300
236	3	456.15	0.12500	0.15000	0.17500	0.200
237	3	393.64	0.12500	0.15000	0.17500	0.200
238	3	806.23	0.22500	0.25000	0.27500	0.300

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Table A-2 – continued from previous page

Road Number	Road Type	Road Length	A1	A2	C1	C2
239	3	755.94	0.22500	0.25000	0.27500	0.300
240	3	1725.69	0.06250	0.07500	0.08750	0.100
241	3	2117.12	0.62500	0.75000	0.87500	1.000
242	1	722.80	0.00025	0.00050	0.00075	0.001
243	1	1175.01	0.00025	0.00050	0.00075	0.001
244	3	2428.48	0.62500	0.75000	0.87500	1.000
245	3	1696.25	0.62500	0.75000	0.87500	1.000
246	3	668.32	0.62500	0.75000	0.87500	1.000
247	3	1223.35	0.62500	0.75000	0.87500	1.000
248	3	1654.16	0.62500	0.75000	0.87500	1.000
249	3	2184.24	0.62500	0.75000	0.87500	1.000
250	3	659.40	0.62500	0.75000	0.87500	1.000
251	3	499.10	0.62500	0.75000	0.87500	1.000
252	3	705.55	0.62500	0.75000	0.87500	1.000
253	3	658.21	0.62500	0.75000	0.87500	1.000
254	3	794.92	0.62500	0.75000	0.87500	1.000
255	3	517.42	0.62500	0.75000	0.87500	1.000
256	3	1145.29	0.12500	0.15000	0.17500	0.200
257	3	1229.28	0.62500	0.75000	0.87500	1.000
258	1	560.57	0.00025	0.00050	0.00075	0.001
259	2	894.87	0.22500	0.25000	0.27500	0.300
260	2	572.88	0.22500	0.25000	0.27500	0.300
261	2	603.08	0.12500	0.15000	0.17500	0.200
262	3	558.61	0.62500	0.75000	0.87500	1.000
263	3	760.97	0.06250	0.07500	0.08750	0.100
264	3	352.69	0.35000	0.40000	0.45000	0.500
265	3	234.72	0.62500	0.75000	0.87500	1.000
266	3	2350.83	0.62500	0.75000	0.87500	1.000
267	3	595.72	0.62500	0.75000	0.87500	1.000
268	1	5381.42	0.00025	0.00050	0.00075	0.001
269	3	555.33	0.62500	0.75000	0.87500	1.000
270	3	1070.99	0.62500	0.75000	0.87500	1.000
271	3	1104.47	0.62500	0.75000	0.87500	1.000
272	3	585.80	0.62500	0.75000	0.87500	1.000
273	3	1083.09	0.22500	0.25000	0.27500	0.300
274	3	488.52	0.62500	0.75000	0.87500	1.000
275	1	508.95	0.00025	0.00050	0.00075	0.001
276	1	610.16	0.00025	0.00050	0.00075	0.001
277	3	543.66	0.62500	0.75000	0.87500	1.000
278	3	799.22	0.62500	0.75000	0.87500	1.000

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Table A-2 – continued from previous page

Road Number	Road Type	Road Length	A1	A2	C1	C2
279	3	585.13	0.62500	0.75000	0.87500	1.000
280	3	677.23	0.62500	0.75000	0.87500	1.000
281	2	521.54	0.06250	0.07500	0.08750	0.100
282	1	1383.01	0.30018	0.30035	0.30053	0.301
283	1	720.74	0.00025	0.00050	0.00075	0.001
284	3	286.08	0.62500	0.75000	0.87500	1.000
285	3	226.09	0.62500	0.75000	0.87500	1.000
286	3	266.24	0.62500	0.75000	0.87500	1.000
287	3	913.79	0.62500	0.75000	0.87500	1.000
288	3	997.47	0.62500	0.75000	0.87500	1.000
289	3	1364.14	0.62500	0.75000	0.87500	1.000
290	1	1100.72	0.00025	0.00050	0.00075	0.001
291	1	156.86	0.00025	0.00050	0.00075	0.001
292	3	103.68	0.62500	0.75000	0.87500	1.000
293	3	1466.57	0.62500	0.75000	0.87500	1.000

Table A-3: Types and Length of Roads and Non-functionality probabilities of roads for each scenarios in the Asian side

Road Number	Road Type	Road Length	A1	A2	C1	C2
1	3	1237.02	0.01250	0.02500	0.03750	0.050
2	3	1298.57	0.01250	0.02500	0.03750	0.050
3	3	384.27	0.06250	0.07500	0.08750	0.100
4	3	411.71	0.06250	0.07500	0.08750	0.100
5	3	577.71	0.06250	0.07500	0.08750	0.100
6	1	832.35	0.00250	0.00500	0.00750	0.010
7	1	837.94	0.00250	0.00500	0.00750	0.010
8	1	1893.26	0.00250	0.00500	0.00750	0.010
9	1	1489.34	0.00250	0.00500	0.00750	0.010
10	1	618.20	0.20200	0.20400	0.20600	0.208
11	1	1083.00	0.00250	0.00500	0.00750	0.010
12	1	1203.34	0.00250	0.00500	0.00750	0.010
13	2	2651.02	0.00025	0.00050	0.00075	0.001
14	2	3121.81	0.30018	0.30035	0.30053	0.301
15	1	2936.51	0.00250	0.00500	0.00750	0.010
16	2	1611.78	0.00025	0.00050	0.00075	0.001
17	1	2324.30	0.55250	0.55500	0.55750	0.560
18	2	4406.16	0.45025	0.45050	0.45075	0.451

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Table A-3 – continued from previous page

