OPTIMIZATION OF LOCATING LOGISTIC SUPPLY COORDINATION CENTERS (LSCC) OF TURKISH LAND FORCES IN AN EARTHQUAKE REGION

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MASTER OF SCIENCE

By

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JULY, 2003

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ABSTRACT

OPTIMIZATION OF LOCATING LOGISTIC SUPPLY COORDINATION CENTERS (LSCC) OF TURKISH LAND FORCES IN AN EARTHQUAKE REGION

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M.S. in Industrial Engineering

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This research aims at finding the optimum location of Military Logistic Supply Coordination Centers (LSCC) that are established by Turkish Land Forces for gathering and distributing the logistic supply materials among citizens in an area of a county damaged by a natural disaster, i.e. earthquake. The problem of finding the optimum locations of LSCCs in disaster regions is modeled as a Maximal Covering Location Problem. Coverage distances are defined based on the capacity of LSCCs that can be located within the area of counties in the damaged regions.

Then, candidate points representing potential sites and demand points representing the provinces having high expected damage estimation due to a probable future earthquake that may occur at the vicinity of Ankara Metropolitan area, are defined.

In order to set the standarts on various issues regarding the selection of candidate points, additional constraints are defined. Furthermore, weights, determined by considering the earthquake damage hazard expected for each region are assigned to the demand points.

The seismicity of Ankara has been investigated by using the statistics of earthquakes equal or larger than Magnitude>4 that occurred in a region with a 140 km radius for the time interval 1900-1997.

Two different scenarios are developed for this model. Optimal solutions are found using mathematical programming software LINGO. Finally, the changes in the optimal solutions are analyzed by altering the problem parameters.

Keywords : Facility Location, Maximal Covering Location Problem, Seismicity

ÖZET

TÜRK KARA KUVVETLERI LOJISTIK DESTEK KOORDINASYON MERKEZLERININ (LDKM) DEPREM AFET BÖLGELERINE KONUSLANDIRILMASININ OPTIMIZASYONU

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Temmuz 2003

Bu çalismada, depremden zarar görmüs bölge sakinleri arasinda lojistik destek malzemelerinin toplanip dagitilmasi için Türk Kara Kuvvetleri tarafindan kurulan Lojistik Destek Koordinasyon Merkezlerinin (LDKM) en uygun konus yerlerinin bulunmasi amaçlanmaktadir. Afet bölgelerindeki LDKM'lerin en uygun konus yerlerinin bulunmasi problemi bir Maximal Kaplama Problemi olarak modellenmistir. Kaplama mesafeleri, ele alinan hasarli bölgede konuslandirilabilecek LDKM'lerin kapasitesine göre belirlenmistir.

Daha sonra, potansiyel yerleri temsilen aday noktalari ve yüksek hasar tahmin beklentisine sahip yerlesim yerlerini temsilen istek noktalari tespit edilmistir.

Aday noktalarindaki belirsizligi en aza indirmek için modele, bölgesel karakteristikleri temsilen ek kisitlar eklenmistir. Ayrica, her bölge için, beklenen deprem hasar tehlikesi göz önüne alinarak belirlenen agirliklar, istek noktalarina atanmistir.

Ankara`nin depremselligi, 1900 ile 1997 yillari arasindaki dönemde 140 km yariçapli bir bölgede meydana gelen 4 ve 4 den büyük depremlerin istatistikleri kullanilarak arastirilmistir.

Bu model için iki farkli senaryo gelistirilmistir. En uygun çözümler LINGO yazilimiyla elde edilmistir. Son olarak ise, problem parametreleri degistirilerek en uygun çözümlerdeki degisimler analiz edilmistir.

Anahtar Sözcükler : Yer seçimi, Maximal Kaplama Problemi, Depremsellik

To my wife and family

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ENGLISH-TURKISH MEANINGS OF SOME MILITARY TERMS

Turkish Land Forces: Türk Kara Kuvvetleri

Corps: Kolordu

Brigade: Tugay

Lojistic Supply Coordination Center: Lojistik Destek Koordinasyon Merkezi

CHAPTER 1

INTRODUCTION

The study of location theory formally began in 1909 when Alfred Weber considered how to position a single warehouse so as to minimize the total distance between it and several customers [30].

Following this initial investigation, location theory was driven by a few applications which inspired researchers from a range of fields. Location theory gained renewed interest in 1964 with a publication by Hakimi [16], who sought to locate switching centers in a communications network and police stations in a highway system.

To do so, Hakimi considered the more general problem of locating one or more facilities on a network so as to minimize the total distance between customers and their closest facility or to minimize the maximum such distance.

Since the mid-1960s, the study of location theory has flourished. The most basic facility location problem formulations can be characterized as both static and deterministic. These problems take constant, known quantities as inputs and derive a single solution to be implemented at one point in time. The solution will be chosen according to one of many possible criteria (or objectives), as selected by the decision maker.

A number of researchers, particularly those working with applied problems and those interested in locating obnoxious facilities, have examined multi-objective extensions of these basic models [9].

The maximal covering location (M.C.L.P.) was initially developed to determine a set of facility locations which would maximize the total demand population served by the facilities within a prespecified maximal service distance. Naturally, the model can be directly applied to most facility-location planning problems, such as the location planning for warehouses, health-care centers, fire stations, recreation centers, libraries, etc.

The M.C.L.P. model can also be applied to many other problems which are not facility-location in nature. For example, it can be applied to data abstraction problems, to portfolio formation (i.e. the selection of stocks), list selection problems and to some classification or grouping problems.

In the following chapter, the problem addressed in this study will be modeled and solved as a M.C.L.P.

In Chapter 2, we shell first briefly review the development of the location theory and the M.C.L.P. and its various applications of the model as a literature survey.

In Chapter 3, the methodology, the analysis and formulation of the problem and the solution strategy will be presented.

Finally, in Chapter 4, conclusion of the study shall be summarized and some directions for future research are going to be suggested.

1.1. Problem Statement

Today, it is impossible to predict the occurrence of earthquakes in any region by available technology. However, it is possible to diminish the damages by a comprehensive planning and application of the activities that have to be done after an earthquake.

After the 1999 earthquake that hit the Marmara Region, Turkish Land Forces has become increasingly more involved and interested in natural disasters -especially earthquakes- like many other private and public sector organizations in Turkey in recent years. It is a fact that being prepared for the expected damage of earthquakes is an essential issue for every country.

For this reason, Turkish Land Forces has decided to establish Logistic Supply Coordination Centers (LSCC) in the disaster regions after an earthquake has occurred, in order to coordinate gathering and distribution of the logistic supply materials -i.e. food, clothes, tents etc.- among the citizens of the provinces damaged.

These LSCCs will be the centers -as huge depots- of the logistic supply materials brought to the disaster area from various places like other cities or foreign countries.

This research aims at finding the optimum location of the military Logistic Supply Coordination Centers (LSCC) that are established by Turkish Land Forces for gathering and distributing the logistic supply materials among citizens in an area of a county damaged by a natural disaster, i.e. earthquake.

The problem of finding the optimum locations of LSCCs in disaster regions is modeled as a Maximal Covering Location Problem. Coverage distances are defined based on the capacity of LSCCs that can be located within the area of counties in the damaged regions.

Then, candidate points representing potential sites and demand points representing the provinces having high expectation of damage estimation due to a probable future earthquake that may occur at the vicinity of Ankara Metropolitan area, are defined.

In order to set the standarts on various issues regarding the selection of candidate points, additional constraints are defined. Furthermore, weights, determined by considering the earthquake damage hazard expected for each region are assigned to these demand points.

The seismcity of Ankara has been investigated by using the statistics of earthquakes equal or larger than Magnitude>4 that occurred in a region with a 140 km radius for the time interval 1900-1997.

Two different scenarios are developed for this model. These scenarios are based on the potential earthquake source zones for Ankara which are North Anatolian Fault Zone (NAFZ) and some lineaments and linear structures determined by remote sensing and imaging techniques applied by the use of satellites.

Optimal solutions are found by using LINGO. Finally, the changes in the optimal solutions are analyzed by altering the problem parameters.

1.2. Organization of Turkish Land Forces LSCCs

Turkish Land Forces Natural Disaster Lojistic Supply Coordination Centers are established and managed by the instructions of a military drill-book which is Kara Kuvvetleri Merkezi Yönergesi (KKY 208-3).

These centers are supposed to work for 24 hours a day in order to gather and distribute the lojistic supply materials needed in the natural disaster region as long as the crisis goes on.

Figure-1 shows an organization chart of natural disaster lojistic supply system in Turkish Land Forces.

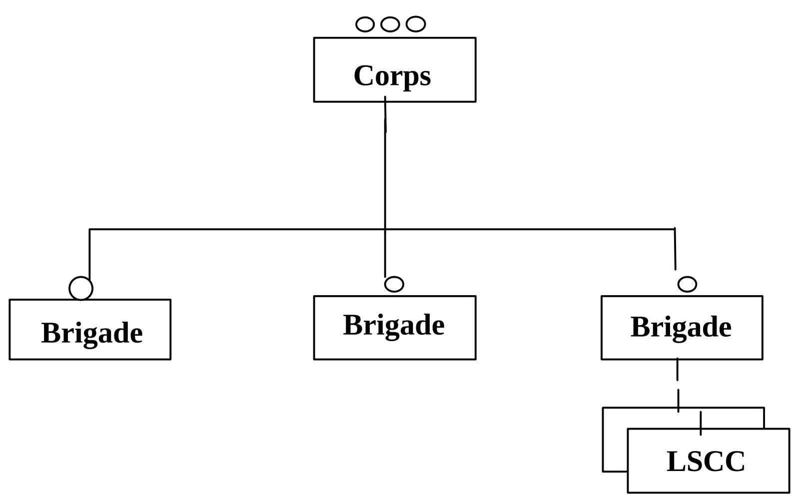

Figure-1: Organization of Natural Disaster LSCC

1.3. Determining the Responsibility Regions of LSCCs

LSCCs are to be located at the center of their responsibility regions which has the greatest accessibility and that are reachable by the citizens with ease.

While determining the responsibility regions of LSCCs, the following attributes are going to be considered ;

1. Geographic constraints

2. Social and economic constraints

3. Population density

4. Transportation attributes

5. Public service necessities

1.4. The Objective of the Study

There are two main objectives taken into consideration in this study. These are ;

1. Locating the least number of LSCCs in the damaged region after a natural disaster, earthquake.

2. Maximizing the coverage of disaster region by LSCCs.

1.5. Assumptions

1. The number of LSCCs to be located are bounded due to the resources in hand.

2. There exists limited number of candidate facility points.

3. The number of the candidate points representing potential sites will be at most two times the number of demand points representing the provinces having high expected damage estimation due to a probable future earthquake.

4. The candidate points are determined by the specialist military personnel Captain Dogan Karadogan who knows the region well and by inspecting the military maps of the city of Ankara while taking the five attributes of the fields into consideration, which are Geographic constraints, Social and economic constraints, Population density, Transportation attributes, Public service necessities.

5. Expected damages of two earthquake scenarios are estimated for Ankara city due to a probable future earthquake that may occur at the vicinity of Ankara by the use of the master thesis which is written by jeology engineer Bülent Özmen in Hacettepe University in 1998.

6. Each demand point will be covered by only one candidate point.

7. Each LSCC has identical service capacities.

CHAPTER 2

LITERATURE REVIEW

For centuries, people are trying to find the best locations for their houses, depots and any other kind of facilities used in their lives. Today, we are more interested in deciding the optimum facility locations in both private and public sectors. In the following review, we will try to introduce the most critical aspects and applications of location theory published in the literature related to our study.

A vast literature has accumulated around the facility location theory. Operations researchers have developed a number of mathematical programming models to represent a wide range of location problems. Several different objective functions have been formulated to make such models amenable to numerous applications.

Unfortunately, we see that the resulting models can be extremely difficult to solve to optimality (most problems are classified as NP-hard). Many of the problems require integer programming formulations. In these problems, all inputs (such as demands, distances, and travel times) are taken as known quantities and outputs are specified as one-time decision values.

Averbakh and Berman [2] noted that the problem of input data uncertainty may be addressed by sensitivity or post-optimality analysis. Labbé [18] also points out the importance of the sensitivity analysis and attempts to quantify the effect of a change in parameter values on the optimal objective function value.

Louveaux [20] points out that “While such results help in evaluating the robustness of a solution after a model is solved, they do nothing to incorporate uncertainty into models proactively”.

Those seeking a more general overview of facility location research can refer to one of the many published review articles or texts, including Refs. [1, 10, 14, 17, 19, 23, 28, 29].

2.1. Median problems

As noted by Church and ReVelle [8]; “One important way to measure the effectiveness of a facility location is by determining the average distance traveled by those who visit it”.

Below, we will use travel time and travel distance interchangeably to represent the "cost" of traveling from one location to another. It is obvious that as average travel distance increases, facility accessibility decreases, and thus the location's effectiveness decreases.

This relationship holds for facilities such as libraries, schools, and emergency service centers, to which proximity is desirable.

In 1970s, ReVelle and Swain [24] note that “An equivalent way to measure location effectiveness when demands are not sensitive to the level of service is to weight the distance between demand nodes and facilities by the associated demand quantity and calculate the total weighted travel distance between demands and facilities”.

The *P-median problem* (introduced by Hakimi [16]) uses this measure of effectiveness, and is stated as follows: Find the location of *P* facilities so as to minimize the total demand-weighted travel distance between demands and facilities. To formulate this problem mathematically, the following notation is necessary:

Parameters :

I ={1,2,3,..................,n}, the index set of demand nodes
J ={1,2,3,.................,m}, the index set of potential facility sites
h_i= demand at node i
d_{ij}= distance between demand node i and potential facility site j
P= number of facilities to be located

Decision variables:

$$X_j = \begin{cases} 1 & \text{if we locate at potential facility site j.} \\ 0 & \text{if not.} \end{cases}$$

$$Y_{ij} = \begin{cases} 1 & \text{if demands at node i are served by a facility at node j.} \\ 0 & \text{if not.} \end{cases}$$

Using these definitions, the *P*-median problem can be written as the following integer linear program:

$$\text{Minimize } D \qquad (1)$$

$$\text{subject to: } \sum_{j=1}^{m} X_j = P, \qquad (2)$$

$$\sum_{j=1}^{n} Y_{ij} = 1 \quad \forall i \in I, \qquad (3)$$

$$Y_{ij} - X_j \le 0, \quad \forall i,j, \qquad (4)$$

$$D \ge \sum_j d_{ij} Y_{ij} \quad \forall i, \qquad (5)$$

$$X_j \in \{0,1\} \quad \forall j, \qquad (6)$$

$$Y_{ij} \in \{0,1\} \quad \forall i, j, \qquad (7)$$

The objective (1), as mentioned above, is to minimize the total demand-weighted distance between customers and facilities. Constraint (2) requires that exactly P facilities be located. Constraint (3) ensures that every demand point is assigned to some facility site, while constraint (4) allows assignment only to sites at which facilities have been located. Constraints (5) and (6) are binary requirements for the problem variables. Since demands will naturally be assigned entirely to the nearest facility in this uncapacitated problem.

A modified version of the P-median problem is presented by ReVelle [22] for locating retail facilities in the presence of competing firms. The objective in this retail environment is to locate facilities to maximize the number of new customers captured or to maximize the retailer's added market share.

For this *maximum capture problem* formulation, the author assumes that all firms in the area supply the same product and that customers patronize the nearest firm. This modification illustrates how the P-median problem can be applied in a strategic decision making context.

As noted by Garey and Johnson [15], a total enumeration approach for solving these problems would be computationally prohibitive for reasonable values of N (hundreds to thousands of nodes) and P (tens of location sites).

The formulation presented above suggests the use of integer programming techniques for solving P-median problems.

Daskin [10] comments that, “While these techniques are often able to reach integer optimal solutions for moderately sized problems in a reasonable time, several efficient heuristics have also been developed for solving median problems”.

2.2. Covering problems

The *P*-median problem we described above can be used to locate a wide range of public and private facilities. For some facilities, however, selecting locations which minimize the *average* distance traveled may not be appropriate. Suppose, for example, that a city is locating emergency service facilities such as fire stations or ambulances.

As noted by Schilling [26] and White [31]; “The critical nature of demands for service will dictate a maximum "acceptable" travel distance or time. Such facilities will thus require a different measure of location efficiency. To locate such facilities, the key issue is "coverage". A demand is said to be *covered* if it can be served within a specified time”.

Two covering problems which illustrate the distinction are the *location set covering problem* and the *maximal covering problem*. We will introduce both problem classes and discuss their relationship to the *P*-median problem..

In the set covering problem, the objective is to minimize the cost of facility location such that a specified level of coverage is obtained. The mathematical formulation of this problem requires the following additional notation:

Parameters :
c_j = fixed cost of siting a facility at node j
S = maximum acceptable service distance (or time)
$N_i = \left\{ j / d_{ij} \leq S \right\}$, set of facility sites j within acceptable distance of node i

The set covering problem can thus be represented by the following integer program:

$$\text{Minimize} \sum_{j} c_j X_j \qquad (7)$$

$$\text{subject to:} \sum_{j \in N_i} X_j \geq 1 \quad \forall i, \qquad (8)$$

$$X_j \in \{0,1\} \quad \forall j. \qquad (9)$$

The objective function (7) minimizes the cost of facility location. In many cases, the costs c_j are assumed to be equal for all potential facility sites *j*, implying an objective equivalent to minimizing the number of facilities located. Constraint (8) requires that all demands *i* have at least one facility located within the acceptable service distance. The remaining constraints (9) require integrality for the decision variables.

We note that this formulation makes no distinction between nodes based on demand size. Each node, whether it contains a single customer or a large portion of the total demand, must be covered within the specified distance, regardless of cost.

As Church and ReVelle [7] stated, "the set covering problem allows us to examine how many facilities are needed to guarantee a certain level of coverage to all customers. In many practical applications, decision makers find that their allocated resources are not sufficient to build the facilities dictated by the desired level of coverage".