Road Number	Road Type	Road Length	A1	A2	C1	C2
19	2	4227.44	0.00025	0.00050	0.00075	0.001
20	2	3855.54	0.20020	0.20040	0.20060	0.201
21	2	1458.66	0.00025	0.00050	0.00075	0.001
22	2	1524.33	0.00025	0.00050	0.00075	0.001
23	2	2131.69	0.00025	0.00050	0.00075	0.001
24	2	2447.93	0.55025	0.55050	0.55075	0.551
25	2	1971.39	0.00025	0.00050	0.00075	0.001
26	2	1991.63	0.00025	0.00050	0.00075	0.001
27	2	2114.42	0.00025	0.00050	0.00075	0.001
28	2	746.43	0.00025	0.00050	0.00075	0.001
29	2	6062.65	0.00025	0.00050	0.00075	0.001
30	1	4833.29	0.00250	0.00500	0.00750	0.010
31	1	1912.79	0.00250	0.00500	0.00750	0.010
32	1	2516.31	0.00250	0.00500	0.00750	0.010
33	2	11969.20	0.00025	0.00050	0.00075	0.001
34	1	2656.28	0.00250	0.00500	0.00750	0.010
35	1	4335.98	0.00250	0.00500	0.00750	0.010
36	1	3681.77	0.00250	0.00500	0.00750	0.010
37	2	3881.24	0.00125	0.00150	0.00175	0.002
38	2	2884.53	0.00025	0.00050	0.00075	0.001
39	2	2945.59	0.00025	0.00050	0.00075	0.001
40	1	3249.71	0.00250	0.00500	0.00750	0.010
41	2	2912.72	0.00125	0.00150	0.00175	0.002
42	2	3318.05	0.00025	0.00050	0.00075	0.001
43	2	4544.44	0.00025	0.00050	0.00075	0.001
44	1	1606.32	0.06250	0.07500	0.08750	0.100
45	1	378.51	0.00250	0.00500	0.00750	0.010
46	1	566.47	0.00250	0.00500	0.00750	0.010
47	1	2159.33	0.06250	0.07500	0.08750	0.100
48	1	1636.22	0.45250	0.45500	0.45750	0.460
49	2	140.74	0.00125	0.00150	0.00175	0.002
50	2	1507.52	0.00250	0.00500	0.00750	0.010
51	3	1737.90	0.12500	0.15000	0.17500	0.200
52	3	698.11	0.62500	0.75000	0.87500	1.000
53	3	691.53	0.06250	0.07500	0.08750	0.100
54	2	638.94	0.00250	0.00500	0.00750	0.010
55	2	1284.62	0.00250	0.00500	0.00750	0.010
56	3	1071.40	0.22500	0.25000	0.27500	0.300
57	3	296.88	0.06250	0.07500	0.08750	0.100
58	3	367.00	0.06250	0.07500	0.08750	0.100

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Table A-3 – continued from previous page

Road Number	Road Type	Road Length	A1	A2	C1	C2
59	2	498.08	0.00250	0.00500	0.00750	0.010
60	2	615.80	0.00250	0.00500	0.00750	0.010
61	3	1398.05	0.35000	0.40000	0.45000	0.500
62	3	1426.76	0.62500	0.75000	0.87500	1.000
63	2	426.92	0.00250	0.00500	0.00750	0.010
64	3	785.82	0.12500	0.15000	0.17500	0.200
65	3	1606.61	0.12500	0.15000	0.17500	0.200
66	3	234.23	0.06250	0.07500	0.08750	0.100
67	2	3148.77	0.00250	0.00500	0.00750	0.010
68	2	1456.97	0.00250	0.00500	0.00750	0.010
69	2	835.36	0.00250	0.00500	0.00750	0.010
70	3	267.03	0.12500	0.15000	0.17500	0.200
71	2	917.98	0.00250	0.00500	0.00750	0.010
72	2	1963.70	0.00250	0.00500	0.00750	0.010
73	2	879.26	0.00250	0.00500	0.00750	0.010
74	2	1991.84	0.00250	0.00500	0.00750	0.010
75	2	2878.06	0.00250	0.00500	0.00750	0.010
76	2	1865.63	0.00250	0.00500	0.00750	0.010
77	2	6628.33	0.00250	0.00500	0.00750	0.010
78	2	1820.92	0.00250	0.00500	0.00750	0.010
79	2	1967.23	0.00250	0.00500	0.00750	0.010
80	2	1751.24	0.00250	0.00500	0.00750	0.010
81	2	2777.31	0.00250	0.00500	0.00750	0.010
82	2	3082.18	0.00250	0.00500	0.00750	0.010
83	2	1620.39	0.00250	0.00500	0.00750	0.010
84	2	1787.35	0.00250	0.00500	0.00750	0.010
85	2	1917.11	0.00250	0.00500	0.00750	0.010
86	3	1270.19	0.62500	0.75000	0.87500	1.000
87	2	1243.73	0.00250	0.00500	0.00750	0.010
88	2	1093.54	0.00250	0.00500	0.00750	0.010
89	3	404.78	0.62500	0.75000	0.87500	1.000
90	3	1440.44	0.62500	0.75000	0.87500	1.000
91	3	668.80	0.12500	0.15000	0.17500	0.200
92	3	814.05	0.12500	0.15000	0.17500	0.200
93	3	2234.88	0.35000	0.40000	0.45000	0.500
94	3	1283.92	0.62500	0.75000	0.87500	1.000
95	3	1349.81	0.62500	0.75000	0.87500	1.000
96	3	321.10	0.62500	0.75000	0.87500	1.000
97	2	645.80	0.00250	0.00500	0.00750	0.010
98	2	6177.12	0.00250	0.00500	0.00750	0.010

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Table A-3 – continued from previous page

Road Number	Road Type	Road Length	A1	A2	C1	C2
99	2	3793.72	0.00250	0.00500	0.00750	0.010
100	2	923.85	0.00250	0.00500	0.00750	0.010
101	3	1587.09	0.62500	0.75000	0.87500	1.000
102	2	2525.23	0.00250	0.00500	0.00750	0.010
103	2	1557.65	0.00250	0.00500	0.00750	0.010
104	2	603.16	0.00250	0.00500	0.00750	0.010
105	2	4200.56	0.00250	0.00500	0.00750	0.010
106	2	1832.96	0.22500	0.25000	0.27500	0.300
107	2	3939.31	0.06250	0.07500	0.08750	0.100
108	3	1107.49	0.35000	0.40000	0.45000	0.500
109	3	802.93	0.62500	0.75000	0.87500	1.000
110	2	1818.91	0.00250	0.00500	0.00750	0.010
111	3	1391.80	0.62500	0.75000	0.87500	1.000
112	3	2711.55	0.62500	0.75000	0.87500	1.000
113	2	3246.68	0.00250	0.00500	0.00750	0.010
114	2	2620.50	0.00250	0.00500	0.00750	0.010
115	2	3951.17	0.00250	0.00500	0.00750	0.010
116	2	3336.11	0.00250	0.00500	0.00750	0.010
117	2	3189.53	0.00250	0.00500	0.00750	0.010
118	2	7248.11	0.40025	0.40050	0.40075	0.401
119	2	840.06	0.00250	0.00500	0.00750	0.010
120	2	1471.47	0.00250	0.00500	0.00750	0.010
121	2	3189.71	0.00250	0.00500	0.00750	0.010
122	2	4242.02	0.00250	0.00500	0.00750	0.010
123	2	3187.45	0.00250	0.00500	0.00750	0.010
124	2	2465.58	0.00250	0.00500	0.00750	0.010
125	2	6081.20	0.00250	0.00500	0.00750	0.010
126	3	789.78	0.62500	0.75000	0.87500	1.000
127	3	3849.55	0.62500	0.75000	0.87500	1.000
128	3	4289.12	0.62500	0.75000	0.87500	1.000
129	2	3114.13	0.00250	0.00500	0.00750	0.010
130	2	2741.94	0.00250	0.00500	0.00750	0.010
131	2	730.40	0.00250	0.00500	0.00750	0.010

Appendix B

COMPUTATIONAL RESULTS FOR CASUALTY TRANSPORTATION MODEL

Table B-1: Computational results (No. of unserved and total casualties and % of unserved casualties) for Model A1 and Model A2 for European side when healing rate=0.25