Specifically, we know that the maximal covering problem seeks to maximize the amount of demand covered within the acceptable service distance *S* by locating a fixed number of facilities. The formulation of this problem requires the following additional set of decision variables:

$$Z_i = \begin{cases} 1 & \text{if node i is covered,} \\ 0 & \text{if not.} \end{cases}$$

Combining these variables with the notation defined above, we derive the following formulation of the maximal covering problem:

$$\text{Maximize } \sum_{i} h_i Z_i \qquad (10)$$

$$\text{subject to: } Z_i \le \sum_{j \in N_i} X_j \quad \forall i, \qquad (11)$$

$$\sum_{j} X_j \le P, \qquad (12)$$

$$X_j \in \{0,1\} \quad \forall j, \qquad (13)$$

$$Z_i \in \{0,1\} \quad \forall i, \qquad (14)$$

The objective (10) is to maximize the amount of demand covered. Constraint (11) determines which demand nodes are covered within the acceptable service distance. Each node *i* can only be considered covered (with Z_i=1) if there is a facility located at some site *j* which is within *S* of node *i* (i.e., if X_j=1 for some $j \in N_i$). If no such facility is located, the right hand side of constraint (11) will be zero, thus forcing Z_i to zero. Constraint (12) limits the number of facilities to be located, to account for limited resources. Constraints (13) and (14) are integrality constraints for the decision variables.

Note that both the set covering and the maximal covering problem formulations assume a finite set of potential facility sites. Typically the set of potential sites consists of some (if not all) of the demand nodes of the underlying network.

Church and Meadows [6] also points out that “Research extensions to these models have shown that even if facilities are allowed anywhere on the network, the problem can be reduced to one with finite choices for facility location”.

One variant of the maximal covering problem noted by White and Case [31] weights all demand points equally (without regard to the size of the demand present) so that the objective is simply to maximize the number of demand nodes covered.

All covering models discussed to this point implicitly assume that if a demand is covered by a facility then that facility will be available to serve the demand. In Ref. [12], Daskin and Stern examine siting Emergency Medical Service (EMS) vehicles to satisfy a specified service requirement.

For such an application, the availability assumption is problematic, as EMS vehicles already responding to a call for service will not be available to answer additional demands. Benedict [11] and Hogan [4] noted that "Applications where facilities experience busy or inoperative periods have inspired a set of models which attempt to provide multiple coverage to demand nodes so that if one facility is busy, others will be within the acceptable range to serve incoming demands".

Batta and Mannur [3] examine models for determining the deployment of multiple EMS vehicles in environments where high demand rates cause frequent unit busy periods. The authors recognize that demands which require a larger response team are typically more critical, and thus should have a tighter coverage level.

They formulate generalized deterministic set covering and maximal covering models which incorporate multiple response units and demand-dependent coverage requirements. Solution strategies for each problem class are discussed, including branch and bound algorithms applied to binary representations of reduced problem formulations.

In Refs. [8, 31], the relationship between the *P*-median (or *central facilities location*) and maximal covering problems is examined. The authors show that through a transformation of distances the maximal covering problem can be viewed as a special case of the *P*-median problem.

Specifically, a *P*-median problem is considered on a network where the distances d_{ij} are transformed as follows:

$$d'_{ij} = \begin{cases} 1 \text{ if } d_{ij} \le S, \\ 0 \text{ if } d_{ij} \ge S. \end{cases}$$

Solving the *P*-median problem with modified distances d'_{ij} minimizes the amount of demand *not* served within coverage distance *S*. It can be shown that this is equivalent to maximizing the amount of demand served within *S*, and thus the transformed version of the *P*-median problem is exactly a maximal covering problem.

Daskin [10] uses this transformation to develop a multi-objective model that trades off minimizing the demand weighted total distance with maximizing the covered demand.

Similar to the *P*-median problem above, both the set covering and maximal covering problems are NP-complete for general networks.

2.3. Center problems

The set covering problem described above determines the minimum number of facilities needed to cover all demands using an exogenously specified coverage distance. It is clear that the potential infeasibility of such an approach in many practical contexts led us to examine the maximal coverage problem.

As we described, this formulation considers the resources available (in terms of the number of facilities we are able to locate) and determines the maximum demand coverage possible.

Another problem class which avoids the set covering problem's potential infeasibility is the class of *P-center problems*. In such problems, it is required the coverage of all demands, but seeking to locate a given number of facilities in such a way that minimizes coverage distance.

Rather than taking an input coverage distance *S*, this model determines endogenously the minimal coverage distance associated with locating *P* facilities.

The *P*-center problem is also known as the *minimax problem*, as seeking to minimize the maximum distance between any demand and its nearest facility. If facility locations are restricted to the nodes of the network, the problem is a *vertex center problem.*

Center problems which allow facilities to be located anywhere on the network are *absolute center problems*. As in the set covering problem, Hakimi's [16] result does not generally hold; the solution to the absolute center problem is often better (i.e., has a lower associated objective function value) than that for the vertex center problem.

The following additional decision variable is needed in order to formulate the vertex *P*-center problem:

D=maximum distance between a demand node and the nearest facility.

The resulting integer programming formulation of the vertex *P*-center problem follows;

$$\text{Minimize } D \qquad (15)$$

$$\text{subject to: } \sum_j X_j = P, \qquad (16)$$

$$\sum_j Y_{ij} = 1 \quad \forall i, \qquad (17)$$

$$Y_{ij} - X_j \le 0, \quad \forall i,j, \qquad (18)$$

$$D \ge \sum_j d_{ij} Y_{ij} \quad \forall i, \qquad (19)$$

$$X_j \in \{0,1\} \quad \forall j, \qquad (20)$$

$$Y_{ij} \in \{0,1\} \quad \forall i, j, \qquad (21)$$

The objective function (15) is simply to minimize the maximum distance between any demand node and its nearest facility. Constraints (16–18) are identical to (2)–(4) of the *P*-median problem. Constraint (19) defines the maximum distance between any demand node *i* and the nearest facility *j*. Finally, constraints (20) and (21) are integrality constraints for the decision variables.

Daskin [10] notes that "this process can also be completed in polynomial time. If the value of *P* is variable, however, both types of the *P*-center problem are NP-complete".

2.4. Additional problem formulations

The *P*-median, covering, and *P*-center problems we discussed above provide a strong foundation for much of the location theory research done to date. In this final section on static and deterministic models, we will briefly describe some of the additional problem formulations found in the literature.

In most of the models discussed thus far, we focused on travel distance or time as a surrogate for operating costs once a facility is located. Although it is acknowledged that limited resources might dictate the number of facilities sited, in only one model (set covering) did we explicitly consider location costs. The set of *fixed charge facility location problems* includes problem instances which have a fixed charge associated with locating at each potential facility site.

Sankaran and Raghavan [25] extend the classical capacitated fixed charge facility location model to incorporate the endogenous selection of facility sizes.

Mukundan and Daskin [21] consider a similar problem in a profit maximization context.

As we mentioned above, one of the earliest applications of facility location modeling considered locating warehouses. Any firm deciding where to site a new warehouse must also consider how to best ship products between its facilities and its customers.

Scott [27] points out that "the set of *location-allocation problems* builds upon a basic location problem formulation (such as those presented above) to simultaneously locate facilities and dictate flows between facilities and demands".

In 1990s, Current, Min and Schilling [9] note that "just as warehouse applications require us to consider issues of both location and allocation, practical applications often introduce more involved objectives than the simple minimization of cost or maximization of coverage".

Finally, note that the models and applications we presented thus far focus on locating facilities to make them accessible to customers. Alternatively, several important real-world applications deal with locating facilities which are undesirable to nearby populations.

For example, if a city locates a waste disposal plant, a water treatment center or even an airport, the objectives for optimal location are contrary to those detailed above. These applications have, in fact, spawned a special area of research for locating "obnoxious" or "noxious" facilities.

Problems which address these situations include the *antimedian problem*, which locates a server to maximize average distance between server and demand points; the *anticenter problem*, which maximizes the minimum distance between server and demand points; and the *p-dispersion problem*, which locates facilities to maximize the minimum distance between any pair of facilities.

While such problems are useful in formulating undesirable facility location problems, the political ramifications involved in locating such facilities often force decision makers to use multi-objective models [5,10,13,26].

CHAPTER 3

ANALYSIS OF THE PROBLEM and MATHEMATICAL FORMULATION

3.1. Data File

3.1.1. Methodology

This research aims at finding the optimum location of Military Logistic Supply Coordination Centers (LSCC) that are established by Turkish Land Forces for gathering and distributing the logistic supply materials among citizens in an area of a county damaged by a natural disaster, i.e. earthquake.

The problem of finding the optimum locations of LSCCs in disaster regions can be modeled as a Maximal Covering Location Problem. In this thesis, we focus on the seismicity and earthquake hazard of center towns of Ankara Metropolitan Area which include Altindag, Cankaya, Etimesgut, Keçiören, Mamak, Sincan and Yenimahalle (Figure-2).

In order to set the standarts on various issues regarding the selection of candidate points and to determine the weights for the demand points, we use the estimations of the expected horizantal peak ground acceleration, seismic intensity and damage expectation for Ankara City due to a probable future earthquake that may occur at the respective towns of Ankara Metropolitan area.

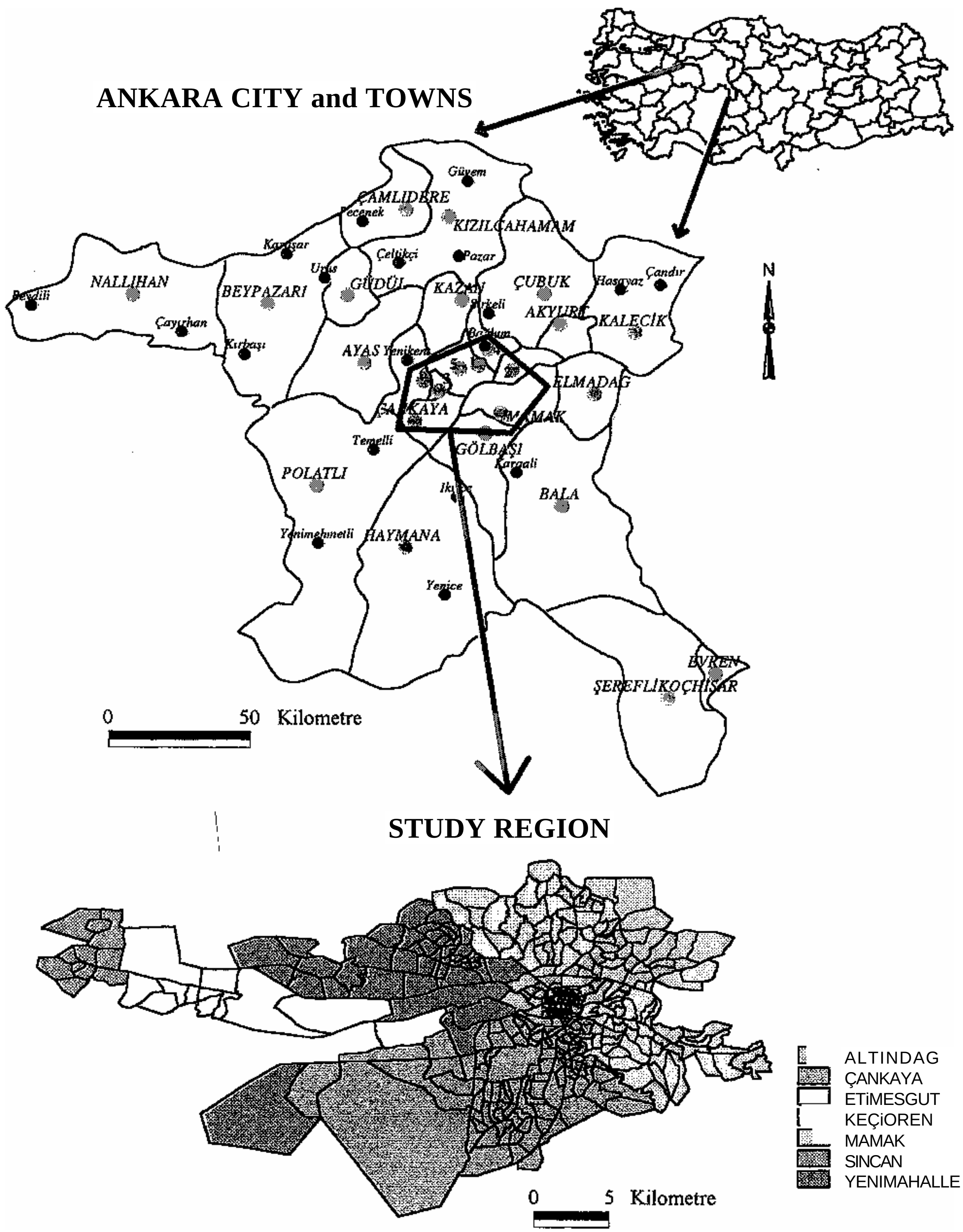

Figure-2 : Location of the Study Region in Ankara and Turkey

The seismicity of Ankara has been investigated by using the statistics of earthquakes equal or larger than Magnitude>4 that occurred in the respective region with a 140 km radius for the time interval 1900-1997. Earthquake specialists predict a probability of .97 for the occurrence of an earthquake magnitude equal or greater than 6.5 within 25 years [33].

It is obvious that each part of any area will have different earthquake damage hazard and importance degrees due to the ground characteristics, proximity to cities and roads, population density, geographic and transportation attributes etc. So, the model developed for this study may be appropriate for any earthquake region by using the same approach.

In order to define the constraints on local differences, candidate points are assigned certain values regarding the regional characteristics which are geographic, transportation, social attributes, population density and proximity to provinces. These are the basic properties concerning the location and responsibility regions of LSCCs.

We also add a constraint to the model which provides that each local characteristic value of a candidate point is over the concerning average characteristic value of all candidates. By this way, we guarantee that the candidate points with higher local characteristic values are selected as the location points of LSCCs.

While developing the model, personnel limitations of Turkish Land Forces is kept in view and to locate least possible number of LSCCs in the region is aimed.

The solution of the model indicates how many demand points are covered and which candidate points are to be selected due to 5 km coverage distance. In the problem, it is provided that a demand point is served by only one

LSCC. Since the objective is to cover the largest number of demand points, it is not mandatory to cover all of them.

The mathematical model aims at maximizing the number of demand points covered due to a certain coverage distance.

In the model, all decision variables are taken as binary variables. By this way, only one LSCC can be located at any candidate point and can cover each demand point only once.

3.1.2. Determining the Candidate Points

The selection of candidate points differ due to the regional characteristics. Each candidate point selected has many advantages and disadvantages. One may use varying criteria in the choice of candidate points, i.e. population density. Also, there are many alternative ways for this selection.

In an area, many points may be seen as candidate points and each of them may have different characteristics. Aiming to maximize covering and to evaluate due to their certain attributes, the candidate points are chosen as closed to each other and the number of them is more than the number of demand points.

Also, the ground characteristics of the region which are horizantal peak ground acceleration, seismic intensity and damage estimation are inspected. Furthermore, the views and opinions of the military specialists who knows about the area are taken into consideration.

In the model, we determine 68 candidate points representing the potential sites of LSCCs for the Ankara Metropolitan Area.

3.1.3. Determining the Demand Points

It is also very important to select the demand points. Because the demand points represent the activity fields of LSCCs. These are the vital points of the model which indicate from where the demands are requested. Being able to be requested from anywhere, demand points may be any point in the concerning region.

Every demand point defines a covering area and they differ from each other due to their importance degrees. In this study, 43 demand points are selected due to the ground characteristics of the region which are horizantal peak ground acceleration, damage estimation and the seismicity of the region which has been investigated by using the statistics of earthquakes equal or larger than M>4 that occurred in the respective region with a 140 km radius for the time interval 1900-1997 [33].

Requests occurring in a region of 5 km square are represented by only one demand point.

The importance of the demand points is defined by the ground characteristics. Model aims at maximizing the number of demand points covered by the candidate points.

3.1.4. Assumptions of the Model

It is necessary to make some assumptions about the number of LSCCs to be located, coverage distance and regional characteristics. The material and staff structure of Turkish Land Forces limits the number of LSCCs to be located in a disaster region due to the financial and other types of costs.

Most appropriate locations and responsibility regions of LSCCs may change due to the number of LSCCs decided by the military decision-makers. In this study, the coverage distances and other capabilities of all facilities are identical and LSCCs are considered to be in service for 24 hours a day having at most 5 km covering distance.

The regional characteristics which include ground characteristics, proximity to cities and roads, population density, geographic and transportation attributes are another essential subject for the solution of the problem. The characteristic values of the candidate points and defining the expectations about them in the constraints help decision-makers choose better and more reliable points.

For these characteristic values, specific criteria are determined and by means of the criteria, the candidate sites are given points from 1 to 5 for each regional characteristic. Also, it is assumed that all regional characteristics have the same priority.

While evaluating the geographic attribute, the candidate points having the largest open area to establish LSCC are assigned a score of 5. However, the candidate points having insufficient, confined and insecure land are assigned the lowest value from the point of view of geographic attribute.

Evaluating the population density criteria, the most important issue is to be able to respond to the demands effectively. Therefore, while evaluating, the total population centering the candidate point in a region with 5 km radius is considered. In the Table-1 below, we show the scores of candidate points due to the population density criteria.

Population	**Point**
Least than 500	1
501-1500	2
1501-2500	3
2501-3500	4
More than 3500	5

Table-1: Population Density

It is also an essential criteria for LSCCs to be close to the counties in order to supply the lojistic needs. In Table-2, we show the scores of candidates due to the proximity to provinces criteria.

Distance (m)	**Point**
4001-5000	1
3001-4000	2
2001-3000	3
1001-2000	4
0-1000	5

Table-2: Proximity to Provinces

While evaluating the transportation attribute, it is important for candidate points to be close to the connection roads which are proper for transportation.

For social attributes of the candidates, demographic and economic properties of the regions are considered and evaluated by the specialists.

Due to these five criteria which are proximity to provinces and geographic, demographic, transportation and social attributes, regional characteristic coefficients table is prepared for all candidate points. Similar tables can be prepared for the other earthquake areas.

Regional characteristic coefficients of the candidate points and the weights of the demand points are shown in the APPENDIX-A and APPENDIX-B.

3.2. Formulation

Indices :

I = {1,2,3,………..,i,…….,**43}** Set of demand points

J = {1,2,3,………..,j,…….,**68}** Set of candidate facility locations

Parameters :

w_i : weight of demand point which is covered by node i.

d_{ij} : distance between i and j.

P : number of facilities to be located to maximize covering.

D_G : Minimum average value for maintaining geographic constraint.

D_N : Minimum average value for maintaining population constraint.

D_K : Minimum average value for maintaining proximity to provinces constraint.

D_T : Minimum average value for maintaining ease of transportation constraint.

D_S : Minimum average value for maintaining social and economic attribute constraint.

G_J : Geographic value for candidate point j.

N_J : Population density value for candidate point j.

K_J : Proximity to provinces value for candidate point j.

T_J : Ease of transportation value for candidate point j.

S_J : Social and economic attribute value for candidate point j.