Model A1	**European Side, Heal Rate=0.25**									
No of Casualties	**B.evler**	**Bakirkoy**	**Sisli**	**Eyup**	**Beyoglu**	**Eminonu**	**Fatih**	**Z.burnu**	**B.pasa**	**Gungoren**
Unserved	42.8	28.8	0.1	17.8	28.8	19.1	22.2	43.9	36.6	31.3
Total	49.9	37.8	16.0	21.9	32.3	29.2	51.3	44.1	37.7	32.4
%(Unserved)	85.7	76.1	0.7	81.4	89.4	65.4	43.3	99.6	97.2	96.6
No of Casualties	**Bagcilar**	**Esenler**	**G.opasa**	**K.cekmece**						
Unserved	37.2	22.1	12.7	48.6						
Total	41.6	22.8	16.8	49.6						
%(Unserved)	89.4	97.1	75.7	97.9						
Model A2	**European Side, Heal Rate=0.25**									
No of Casualties	**B.evler**	**Bakirkoy**	**Sisli**	**Eyup**	**Beyoglu**	**Eminonu**	**Fatih**	**Z.burnu**	**B.pasa**	**Gungoren**
Unserved	39.6	31.8	0.1	17.8	29.5	18.5	22.5	43.9	36.6	31.3
Total	49.9	37.8	16.0	21.9	32.3	29.2	51.3	44.1	37.7	32.4
%(Unserved)	79.4	84.3	0.3	81.3	91.5	63.5	43.7	99.6	97.1	96.5
No of Casualties	**Bagcilar**	**Esenler**	**G.opasa**	**K.cekmece**						
Unserved	37.5	21.9	12.7	48.5						
Total	41.6	22.8	16.8	49.6						
%(Unserved)	90.0	96.1	75.6	97.8						

B.evler: Bahcelievler, Z.burnu: Zeytinburnu, B.pasa: Bayramapasa, G.opasa: Gaziosmanpasa, K.cekmece: Kucukcekmece

Table B-2: Computational results (No. of unserved and total casualties and % of unserved casualties) for Model C1 and Model C2 for European side when healing rate=0.25

Model C1	**European Side, Heal Rate=0.25**									
No of Casualties	**B.evler**	**Bakirkoy**	**Sisli**	**Eyup**	**Beyoglu**	**Eminonu**	**Fatih**	**Z.burnu**	**B.pasa**	**Gungoren**
Unserved	42.3	36.0	2.9	20.4	33.6	21.0	24.9	48.1	40.0	36.1
Total	53.1	41.3	20.2	24.5	35.7	31.6	53.5	48.3	41.1	37.3
%(Unserved)	79.6	87.2	14.6	83.4	94.1	66.4	46.6	99.6	97.4	97.0
No of Casualties	**Bagcilar**	**Esenler**	**G.opasa**	**K.cekmece**						
Unserved	43.0	25.4	15.1	51.3						
Total	47.2	26.2	19.2	52.4						
%(Unserved)	91.0	97.1	78.8	98.0						
Model C2	**European Side, Heal Rate=0.25**									
No of Casualties	**B.evler**	**Bakirkoy**	**Sisli**	**Eyup**	**Beyoglu**	**Eminonu**	**Fatih**	**Z.burnu**	**B.pasa**	**Gungoren**
Unserved	42.3	36.0	2.9	20.5	33.6	21.0	25.0	48.1	40.0	36.1
Total	53.1	41.3	20.2	24.5	35.7	31.6	53.5	48.3	41.1	37.3
%(Unserved)	79.6	87.2	14.5	83.4	94.1	66.4	46.6	99.7	97.4	96.9
No of Casualties	**Bagcilar**	**Esenler**	**G.opasa**	**K.cekmece**						
Unserved	43.0	25.4	15.1	51.3						
Total	47.2	26.2	19.2	52.4						
%(Unserved)	91.1	96.8	78.8	98.0						

Table B-3: Computational results (No. of unserved and total casualties and % of unserved casualties) for Model A1 and Model A2 for European side when heal rate=0.5

Model A1	**European Side, Heal Rate=0.5**									
No of Casualties	**B.evler**	**Bakirkoy**	**Sisli**	**Eyup**	**Beyoglu**	**Eminonu**	**Fatih**	**Z.burnu**	**B.pasa**	**Gungoren**
Unserved	37.6	20.8	0.1	12.9	8.2	0.2	8.1	31.3	34.7	25.8
Total	49.9	37.8	16.0	21.9	32.3	29.2	51.3	44.1	37.7	32.4
%(Unserved)	75.4	55.0	0.9	58.9	25.3	0.8	15.7	71.0	91.9	79.5
No of Casualties	**Bagcilar**	**Esenler**	**G.opasa**	**K.cekmece**						
Unserved	33.4	20.2	7.8	47.5						
Total	41.6	22.8	16.8	49.6						
%(Unserved)	80.2	88.5	46.4	95.8						
Model A2	**European Side, Heal Rate=0.5**									
No of Casualties	**B.evler**	**Bakirkoy**	**Sisli**	**Eyup**	**Beyoglu**	**Eminonu**	**Fatih**	**Z.burnu**	**B.pasa**	**Gungoren**
Unserved	37.6	20.8	0.1	12.9	8.2	0.2	8.0	31.3	34.7	25.8
Total	49.9	37.8	16.0	21.9	32.3	29.2	51.3	44.1	37.7	32.4
%(Unserved)	75.4	55.0	0.7	58.9	25.5	0.7	15.7	71.0	91.9	79.6
No of Casualties	**Bagcilar**	**Esenler**	**G.opasa**	**K.cekmece**						
Unserved	32.5	21.0	7.8	47.5						
Total	41.6	22.8	16.8	49.6						
%(Unserved)	78.1	92.2	46.4	95.8						

Table B-4: Computational results (No. of unserved and total casualties and % of unserved casualties) for Model C1 and Model C2 for European side when heal rate=0.5

Model C1	**European Side, Heal Rate=0.5**									
No of Casualties	**B.evler**	**Bakirkoy**	**Sisli**	**Eyup**	**Beyoglu**	**Eminonu**	**Fatih**	**Z.burnu**	**B.pasa**	**Gungoren**
Unserved	40.3	24.3	0.1	15.5	13.3	2.6	9.2	39.1	38.0	31.1
Total	53.1	41.3	20.2	24.5	35.7	31.6	53.5	48.3	41.1	37.3
%(Unserved)	75.8	58.9	0.7	63.4	37.3	8.2	17.1	81.0	92.6	83.5
No of Casualties	**Bagcilar**	**Esenler**	**G.opasa**	**K.cekmece**						
Unserved	37.8	24.8	10.2	50.3						
Total	47.2	26.2	19.2	52.4						
%(Unserved)	79.9	94.5	53.1	96.0						
Model C2	**European Side, Heal Rate=0.5**									
No of Casualties	**B.evler**	**Bakirkoy**	**Sisli**	**Eyup**	**Beyoglu**	**Eminonu**	**Fatih**	**Z.burnu**	**B.pasa**	**Gungoren**
Unserved	40.3	24.3	0.1	15.5	13.3	2.6	9.1	39.1	38.0	31.1
Total	53.1	41.3	20.2	24.5	35.7	31.6	53.5	48.3	41.1	37.3
%(Unserved)	75.8	58.9	0.6	63.4	37.3	8.3	17.1	81.0	92.6	83.5
No of Casualties	**Bagcilar**	**Esenler**	**G.opasa**	**K.cekmece**						
Unserved	38.5	24.0	10.2	50.3						
Total	47.2	26.2	19.2	52.4						
%(Unserved)	81.5	91.8	53.1	96.0						