Decision Variables :

$$Z_i = \begin{cases} 1, \text{ if demand point i is covered by a candidate point.} \\ 0, \text{ otherwise.} \end{cases}$$

$$X_j = \begin{cases} 1, \text{ if a facility is located at candidate point j.} \\ 0, \text{ otherwise.} \end{cases}$$

$Q_i = \left\{ j \in J : d_{ij} \leq g \right\} \; \forall \; i \in I$ (Group of demand points which are covered by the facility located at point i.) (γ : Max. service distance limit for LSCCs)

Constraints :

$$\sum_{j=1}^{68} X_j \leq P \tag{1}$$

Constraint (1) bounds the maximum number of facilities to be located.

$$\sum_{j=1}^{68} G_j . X_j \geq D_G \sum_{j=1}^{68} X_j \tag{2}$$

Constraint (2) assures that the average geographic attribute criteria value for each candidate point is greater than the minimum average geographic value of all candidates.

$$\sum_{j=1}^{68} N_j . X_j \geq D_N \sum_{j=1}^{68} X_j \tag{3}$$

Constraint (3) assures that the average population density criteria value for each candidate point is greater than the minimum average value of all candidates.

$$\sum_{j=1}^{68} K_j . X_j \geq D_K \sum_{j=1}^{68} X_j \tag{4}$$

Constraint (4) assures that the average proximity to provinces criteria value for each candidate point is greater than the minimum average value of all candidates.

$$\sum_{j=1}^{68} T_j . X_j \geq D_T \sum_{j=1}^{68} X_j \qquad (5)$$

Constraint (5) assures that the average transportation easiness criteria value for each candidate point is greater than the minimum average value of all candidates.

$$\sum_{j=1}^{68} S_j . X_j \geq D_S \sum_{j=1}^{68} X_j \qquad (6)$$

Constraint (6) assures that the average social and economic attribute criteria value for each candidate point is greater than the minimum average value of all candidates.

$$Z_i \leq \sum_{j \in Q_i} X_j \qquad \forall \text{ i} \in \text{I} \qquad (7)$$

Constraint (7) indicates the demand point which is covered by any facility in an acceptable service distance. It means that if a facility is located in the covering distance of a demand point i , than this demand point i will be accepted as covered otherwise not.

$$X_j \in \{0,1\} \qquad \forall \text{ j} \qquad (8)$$

$$Z_i \in \{0,1\} \qquad \forall \text{ i} \qquad (9)$$

Constraint (8) and (9) assures the decision variables for the candidate and demand points to be assigned only (0/1) binary values respectively.

Objective Function :

$$\text{Maximize} \quad \sum_{i=1}^{43} w_i . Z_i \qquad (0)$$

At the objective function (0) ; Since the decision variable w_i indicates the importance degree (weights) of the demand points, It is desired to maximize the coverage of the region while considering whether the demand points are covered or not in a range of certain distances.

Statistics for the models and their solutions :

For scenario 1 ;

Total number of 0/1 variables	: 111
Total number of constraints	: 167
Number of Nonzero entries of the constraint matrix	: 934
Number of Iterations	: 2364
Number of Branches	: 28

For scenario 2 ;

Total number of 0/1 variables	: 113
Total number of constraints	: 174
Number of Nonzero entries of the constraint matrix	: 945
Number of Iterations	: 2693
Number of Branches	: 73

3.3. Experimentation

Damage creating earthquakes did not occur near to Ankara in the near history. However, the city was affected at the important degree from Bolu-Gerede (1944) earthquake that was occurred by North Anatolian Fault Zone (NAFZ) and Kirsehir (1938) earthquake occurred by Kirsehir Fault.

Nevertheless, it seems that Ankara will be affected much more from a future earthquake with similar magnitude. Ankara is growing and expanding every year but especially in recent years. Greater part of metropolitan Ankara settled on soft soils like river and lake sediments and deep alluvial valleys.

Potential earthquake source zones for Ankara are NAFZ and some lineaments and linear structures determined by use of Remote Sensing and Imaging techniques.

Two scenarios are considered which are based on the possible earthquake source zones; NAFZ and Kirsehir Fault zone respectively. The estimations of the expected horizantal peak ground acceleration, seismic intensity and building damage for Ankara City due to a probable future earthquake that may occur at the vicinity of Ankara are gathered from the master thesis of a jeology engineer [33].

Weights of the demand points and the regional characteristic values of the candidate sites are determined due to the ground inspections and damage estimations made by the military personnel and the earthquake specialists.

In each scenario, demand points are assigned weights at first but later they are taken as equally weighted. The model is seen to reach different results in each situation.

While determining the weights of the demand points, earthquake damage estimations made by the specialists due to a probable future earthquake are taken into consideration.

In the model, it is assumed that LSCCs are not licenced to response the demands which are out of their own responsibility region. Therefore, 0/1 integer variables are used in the model. By this way, it is assured that logistic demands occurred at any point in the disaster region are responsed by only one LSCC.

For each scenario, we begin to solve the model by locating at least five LSCC in the region, and then this number is increased one by one until reaching %100 coverage.

Therefore, we tried to determine the least number of LSCCs with a maximum responsibility region. Then, the solutions of the scenarios are compared to eachother.

Finally, altering the parameters of the problem, the model is resolved and changes in the results are analysed.

3.4. Results

After reaching the optimal solution of a mathematical model of a problem, it is necessary to do the sensitivity analysis that aims at inspecting the effects of the probable changes of the model parameters over the solution.

In linear programming problems, this analysis can be easily done. However, in integer programming models like this study, sensitivity analysis over the solution is not that straightforward. For this reason, for this type of models, it is essential to resolve the problem and compare the results while changing the model parameters again and again.

In this study, the solutions of the developed model are analyzed due to two distinct earthquake scenarios. Furthermore, the solutions gotten for each scenario by altering the problem parameters (covering distance, number of LSCCs to be located, sites of the selected candidate points and the regional characteristic standarts) are compared to each other.

Scenarios are developed due to the building damage estimations made by the earthquake specialists after a probable future earthquake occurred in the region. In each scenario, we aimed to determine the least necessary number and the most appropriate locations of LSCCs which provide to respond the most possible number of demands in a proper time horizon.

The model developed for this study is solved by LINGO. The LINGO code is shown in APPENDIX-C.

3.4.1. Solutions of the Scenario 1

Scenario 1 is done for the probable earthquake of 7.5 magnitude which occurs at the nearest site of North Anatolian Fault Zone. The damage estimation for each town of the disaster region is done by Ergünay and Gülkan [32] using the ratios based on the statistics obtained from the earthquakes occurred in recent years.

The candidate and demand points selected for scenario 1 is in the Figure-3 and Figure-4 respectively.

In scenario 1, we begin to solve the model for 5 LSCCs located in the region and then it is tried to reach the maximum %100 coverage while increasing the number of facilities to be located one by one.

It is seen that maximum %98 coverage is determined by locating 10 LSCCs in the region. Furthermore, By the military decision-makers, it is accepted that a coverage of %90 or more is satisfactory for the logistic supply purposes.

STUDY REGION

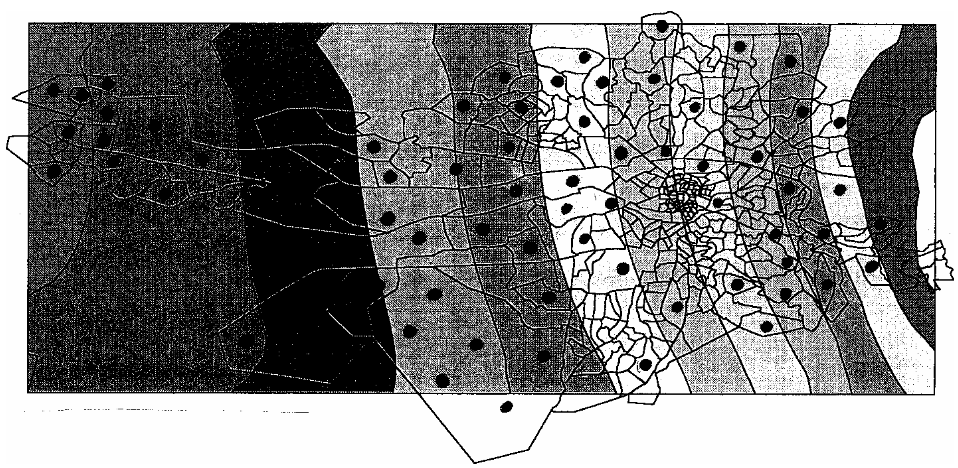

Figure-3 : Candidate points selected for scenario 1

STUDY REGION

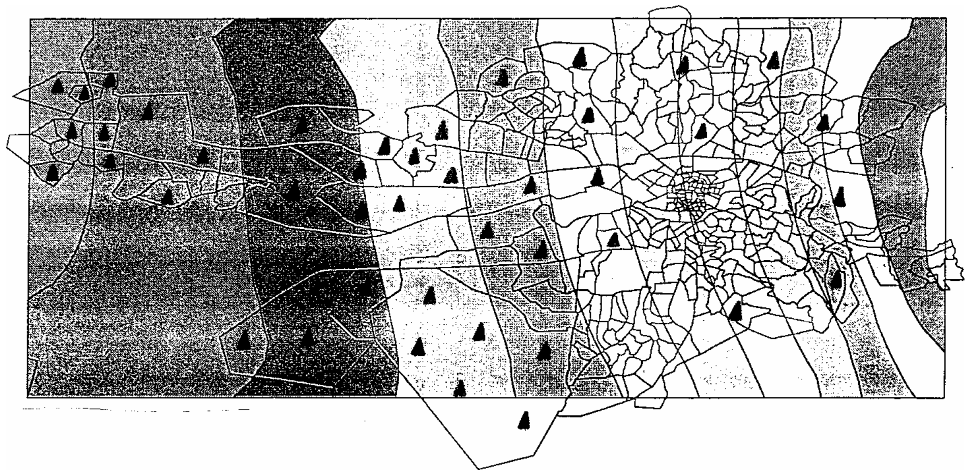

Figure-4 : Demand Points Selected for scenario 1

In Table-3 and Table-4, we show the weighted and equally weighted results of earthquake scenario 1 respectively.

Facility number	Selected Candidate Points (X)	Number of Demand Points Covered	Coverage Rate (%)
5	26, 32, 52, 53, 61	28	65,5
6	7, 26, 37, 52, 53, 61	33	76,7
7	15, 26, 37, 41, 51, 53, 61	36	83,7
8	9, 15, 26, 37, 51, 52, 53, 61	38	88,3
9	15, 26, 37, 41, 51, 52, 53, 61, 62	40	93,1
10	**9, 15, 26, 37, 41, 51, 52, 53, 61, 62**	**42**	**98**

Table-3: Solution of scenario 1 (Equally weighted)

Facility number	Selected Candidate Points (X)	Number of Demand Points Covered	Coverage Rate (%)
5	15, 37, 51, 57, 61	28	65,5
6	9, 15, 26, 37, 41, 61	32	76,7
7	26, 33, 37, 51, 53, 57, 63	35	83,7
8	15, 26, 37, 51, 52, 53, 57, 59	38	88,3
9	37, 39, 43, 47, 53, 57, 61, 62, 63	40	93,1
10	**15, 37, 43, 47, 52, 57, 59, 60, 61, 63**	**42**	**98**

Table-4: Solution of scenario 1 (Weighted)

3.4.2. Solutions of the Scenario 2

Scenario 2 is done for the probable earthquake of 6,0 magnitude occurring at the fault zone that is 23 km away from the east of Ankara. The damage estimation for each town of the disaster region is again done by Ergünay and Gülkan [32] using the ratios based on the earthquakes occurred in recent years.

The candidate and demand points selected for scenario 2 is in the Figure-5 and Figure-6 respectively.

In scenario 2, we also begin to solve the model for 5 LSCCs located in the region firstly and then we tried to reach the maximum coverage while increasing the number of facilities to be located one by one.

It is seen that maximum %95 coverage is determined by locating 12 LSCCs in the region. Furthermore, by the military decision-makers, it is accepted that a coverage of %90 or more is satisfactory for the lojistic supply needes.

STUDY REGION

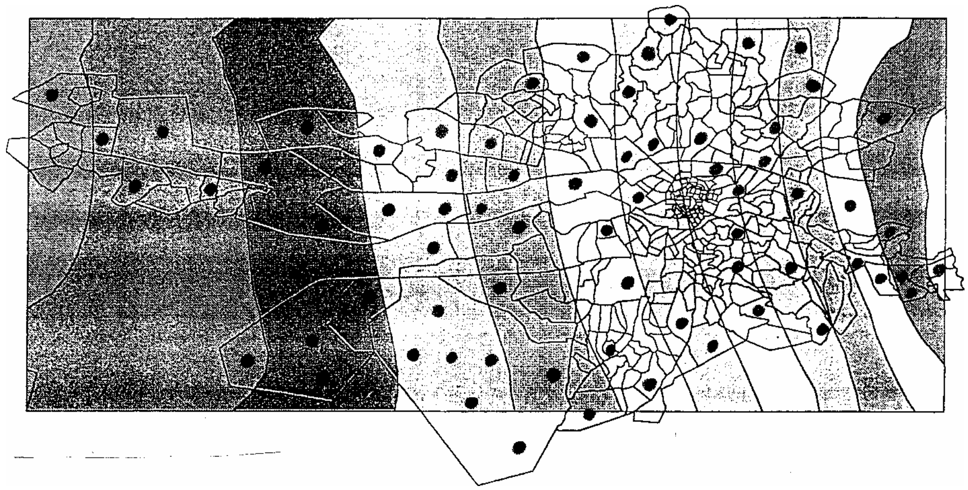

Figure-5 : Candidate points selected for scenario 2

STUDY REGION

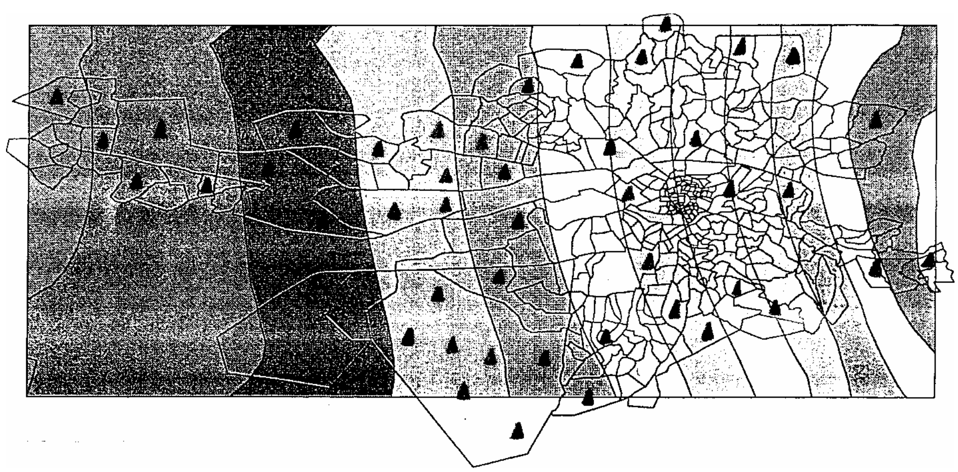

Figure-6 : Demand points selected for scenario 2

In Table-5 and Table-6, we show the weighted and equally weighted results of earthquake scenario 2 respectively.

Facility number	Selected Candidate Points (X)	Number of Demand Points Covered	Coverage Rate (%)
5	26, 32, 41, 51, 53	24	55,8
6	7, 15, 19, 26, 37, 41	29	67,4
7	15, 26, 37, 41, 51, 53, 61	33	76,7
8	9, 15, 28, 39, 51, 52, 53, 61	35	81,3
9	15, 26, 33, 43, 53, 57, 59, 61, 62	38	88,3
10	7, 9, 19, 24, 37, 41, 44, 47, 49, 52	39	90,6
11	9, 15, 28, 39, 43, 53, 57, 59, 61, 62, 63	40	93,0
12	**9, 15, 26, 37, 41, 51, 52, 53, 57, 59, 61, 62**	**41**	**95,3**

Table-5: Solution of scenario 2 (Equally weighted)

Facility number	Selected Candidate Points (X)	Number of Demand Points Covered	Coverage Rate (%)
5	7, 15, 19, 26, 37	23	53,4
6	26, 32, 41, 51, 53, 57	28	65,1
7	9, 15, 28, 39, 51, 52, 53	34	79,0
8	26, 37, 43, 49, 53, 61, 63, 65	36	83,7
9	15, 28, 39, 43, 53, 57, 59, 61, 62	38	88,3
10	7, 15, 19, 34, 37, 41, 43, 47, 51, 52	39	90,6
11	15, 23, 33, 41, 53, 57, 59, 61, 62, 63	40	93,0
12	**9, 15, 26, 33, 37, 42, 47, 51, 52, 53, 61, 62**	**41**	**95,3**

Table-6: Solution of scenario 2 (Weighted)

Comparing to each other, it is seen that the objective function value and the covering rates of solutions for each scenario are changing.

In scenario 1, adding each extra facility provides a higher increase than in scenario 2 for both weighted and equally weighted values.

In Figure-7 and Figure-8, it is obvious that as the facility number increases, coverage rates change due to the objective function value.