Table B-5: Computational results (No. of unserved and total casualties and % of unserved casualties) for Model A1, A2, C1, and C2 for the Asian side when heal rate=0.25

Model A1	**The Asian Side, Heal Rate=0.25**							
No of Casualties	**Beykoz**	**Uskudar**	**Kadikoy**	**Umraniye**	**Maltepe**	**Kartal**	**Pendik**	**Tuzla**
Unserved	1.9	4.2	10.8	4.9	23.0	26.1	21.8	17.4
Total	4.9	18.5	34.4	14.5	26.1	28.2	29.9	18.5
%(Unserved)	38.2	22.8	31.2	33.7	88.1	92.6	72.8	94.5
Model A2	**The Asian Side, Heal Rate=0.25**							
No of Casualties	**Beykoz**	**Uskudar**	**Kadikoy**	**Umraniye**	**Maltepe**	**Kartal**	**Pendik**	**Tuzla**
Unserved	1.9	4.2	10.7	4.9	23.0	26.1	21.7	17.5
Total	4.9	18.5	34.4	14.5	26.1	28.2	29.9	18.5
%(Unserved)	38.4	22.9	31.2	33.8	88.2	92.6	72.8	94.5
Model C1	**The Asian Side, Heal Rate=0.25 Ambulance usage=51.84 %**							
No of Casualties	**Beykoz**	**Uskudar**	**Kadikoy**	**Umraniye**	**Maltepe**	**Kartal**	**Pendik**	**Tuzla**
Unserved	2.9	7.8	18.5	7.0	26.3	29.8	25.2	20.0
Total	5.9	23.1	40.2	17.5	29.4	31.9	33.3	21.0
%(Unserved)	48.8	33.6	46.1	40.0	89.5	93.5	75.6	95.1
Model C2	**The Asian Side, Heal Rate=0.25**							
No of Casualties	**Beykoz**	**Uskudar**	**Kadikoy**	**Umraniye**	**Maltepe**	**Kartal**	**Pendik**	**Tuzla**
Unserved	2.9	7.8	18.5	7.0	26.3	29.8	25.2	20.0
Total	5.9	23.1	40.2	17.5	29.4	31.9	33.3	21.0
%(Unserved)	48.5	33.7	46.0	40.2	89.5	93.4	75.7	95.1

Table B-6: Computational results (No. of unserved and total casualties and % of unserved casualties) for Model A1, A2, C1, and C2 for the Asian side when heal rate=0.5

Model A1	**The Asian Side, Heal Rate=0.5**							
No of Casualties	**Beykoz**	**Uskudar**	**Kadikoy**	**Umraniye**	**Maltepe**	**Kartal**	**Pendik**	**Tuzla**
Unserved	0.014	0.04	0.1	0.04	5.4	23.1	13.7	15.5
Total	4.9	18.5	34.4	14.5	26.1	28.2	29.9	18.5
%(Unserved)	0.3	0.2	0.2	0.3	20.6	82.0	45.8	83.8
Model A2	**The Asian Side, Heal Rate=0.5**							
No of Casualties	**Beykoz**	**Uskudar**	**Kadikoy**	**Umraniye**	**Maltepe**	**Kartal**	**Pendik**	**Tuzla**
Unserved	0.014	0.04	0.1	0.04	5.4	23.1	13.7	15.5
Total	4.9	18.5	34.4	14.5	26.1	28.2	29.9	18.5
%(Unserved)	0.3	0.2	0.2	0.3	20.7	82.0	45.8	83.8
Model C1	**The Asian Side, Heal Rate=0.5**							
No of Casualties	**Beykoz**	**Uskudar**	**Kadikoy**	**Umraniye**	**Maltepe**	**Kartal**	**Pendik**	**Tuzla**
Unserved	0.05	0.1	0.3	1.6	12.8	26.9	17.5	18.0
Total	5.9	23.1	40.2	17.5	29.4	31.9	33.3	21.0
%(Unserved)	0.8	0.3	0.8	9.0	43.7	84.1	52.5	85.8
Model C2	**The Asian Side, Heal Rate=0.5**							
No of Casualties	**Beykoz**	**Uskudar**	**Kadikoy**	**Umraniye**	**Maltepe**	**Kartal**	**Pendik**	**Tuzla**
Unserved	0.04	0.1	0.2	0.7	12.9	26.8	18.4	18.0
Total	5.9	23.1	40.2	17.5	29.4	31.9	33.3	21.0
%(Unserved)	0.6	0.3	0.6	4.2	43.8	84.1	55.3	85.8

Table B-7: Average travel time of served and average waiting time of unserved casualties in minutes for Model A1, A2, C1, and C2 for the European and Asian sides

The European side Heal Rate 0.25	**Model A1**	**Model A2**	**Model C1**	**Model C2**
Ave.Travel Time/Person	3.72	3.78	3.71	3.78
Ave.Waiting Time/Person	3099.19	3099.19	3090.64	3090.65
The European side Heal Rate 0.5	**Model A1**	**Model A2**	**Model C1**	**Model C2**
Ave.Travel Time/Person	5.06	5.14	4.91	4.98
Ave.Waiting Time/Person	3420.93	3420.93	3363.54	3363.54
The Asian side Heal Rate 0.25	**Model A1**	**Model A2**	**Model C1**	**Model C2**
Ave.Travel Time/Person	7.39	7.42	7.04	7.07
Ave.Waiting Time/Person	3318.52	3318.58	3252.50	3252.50
The Asian side Heal Rate 0.5	**Model A1**	**Model A2**	**Model C1**	**Model C2**
Ave.Travel Time/Person	9.67	9.70	9.01	9.07
Ave.Waiting Time/Person	4094.37	4095.15	4087.89	4087.15

Table B-8: Computational results (Objective function values by means of the travel times of served and unserved casualties and the gaps between relaxed solutions) for Model A1, A2, C1, and C2 for European side when heal rate=0.25