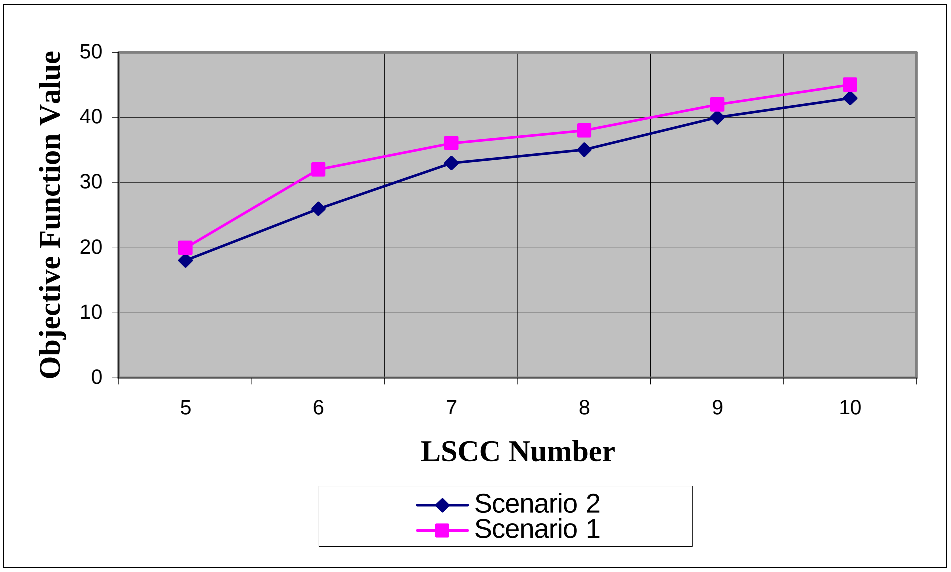

Figure-7: Coverage Rate (Equally weighted)

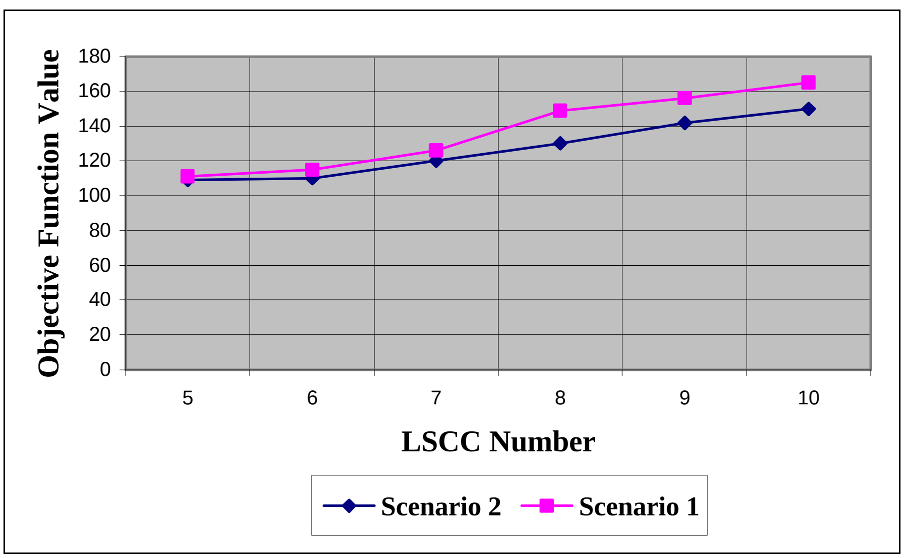

Figure-8: Coverage Rate (Weighted)

3.4.3. Analysis of the Local Characteristic Values

In this study, we aimed at providing the average of local characteristic value of each candidate point to be higher than those of 68 candidate points. If these standards of the regional characteristic values are increased to 4 which is higher than the average value, it is seen that the selected candidate points change while the coverage rates are same.

If these standards are increased more, providing that the number of LSCCs to be located are same, it cause serious decreases on the coverage rates. In this situation, in order to increase the covering rates, it is necessary to locate more number of LSCCs.

Furthermore, for each two scenario, it is observed that when the standards of the local characteristic values increase, the importance of the weights assigned to the demand points and the coverage for both the weighted and the equally weighted models decrease in the same manner, because of the reduction of the number of candidate points having high standards.

Also, especially in scenario 1, it is seen that the demand points can be covered by the alternative candidate points since the coverage configuration of the candidate points on the demand points is higher comparing to scenario 2.

After analyzing the regional characteristic values, it is evident that these values of the candidate points are important and affecting the solution.

In Figure-9 and Figure-10, for scenario 1 and scenario 2, we show how much the covering capabilities of %98 and %95 are affected by the changes in the local characteristic coefficient standards respectively.

While analyzing the scenario 1 and scenario 2, it is considered the maximum covering situations of %98 and %95 at which are located 10 and 12 LSCCs respectively.

Also, it is observed that if the candidate points which have higher local characteristic coefficient values are chosen for each scenario, the number of candidate points and the covering rates decrease as the standards increase. It is seen that if the candidate points occurring frequently are discarded from the solution, both the covering rates and the selected candidate points will change.

To sum up, considering the expected probable future earthquake scenario 1 and scenario 2, the model gives the optimal solutions when locating 10 and 12 LSCCs at the selected candidate points in the region respectively.

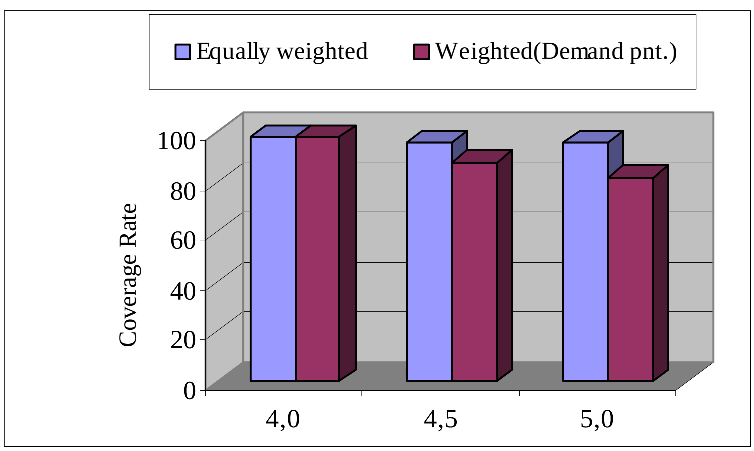

Figure-9: Standards and Coverage Rate for scenario 1

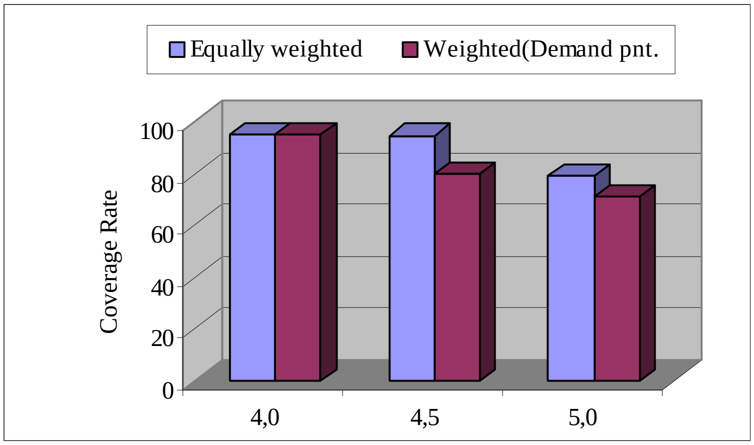

Figure-10: Standards and Coverage Rate for scenario 2

CHAPTER 4

CONCLUSION AND RECOMMENDATIONS

This research aims at finding the optimum location of Military Logistic Supply Coordination Centers (LSCC) that are established by Turkish Land Forces for gathering and distributing the logistic supply materials among citizens in an area of a county damaged by a natural disaster, i.e. earthquake.

It is obvious that each part of any area will have different earthquake damage hazard and importance degrees due to the ground characteristics, proximity to cities and roads, population density, geographic and transportation attributes etc.

So, the model developed for this study may be appropriate and succesful for any earthquake region by using the same approach.

In scenario 1, it is seen that maximum %98 coverage is determined by locating 10 LSCCs in the region.

In scenario 2, it is seen that maximum %95 coverage is determined by locating 12 LSCCs in the region.

Furthermore, by the military decision-makers, it is accepted that a coverage of %90 or more is satisfactory for the lojistic supply needes.

The effectiveness and the feasibility of this model depends on reflecting the real situations as much as possible in a correct manner. Therefore, especially, while determining the regional characteristic values of the candidate points, it is not only essentially important to take into consideration the point of view of the military personnel working in the region and the earthquake specialists but also to make a comprehensive ground inspection.

The advantages of this type of mathematical models can be stated as follows ;

a. **Scientific Decision Support :** The results gotten from the solution of the models can be used as a decision support for determining the locations, numbers and the responsibility regions of LSCCs. For instance, the mathematical confirmation of the location sites of LSCCs considered by the decision-maker provides a notable support in this kind of decision-making environments.

b. **Effective Usage of LSCCs :** The aim of the linear and the integer programming models is to ensure using the sources in hand effectively. Therefore, after an earthquake disaster in a region, the usage of LSCCs effectively by the army lojistic units is inevitably one of the most critical subjects to be taken into consideration.

c. **Flexibility :** Another property of the mathematical models is to be easily adaptable to the changing conditions. After establishing a model which represents the problem correctly, the representation of location of LSCCs in a different disaster region can be provided by making proper changes on the model.

4.1. Future Research Topics

Another point of view of the problem can be determining the response times of LSCCs due to the urgency of the demands and maximizing the number of requests to be responsed in the least time horizon by considering the objective function “Maximin” for the problem.

After locating LSCCs and evaluating their response regions, it can be determined by a shortest path algorithm that which demand point has to be assigned to which service center point in the disaster region.

Also, getting the optimal solution, the feasibility of the model can be proved and the solution can be tested by a simulation application.

Furthermore, selecting the candidate points on the road networks can provide establishing a reasonable group of candidates and using a different location model for the problem.

Although this study is limited to modeling and solving the problem in Ankara Metropolitan City, the same approach can easily be applied for the other cities or countries after facing a natural disaster like earthquake. This approach can be expanded for more complex scenarios by using different assumptions and more parameters.

In this study, the developed 0/1 integer programming model is solved by LINGO software at a computer (INTEL PENTIUM III, CPU 650 Mhz.) in 15 seconds. For larger problems, it may take very long time or can not reach to the solution. In this condition, it may be better to use heuristic techniques.