Model A1	**1-48**	**48-96**	**96-144**	**Total**	**No.of Casualties**	**Relaxed**	**Gap(%)**
Served	264.00	255.02	302.24	821.25	13230	808.22	
Unserved	491705.47	1084350.03	1336304.60	2912360.10	56384	2912132.77	
Total	491969.46	1084605.05	1336606.84	2913181.35	69613	2912940.98	0.008
Model A2	**1-48**	**48-96**	**96-144**	**Total**	**No.of Casualties**	**Relaxed**	**Gap(%)**
Served	266.02	259.35	307.84	833.21	13229	821.77	
Unserved	491705.47	1084352.10	1336304.08	2912361.65	56383	2912132.77	
Total	491971.49	1084611.45	1336611.93	2913194.86	69612	2912954.54	0.008
Model C1	**1-48**	**48-96**	**96-144**	**Total**	**No.of Casualties**	**Relaxed**	**Gap(%)**
Served	266.10	259.45	292.77	818.32	13229	807.28	
Unserved	548781.12	1212687.97	1499410.07	3260879.15	63305	3260569.67	
Total	549047.21	1212947.41	1499702.84	3261697.47	76534	3261376.95	0.010
Model C2	**1-48**	**48-96**	**96-144**	**Total**	**No.of Casualties**	**Relaxed**	**Gap(%)**
Served	270.73	264.10	297.60	832.43	13229	820.32	
Unserved	548788.87	1212690.03	1499409.55	3260888.45	63305	3260569.67	
Total	549059.60	1212954.13	1499707.15	3261720.88	76534	3261389.98	0.010

Table B-9: Computational results (Objective function values by means of the travel times of served and unserved casualties and the gaps between relaxed solutions) for Model A1, A2, C1, and C2 for European side when heal rate=0.5

Model A1	**1-48**	**48-96**	**96-144**	**Total**	**No.of Casualties**	**Relaxed**	**Gap(%)**
Served	618.85	769.54	993.83	2382.22	28271	2349.40	
Unserved	432781.18	899291.92	1025064.08	2357137.18	41342	2357137.18	
Total	433400.03	900061.45	1026057.92	2359519.40	69613	2359486.58	0.001

Model A2	**1-48**	**48-96**	**96-144**	**Total**	**No.of Casualties**	**Relaxed**	**Gap(%)**
Served	628.76	782.66	1010.57	2421.98	28271	2381.79	
Unserved	432781.18	899291.92	1025064.08	2357137.18	41342	2357137.18	
Total	433400.03	900074.57	1026074.65	2359549.25	69613	2359518.97	0.001

Model C1	**1-48**	**48-96**	**96-144**	**Total**	**No.of Casualties**	**Relaxed**	**Gap(%)**
Served	603.53	751.72	959.70	2314.95	28271	2255.75	
Unserved	489835.65	1027605.57	1188132.87	2705574.08	48263	2705574.08	
Total	490439.18	1028357.28	1189092.57	2707889.03	76534	2707829.83	0.002

Model C2	**1-48**	**48-96**	**96-144**	**Total**	**No.of Casualties**	**Relaxed**	**Gap(%)**
Served	613.36	762.10	970.70	2346.16	28271	2287.08	
Unserved	489835.65	1027605.57	1188132.87	2705574.08	48263	2705574.08	
Total	490449.01	1028367.66	1189103.57	2707920.24	76534	2707861.17	0.002

Table B-10: Computational results (Objective function values by means of the travel times of served and unserved casualties and the gaps between relaxed solutions) for Model A1, A2, C1, and C2 for the Asian side when heal rate=0.25

Model A1	**1-48**	**48-96**	**96-144**	**Total**	**No.of Casualties**	**Relaxed**	**Gap(%)**
Served	344.47	373.57	440.30	1158.34	9406	1149.30	
Unserved	154931.80	331235.00	386824.20	872991.00	15784	872991.00	
Total	155276.27	331608.57	387264.50	874149.34	25190	874140.30	0.001

Model A2	**1-48**	**48-96**	**96-144**	**Total**	**No.of Casualties**	**Relaxed**	**Gap(%)**
Served	345.59	382.03	435.02	1162.63	9405	1154.41	
Unserved	154955.05	331259.80	386849.00	873063.85	15785	872991.00	
Total	155300.64	331641.83	387284.02	874226.48	25190	874145.41	0.009

Model C1	**1-48**	**48-96**	**96-144**	**Total**	**No.of Casualties**	**Relaxed**	**Gap(%)**
Served	341.83	355.48	405.69	1103.00	9405	1092.18	
Unserved	187326.28	403634.98	478406.47	1069367.73	19727	1069293.33	
Total	187668.12	403990.46	478812.15	1070470.73	29132	1070385.51	0.008

Model C2	**1-48**	**48-96**	**96-144**	**Total**	**No.of Casualties**	**Relaxed**	**Gap(%)**
Served	344.72	356.97	407.09	1108.78	9405	1096.66	
Unserved	187326.28	403634.98	478406.47	1069367.73	19727	1069293.33	
Total	187671.00	403991.95	478813.56	1070476.51	29132	1070390.00	0.008

Table B-11: Computational results (Objective function values by means of the travel times of served and unserved casualties and the gaps between relaxed solutions) for Model A1, A2, C1, and C2 for the Asian side when heal rate=0.5

Model A1	**1-48**	**48-96**	**96-144**	**Total**	**No.of Casualties**	**Relaxed**	**Gap(%)**
Served	649.99	1011.64	1068.10	2729.73	16937	3155.08	
Unserved	121870.30	224471.00	216361.92	562703.22	8246	552621.50	
Total	122520.29	225482.64	217430.02	565432.94	25183	555776.58	1.737

Model A2	**1-48**	**48-96**	**96-144**	**Total**	**No.of Casualties**	**Relaxed**	**Gap(%)**
Served	649.96	1016.59	1071.57	2738.12	16937	3167.85	
Unserved	121870.30	224471.00	216468.35	562809.65	8246	552621.50	
Total	122520.26	225487.59	217539.92	565547.77	25183	555789.35	1.756

Model C1	**1-48**	**48-96**	**96-144**	**Total**	**No.of Casualties**	**Relaxed**	**Gap(%)**
Served	601.20	830.00	1294.14	2725.33	18140	2594.63	
Unserved	154239.98	296846.18	297814.93	748901.10	10992	748899.03	
Total	154841.18	297676.18	299109.07	751626.43	29132	751493.67	0.018

Model C2	**1-48**	**48-96**	**96-144**	**Total**	**No.of Casualties**	**Relaxed**	**Gap(%)**
Served	602.55	833.32	1304.78	2740.65	18138	2604.89	
Unserved	154239.98	296846.18	297815.97	748902.13	10994	748899.55	
Total	154842.53	297679.50	299120.74	751642.78	29132	751504.44	0.018