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Appendix

APPENDIX-A

LOCAL CHARACTERISTIC COEFFICIENTS OF THE CANDIDATE POINTS

Candidate Points	***Geog. Attribute***	***Population Density***	***Proximity to Province***	***Transport. Comfort***	***Social and Economic Attribute***
X(1)	1	3	1	3	2
X(2)	1	1	4	3	2
X(3)	2	1	4	4	3
X(4)	3	2	5	5	4
X(5)	1	1	4	4	5
X(6)	4	2	1	3	3
X(7)	4	1	2	1	2
X(8)	5	3	3	1	1
X(9)	4	4	3	2	1
X(10)	1	5	4	1	2
X(11)	2	4	5	2	2
X(12)	3	3	4	1	3
X(13)	3	2	3	3	4
X(14)	4	4	1	4	3
X(15)	5	5	5	5	2
X(16)	4	4	4	4	1
X(17)	3	3	3	3	2
X(18)	1	2	1	2	1
X(19)	1	3	4	1	1
X(20)	2	4	3	1	2
X(21)	1	5	2	2	3
X(22)	2	4	1	1	1
X(23)	1	3	2	1	1
X(24)	3	2	1	1	3
X(25)	4	1	1	1	4
X(26)	5	1	2	2	5
X(27)	4	2	3	2	4
X(28)	3	1	1	3	3
X(29)	2	1	3	4	2

X(30)	1	1	4	5	1
X(31)	1	1	5	3	1
X(32)	2	3	1	3	3
X(33)	1	2	3	2	3
X(34)	1	3	3	1	2
X(35)	1	4	2	1	1
X(36)	1	5	1	2	1
X(37)	2	3	4	2	2
X(38)	2	2	5	3	2
X(39)	3	1	3	4	3
X(40)	4	1	1	3	4
X(41)	5	2	3	2	3
X(42)	3	3	4	1	2
X(43)	2	2	5	2	1
X(44)	1	1	2	1	2
X(45)	1	1	3	1	1
X(46)	2	2	3	2	1
X(47)	2	2	1	3	2
X(48)	3	3	2	1	3
X(49)	4	3	2	3	1
X(50)	3	5	3	4	3
X(51)	2	2	2	5	4
X(52)	1	3	1	2	5
X(53)	2	3	2	3	2
X(54)	1	2	1	3	1
X(55)	1	1	1	1	1
X(56)	2	4	2	2	2
X(57)	3	5	3	3	3
X(58)	1	5	2	1	3
X(59)	3	2	3	1	4
X(60)	4	3	3	2	3
X(61)	5	3	2	2	2
X(62)	2	2	1	3	1
X(63)	3	1	4	2	2
X(64)	3	4	5	1	1
X(65)	2	5	2	2	1
X(66)	1	5	2	4	2
X(67)	4	2	3	3	3
X(68)	5	3	3	2	5
Average	3.95	3.82	3.35	3.45	3.65

APPENDIX-B

WEIGHTS OF THE DEMAND POINTS

Demand Points	*Weights*
Z(1)	5
Z(2)	4
Z(3)	5
Z(4)	5
Z(5)	4
Z(6)	5
Z(7)	3
Z(8)	2
Z(9)	3
Z(10)	4
Z(11)	3
Z(12)	4
Z(13)	3
Z(14)	4
Z(15)	5
Z(16)	3
Z(17)	4
Z(18)	4
Z(19)	5
Z(20)	3
Z(21)	5
Z(22)	4
Z(23)	4
Z(24)	3
Z(25)	4
Z(26)	4
Z(27)	5
Z(28)	4
Z(29)	5
Z(30)	5
Z(31)	5
Z(32)	4
Z(33)	5
Z(34)	5
Z(35)	4
Z(36)	4
Z(37)	5
Z(38)	5
Z(39)	5
Z(40)	4
Z(41)	4
Z(42)	3
Z(43)	4

APPENDIX-C

LINGO CODE OF THE MATHEMATICAL MODEL

```
MODEL:
SETS:
ADAY / 1..68 / : X,GEO,NUF,YER,ULS,SOS;
ISTEK / 1..43 / : Z,AGR;
MATRIX (ISTEK,ADAY):COEFF1;
ENDSETS
MAX = @SUM (ISTEK(I):(Z(I))*AGR(I));
P=@SUM (ADAY(K):X(K));
P<=10;
@FOR(ADAY (J):
X(J)<=1);
@FOR(ISTEK(I):
Z<=1);
@FOR(ISTEK(J):
@SUM(ADAY(P):COEFF1(J,P)*X(P))>=Z(J));
C=@SUM (ADAY(C):X(C)*GEO(C));
C>3.95*P;
N=@SUM (ADAY(N):X(N)*NUF(N));
N>3.82*P;
Y=@SUM (ADAY(Y):X(Y)*YER(Y));
Y>3.35*P;
U=@SUM (ADAY(U):X(U)*ULS(U));
U>3.35*P;
S=@SUM (ADAY(S):X(S)*SOS(S));
S>3.65*P;
@FOR( ADAY( I): @BIN( X));
@FOR( ISTEK( J): @BIN( Z));
DATA:
COEFF1= !Z1; 0 0 0 0 0 0 1 1 0 0 0 0 1 0 1 1 1 0 0 0 1 1 1 1 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0
!Z2; 1 0 0 1 1 0 1 1 1 1 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0
!Z3; 1 1 1 1 1 1 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0
!Z4; 1 1 1 1 1 1 1 1 0 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0
!Z5; 1 1 1 1 1 1 1 0 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0
!Z6; 1 1 1 1 1 1 0 0 0 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0
!Z7; 0 0 0 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0
!Z8; 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0
```

```
!Z9; 0 0 0 0 0 0 0 1 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0
!Z10; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 0 1 1 1 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0
!Z11; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0
!Z12; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0
!Z13; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 0
1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0
!Z14; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 1 1 0 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0
!Z15; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 1 1 0 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0
!Z16; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 1 1 0 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0
!Z17; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 1 1 1 0 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0
!Z18; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 1 1 1 1 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0
!Z19; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0
!Z20; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 1 1 1 1 1 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0
!Z21; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 0
0 0 0 0 0 0 0 0 0 1 1 0 0 1 1 1 1 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0
!Z22; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0
!Z23; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0
0 0 0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0
!Z24; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0
0 0 0 0 0 1 0 0 1 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0
!Z25; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0
0 0 1 1 1 1 1 0 1 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0
!Z26; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 1 1 0 1 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0
!Z27; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 1 0 0 0 1 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0
```

```
!Z28; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 1 1 1 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0
!Z29; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 1 0 0 0 0 0 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0
!Z30; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 1 1 0 1 1 1 1 1 0 1 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0
!Z31; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 0 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0
!Z32; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 1 1 1 1 1 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0
!Z33; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0
0 0 0 0 0 0 0
!Z34; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0
0 0 0 1 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0
!Z35; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 1 1 1 1 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0
!Z36; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 1 1 1 0 1 1 0 0 0 0 0 0 0
0 0 0 0 0 0 0
!Z37; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 1 1 0 0 0 0 0
0 0 0 0 0 0 0
!Z38; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 0 1 1 1 1 0 0 0 0
0 0 0 0 0 0 0
!Z39; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 1 1 1 0
0 0 0 0 0 0 0
!Z40; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 1 0 0 0 0 1 1
0 0 0 0 0 0 0
!Z41; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
1 1 1 0 0 0 0
!Z42; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1
1 1 1 1 1 0 0
!Z43; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1
1 1 1 1 1 1 0;
GEO= 1 1 2 3 1 4 4 5 4 1 2 3 3 4 5 4 3 1 1 2 1 2 1 3 4 5 4 3 2
1 1 2 1 1 1 1 2 2 3 4 5 3 2 1 4 1 1 2 2 1 3 5 4 4 3 2 1 1 2 3 4
3 2 1 1 3 4 5;
NUF= 1 1 1 2 2 1 2 1 3 4 1 2 1 2 3 2 2 3 1 2 1 2 3 2 1 3 4 4 5
5 4 3 4 5 4 5 4 4 5 3 2 1 2 2 1 2 2 1 3 2 5 4 5 3 4 5 4 4 3 4 5
5 4 5 3 4 3 4;
YER= 5 4 4 3 2 3 4 4 5 5 5 4 4 3 2 3 4 3 4 4 5 4 4 5 4 4 4 3 5
5 4 5 4 4 5 4 4 3 4 4 3 4 4 4 3 4 4 5 4 3 5 4 5 5 4 4 5 4 4 5 5
5 4 5 4 4 4 3;
```

```
ULS= 3 4 4 3 4 4 4 5 4 5 3 2 2 2 3 4 4 3 4 3 4 5 5 4 5 5 4 5 4
5 4 4 3 5 4 4 3 4 3 3 4 3 4 3 4 4 4 3 4 3 5 5 4 5 5 5 4 5 5 5 4
5 4 4 5 4 3 3;
SOS= 2 2 1 2 1 2 3 2 3 2 3 2 2 2 1 3 3 2 3 2 3 4 4 5 4 5 4 5 4
5 4 5 4 4 3 3 3 2 3 2 3 4 3 3 3 4 4 5 5 5 5 4 5 4 5 4 5 4 5 4 4
4 5 5 4 3 2 1;
AGR= 5 4 5 5 4 5 3 2 3 4 3 4 3 4 5 3 4 4 5 3 5 4 4 3 4 4 5 5 5
5 5 4 5 5 4 4 5 5 5 4 4 3 4;
ENDDATA
END
```