Table B-12: Ambulance usage percentages overall periods for all scenarios

		Total Ambulance	**Ambulance Usage %**
The European side Healing rate=0.25	Model A1	204	45.04
	Model A2	204	45.04
	Model C1	204	45.03
	Model C2	204	45.03
The European side Healing rate=0.5	Model A1	204	96.24
	Model A2	204	96.24
	Model C1	204	96.24
	Model C2	204	96.24
The Asian side Healing rate 0.25	Model A1	126	51.84
	Model A2	126	51.84
	Model C1	126	51.84
	Model C2	126	51.84
The Asian side Healing rate 0.5	Model A1	126	93.39
	Model A2	126	93.35
	Model C1	126	99.98
	Model C2	126	99.97

Appendix C

COMPUTATIONAL RESULTS FOR CASUALTY TRANSPORTATION AND EMERGENCY UNIT LOCATION MODEL

Table C-1: Percentages of unserved casualties and Capacities and locations of TEU for model A1 for the European side

Percentage of Unserved Casualties														
Model A1	**B.evler**	**Bakirkoy**	**Sisli**	**Eyup**	**Beyoglu**	**Eminonu**	**Fatih**	**Z.burnu**	**B.pasa**	**Gungoren**	**Bagcilar**	**Esenler**	**G.opasa**	**K.cekmece**
1st Model	92.1	87.9	41.6	89.7	96.0	78.3	72.8	98.8	98.2	97.5	94.5	98.0	86.7	98.9
Case 1	3.6	3.6	3.4	3.4	3.6	3.6	3.5	3.5	3.5	3.5	3.4	3.5	3.4	3.5
Case 2														
VN=816,γ=20	20.4	27.5	48.1	16.3	60.1	4.1	44.8	58.3	18.8	3.5	28.9	16.9	3.4	78.3
VN=1020,γ=25	18.9	26.0	40.8	11.2	42.5	3.6	28.9	33.9	4.2	3.8	26.4	8.4	3.4	20.6
VN=1020,γ=30	3.9	3.6	6.9	4.0	25.6	3.6	18.4	25.9	3.9	4.4	4.3	3.5	4.8	3.6
VN=1224,γ=35	3.6	3.6	3.4	3.4	3.6	3.6	3.5	3.5	3.5	3.5	3.4	3.5	3.4	3.5

Table C-2: Capacities of TEU for model A1 for the European side

Capacities of TEU														
Model A1	**B.evler**	**Bakirkoy**	**Eyup**	**Beyoglu**	**Z.burnu**		**B.pasa**		**Gungoren**		**Bagcilar**	**Esenler**		**K.cekmece**
Case 1	301	407	218	655	87	361	186	0	687	97	320	0	185	1	87
Case 2															
VN=816,γ=20	200	200	100	300	0	100	100	0	300	300	200	0	200	0	0
VN=1020,γ=25	200	200	100	400	200	100	0	100	300	300	200	200	0	0	200
VN=1020,γ=30	300	400	200	400	0	300	100	100	400	300	200	0	100	100	100
VN=1224,γ=35	300	400	200	400	100	300	300	0	400	400	300	0	200	100	100

Table C-3: Percentages of unserved casualties for model A2 for the European side

Percentage of Unserved Casualties														
Model A2	**B.evler**	**Bakirkoy**	**Sisli**	**Eyup**	**Beyoglu**	**Eminonu**	**Fatih**	**Z.burnu**	**B.pasa**	**Gungoren**	**Bagcilar**	**Esenler**	**G.opasa**	**K.cekmece**
1st Model	86.7	95.3	41.5	89.8	96.0	78.1	72.9	98.8	98.0	97.3	94.8	98.3	86.8	98.4
Case 1	3.6	3.6	3.4	3.4	3.6	3.6	3.5	3.5	3.5	3.5	3.4	3.5	3.4	3.5
Case 3														
VN=816,γ=20	22.1	29.5	45.8	14.9	60.8	3.6	45.3	71.9	20.2	3.6	29.7	30.6	3.4	58.6
VN=1020,γ=25	18.4	26.1	43.1	11.2	40.4	3.8	28.8	35.0	4.2	4.5	26.1	8.3	3.4	20.4
VN=1020,γ=30	4.1	3.6	8.3	4.4	11.4	5.8	5.3	21.3	3.8	4.3	3.7	4.0	3.4	27.1
VN=1224,γ=35	3.6	3.6	3.4	3.4	3.6	3.6	3.5	3.5	3.5	3.5	3.4	3.5	3.4	3.5

Table C-4: Capacities of TEU for model A2 for the European side

Capacities of TEU															
Model A2	**B.evler**	**Bakirkoy**	**Eyup**	**Beyoglu**	**Z.burnu**		**B.pasa**		**Gungoren**		**Bagcilar**	**Esenler**		**K.cekmece**	
Case 1	303	404	222	658	89	359	193	1	681	93	324	2	181	5	86
Case 2															
VN=816,γ=20	200	200	100	300	100	0	0	100	300	200	200	200	0	0	100
VN=1020,γ=25	200	300	100	400	100	300	100	0	300	200	200	0	200	0	100
VN=1020,γ=30	300	400	200	400	200	200	200	0	400	200	300	0	200	0	0
VN=1224,γ=35	300	400	200	400	100	400	300	0	400	300	300	0	200	100	100

Table C-5: Percentages of unserved casualties for model C1 for the European side

Percentage of Unserved Casualties														
Model C1	**B.evler**	**Bakirkoy**	**Sisli**	**Eyup**	**Beyoglu**	**Eminonu**	**Fatih**	**Z.burnu**	**B.pasa**	**Gungoren**	**Bagcilar**	**Esenler**	**G.opasa**	**K.cekmece**
1st Model	87.5	95.7	53.8	90.8	96.4	78.9	74.6	98.9	98.3	97.8	95.1	98.9	88.7	98.7
Case 1	5.2	4.3	3.8	4.3	5.1	3.4	16.9	18.6	4.7	3.9	4.2	3.5	3.5	4.0
Case 2														
VN=816,γ=20	22.5	44.6	45.6	29.1	60.8	6.0	57.8	75.5	25.6	4.3	30.9	50.6	3.5	77.8
VN=1020,γ=25	22.6	41.4	43.6	13.3	39.5	3.7	32.2	56.2	3.5	3.8	26.5	38.4	3.5	49.4
VN=1020,γ=30	18.4	18.2	5.9	8.7	37.2	3.4	34.0	36.5	3.8	4.4	21.3	5.0	4.2	20.8
VN=1224,γ=35	4.3	3.7	3.9	3.5	5.8	4.6	12.4	6.6	4.3	3.5	4.9	3.4	3.5	11.6

Table C-6: Capacities of TEU for model C1 for the European side

Capacities of TEU														
Model C1	**B.evler**	**Bakirkoy**	**Eyup**	**Beyoglu**	**Z.burnu**		**B.pasa**		**Gungoren**		**Bagcilar**	**Esenler**		**K.cekmece**
Case 1	378	439	244	681	100	256	174	48	698	110	372	1	195	24	86
Case 2															
VN=816,γ=20	200	200	100	300	0	100	100	0	400	100	200	0	200	0	100
VN=1020,γ=25	200	300	100	400	0	300	200	0	400	100	200	100	100	0	100
VN=1020,γ=30	300	400	200	400	200	200	0	100	300	300	300	0	200	0	100
VN=1224,γ=35	400	300	200	400	200	300	200	0	400	300	400	0	200	100	100

Table C-7: Percentages of unserved casualties for model C2 for the European side

Percentage of Unserved Casualties														
Model C2	**B.evler**	**Bakirkoy**	**Sisli**	**Eyup**	**Beyoglu**	**Eminonu**	**Fatih**	**Z.burnu**	**B.pasa**	**Gungoren**	**Bagcilar**	**Esenler**	**G.opasa**	**K.cekmece**
1st Model	87.5	95.7	53.7	90.9	96.7	79.0	74.5	99.0	98.1	97.7	95.7	98.2	88.6	98.7
Case 1	5.2	4.3	3.8	4.3	5.1	3.4	16.9	18.6	4.7	3.9	4.2	3.5	3.5	4.0
Case 2														
VN=816,γ=20	23.0	44.6	45.9	29.1	62.1	4.6	57.8	75.4	25.1	3.8	42.3	50.7	3.5	67.8
VN=1020,γ=25	22.6	40.0	44.1	12.7	36.9	4.2	35.8	64.9	4.4	3.6	26.8	3.4	3.5	55.3
VN=1020,γ=30	19.2	18.0	5.1	5.2	37.9	3.4	31.8	35.9	4.6	4.0	25.6	3.4	3.7	21.1
VN=1224,γ=35	3.7	3.5	3.6	4.3	16.5	3.4	5.1	16.5	4.1	5.3	4.2	3.4	3.5	3.5

Table C-8: Capacities of TEU for model C2 for the European side

Capacities of TEU															
Model C2	**B.evler**	**Bakirkoy**	**Eyup**	**Beyoglu**	**Z.burnu**		**B.pasa**		**Gungoren**		**Bagcilar**	**Esenler**		**K.cekmece**	
Case 1	372	451	238	681	103	274	177	6	666	117	377	5	192	20	85
Case 2															
VN=816,γ=20	200	200	100	300	0	100	100	0	400	100	200	0	200	0	100
VN=1020,γ=25	200	200	200	400	200	0	0	100	400	200	300	200	0	100	0
VN=1020,γ=30	300	300	200	400	100	200	200	0	300	300	300	0	200	100	100
VN=1224,γ=35	400	400	200	400	100	400	200	0	400	300	300	0	200	100	100

Table C-9: Percentages of unserved casualties for model A1 for the Asian side

Percentage of Unserved Casualties								
Model A1	**Beykoz**	**Uskudar**	**Kadikoy**	**Umraniye**	**Maltepe**	**Kartal**	**Pendik**	**Tuzla**
1st Model	63.8	57.0	63.9	63.6	93.7	95.4	85.1	97.1
Case 1	3.7	3.4	3.4	3.6	3.6	3.6	3.4	3.4
Case 2								
VN=252, γ=6	56.0	8.7	5.3	34.4	30.0	45.1	42.4	90.8
VN=378, γ=8	45.4	4.3	4.0	28.3	17.2	39.7	17.7	20.9
VN=378, γ=10	3.7	4.3	4.0	3.7	3.8	4.7	14.1	10.5

Table C-10: Capacities of TEU for model A1 for the Asian side

Capacities of TEU												
Model A1	**Beykoz**	**Uskudar**	**Kadikoy**	**Umraniye**	**Maltepe**		**Kartal**		**Pendik**		**Tuzla**	
Case 1	27	137	58	42	203	157	58	162	105	111	50	52
Case 2												
VN=252, γ=6	0	100	200	0	100	0	0	100	100	0	0	0
VN=378, γ=8	0	100	100	0	100	100	0	100	100	100	100	0
VN=378, γ=10	0	200	100	0	100	100	100	100	100	100	100	0

Table C-11: Percentages of unserved casualties for model A2 for the Asian side

Percentage of Unserved Casualties								
Model A2	**Beykoz**	**Uskudar**	**Kadikoy**	**Umraniye**	**Maltepe**	**Kartal**	**Pendik**	**Tuzla**
1st Model	63.3	56.8	64.0	64.1	93.3	95.7	85.2	96.9
Case 1	3.7	3.4	3.4	3.6	3.6	3.6	3.4	3.4
Case 2								
VN=252, γ=6	16.5	7.5	36.3	34.4	4.1	39.1	42.4	90.8
VN=378, γ=8	50.0	3.9	20.3	21.2	3.7	16.2	13.8	57.1
VN=378, γ=10	4.6	4.8	7.6	3.7	4.0	3.6	4.0	21.0

Table C-12: Capacities of TEU for model A2 for the Asian side

Capacities of TEU												
Model A2	**Beykoz**	**Uskudar**	**Kadikoy**	**Umraniye**	**Maltepe**		**Kartal**		**Pendik**		**Tuzla**	
Case 1	27	171	169	41	101	108	59	118	125	136	54	54
Case 2												
VN=252, γ=6	0	100	100	0	100	100	0	100	100	0	0	0
VN=378, γ=8	0	100	0	0	200	100	100	100	100	100	0	0
VN=378, γ=10	0	200	100	0	100	100	100	100	100	100	100	0

Table C-13: Percentages of unserved casualties for model C1 for the Asian side

Percentage of Unserved Casualties								
Model C1	**Beykoz**	**Uskudar**	**Kadikoy**	**Umraniye**	**Maltepe**	**Kartal**	**Pendik**	**Tuzla**
1st Model	70.9	67.8	69.6	67.0	94.1	96.1	86.9	97.3
Case 1	4.1	4.6	15.3	4.1	3.6	4.0	20.3	8.5
Case 2								
VN=252, γ=6	65.3	20.7	59.9	36.7	5.1	11.3	86.1	96.0
VN=378, γ=8	64.2	20.4	38.1	3.9	7.7	43.2	24.7	73.2
VN=378, γ=10	20.1	17.9	21.8	4.2	4.7	27.9	24.0	40.1

Table C-14: Capacities of TEU for model C1 for the Asian side

Capacities of TEU												
Model C1	**Beykoz**	**Uskudar**	**Kadikoy**	**Umraniye**	**Maltepe**		**Kartal**		**Pendik**		**Tuzla**	
Case 1	39	170	64	55	186	183	66	174	129	120	63	58
Case 2												
VN=252, γ=6	0	100	0	0	100	200	100	100	0	0	0	0
VN=378, γ=8	0	100	0	100	200	100	0	100	100	100	0	0
VN=378, γ=10	0	100	100	100	200	100	0	100	100	100	0	100

Table C-15: Percentages of unserved casualties for model C2 for the Asian side

Percentage of Unserved Casualties								
Model C2	**Beykoz**	**Uskudar**	**Kadikoy**	**Umraniye**	**Maltepe**	**Kartal**	**Pendik**	**Tuzla**
1st Model	70.1	67.6	69.4	67.9	94.1	95.9	87.2	97.3
Case1	4.1	4.3	14.7	3.9	4.7	3.8	20.9	8.2
Case 3								
VN=252, γ=6	67.5	34.2	66.5	45.2	15.5	50.4	28.2	79.3
VN=378, γ=8	27.6	19.8	28.3	37.3	6.8	47.2	24.4	70.7
VN=378, γ=10	65.3	18.8	25.2	34.1	3.7	3.9	22.1	36.7

Table C-16: Capacities of TEU for model C2 for the Asian side

Capacities of TEU												
Model C2	**Beykoz**	**Uskudar**	**Kadikoy**	**Umraniye**	**Maltepe**		**Kartal**		**Pendik**		**Tuzla**	
Case 1	35	170	67	53	191	181	65	179	129	117	62	56
Case 2												
VN=252, γ=6	0	100	0	0	100	100	0	100	100	100	0	0
VN=378, γ=8	0	100	100	0	200	100	0	100	100	100	0	0
VN=378, γ=10	0	100	0	0	200	200	100	100	100	100	100	0

Table C-17: Performance of Model A1, A2, C1, and C2 for the European side

Model A1	**Ave.Travel Time/person**	**Ave.Waiting Time/person**	**No of served cas.**	**No of unserved cas.**	**Obj.func. value**	**Relaxed Sol.**	**Gap(%)**
1st Model	3.58	407.05	2430	20028			
Case 1	7.40	0.00	22548	0	5171.04	5170.02	0.00
Case 2							
VN=816,γ=20	5.39	413.31	15314	7234	52007.43	51949.23	0.11
VN=1020,γ=25	6.29	412.51	18586	3962	29989.06	29935.6	0.18
VN=1020,γ=30	7.13	552.74	21382	1166	14082.53	13998.62	0.60
VN=1224,γ=35	7.49	0.00	22548	0	3618.25	3613.36	0.14
Model A1	**Ave.Travel Time/person**	**Ave.Waiting Time/person**	**No of served cas.**	**No of unserved cas.**	**Obj.func. value**	**Relaxed Sol.**	**Gap(%)**
1st Model	3.53	407.06	2430	20028			
Case 1	7.47	0.00	22548	0	5199.06	5198.1	0.00
Case 2							
VN=816,γ=20	5.50	413.40	15312	7236	52045.12	51962.67	0.16
VN=1020,γ=25	5.50	413.40	18585	3963	30009.84	29953.08	0.19
VN=1020,γ=30	7.30	552.61	21381	1167	14148.21	14020.65	0.91
VN=1224,γ=35	7.56	0.00	22548	0	3639.91	3638.21	0.05
Model A1	**Ave.Travel Time/person**	**Ave.Waiting Time/person**	**No of served cas.**	**No of unserved cas.**	**Obj.func. value**	**Relaxed Sol.**	**Gap(%)**
1st Model	3.55	407.26	2429	22761			
Case 1	7.27	1153.07	24480	710	17914.88	17912.7	0.00
Case 2							
VN=816,γ=20	5.01	411.91	15312	9878	69892.25	69817.32	0.11
VN=1020,γ=25	5.87	410.71	18585	6605	47829.91	47769.12	0.13
VN=1020,γ=30	6.54	452.38	21380	3810	31857.51	31763.55	0.30
VN=1224,γ=35	7.59	686.80	24647	543	10133.83	10091.5	0.42
Model A1	**Ave.Travel Time/person**	**Ave.Waiting Time/person**	**No of served cas.**	**No of unserved cas.**	**Obj.func. value**	**Relaxed Sol.**	**Gap(%)**
1st Model	3.61	407.28	2429	22761			
Case 1	7.34	1153.07	24480	710	17924.84	17921	0.00
Case 2							
VN=816,γ=20	5.07	411.92	15311	9879	69915.35	69832.41	0.12
VN=1020,γ=25	5.94	410.75	18584	6606	47862.86	47786.59	0.16
VN=1020,γ=30	6.58	452.60	21379	3811	31891.89	31785.51	0.33
VN=1224,γ=35	7.63	686.89	24645	545	10175.04	10132.18	0.42

Table C-18: Performance of Model A1, A2, C1, and C2 for the Asian side

Model A1	**Ave.Travel Time/person**	**Ave.Waiting Time/person**	**No of served cas.**	**No of unserved cas.**	**Obj.func. value**	**Relaxed Sol.**	**Gap(%)**
1st Model	6.48	405.19	1725	6175			
Case 1	10.37	9.00	7900	0	1813.54	1812.3	0.00
Case 2							
VN=252, γ=6	8.95	405.46	5232	2668	19850.13	19709.29	0.71
VN=378, γ=8	10.08	383.39	6596	1304	10480.77	10284.29	1.91
VN=378, γ=10	11.61	577.71	7672	228	4720.1	4509.83	4.66
Model A1	**Ave.Travel Time/person**	**Ave.Waiting Time/person**	**No of served cas.**	**No of unserved cas.**	**Obj.func. value**	**Relaxed Sol.**	**Gap(%)**
1st Model	6.46	405.22	1725	6175			
Case 1	10.64	9.00	7900	0	1817.66	1815.4	0.00
Case 2							
VN=252, γ=6	8.89	405.59	5226	2674	19890.16	19712.41	0.90
VN=378, γ=8	10.49	384.75	6592	1308	10580.18	10296.38	2.76
VN=378, γ=10	11.57	596.48	7672	228	4750.58	4510.32	5.33
Model A1	**Ave.Travel Time/person**	**Ave.Waiting Time/person**	**No of served cas.**	**No of unserved cas.**	**Obj.func. value**	**Relaxed Sol.**	**Gap(%)**
1st Model	6.37	405.74	1725	7876			
Case 1	10.10	774.77	9072	529	8715.34	8713.28	0.00
Case 2							
Model A1	**Ave.Travel Time/person**	**Ave.Waiting Time/person**	**No of served cas.**	**No of unserved cas.**	**Obj.func. value**	**Relaxed Sol.**	**Gap(%)**
VN=378, γ=8	9.58	405.99	6823	2778	20926.29	20764.86	0.78
VN=378, γ=10	10.29	442.06	7944	1657	14610.78	14411.55	1.38
Model A1	**Ave.Travel Time/person**	**Ave.Waiting Time/person**	**No of served cas.**	**No of unserved cas.**	**Obj.func. value**	**Relaxed Sol.**	**Gap(%)**
1st Model	6.49	405.74	1725	7876			
Case 1	10.19	774.77	9072	529	8730.69	8726.67	0.00
Case 2							
VN=252, γ=6	8.38	419.33	5394	4207	31187.38	31031.51	0.50
VN=378, γ=8	9.83	406.36	6821	2780	20985.42	20774.81	1.01
VN=378, γ=10	10.55	442.37	7943	1658	14661.11	14422.71	1.65

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