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MODELLING OF REPAIR AND MAINTENANCE FACILITIES LOCATION: AN APPLICATION IN GENDARMERIE SIGNAL CORPS

By

Tamer ERDOĞDU

Supervisor

Asst. Prof. Dr. Varol GÜNYAŞAR

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Tamer ERDOĞDU

Approved by:

Asst. Prof. Dr. Varol GÜNYAŞAR ....
(Supervisor)

Asst. Prof. Dr. Mehmet YAHYAGİL ....

Asst. Prof. Dr. Atilla ÖNER ....

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LIST OF SYMBOLS

R_{ij}	Total repair cycle time between node *i* and *j*,
W_{ij}	Risk of being non-functional of devices at site *i*,
i,I	Index and set of intermediate repair centers,
j,J	Index and set of nominee facility nodes of depot repair centers,
r_i	Mean inspection time of node *i*,
r_j	Mean inspection and repair time of node *j*,
t_{ij}	Transportation time from node *i* to node *j*,
k_i	Mean number of incidents of node *i* (regional risk coefficient),
h_i	Mean faulty devices at node *i*,
f_i	Total number of devices at node *i*,
d_{ij}	Distance between node *i* and node *j*,
X_j	The zero-one decision variables for the location of a depot repair center (DRC) at candidate site *j*
Y_{ij}	The zero-one decision variables for the allocation of demand at intermediate repair center *i* (IRC) to the DRC located at candidate site *j*
P	The number of depot repair centers to locate

LIST OF ABBREVIATIONS

GCoG	General Command of Gendarmerie
GSC	Gendarmerie Signal Corps
SC	Signal Corps
EOM	Echelon of Maintenance
O-level	Organizational level
I-level	Intermediate level
D-level	Depot level
FCD	Faulty Communication Device
FHHR	Faulty Hand Held Radio
RCT	Repair Cycle Time
SRO	Service Request Order
RD	Refusal Document
NMC	Not Mission Capable
RFI	Ready for Issue
VM	Velocity Management
DM	Decision Maker
MOP	Multiobjective Programming
UFLP	Uncapacitated facility location problem
CFLP	Capacitated facility location problem
MCLP	Maximum Covering Location Problem
MOFLO	Multiobjective Facility Location
DRC	Depot Repair Center
IRC	Intermediate Repair Center
GRC	Gendarmerie Regional Command

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ABSTRACT

The Gendarmerie Signal Corps, who wishes to provide a more effective and quick communication service to Gendarmerie forces, is paying a particular attention in the repair and maintenance of communication equipments and in the site selection of repair center where the Signal Corps executes repairing and maintenance activities. An effective and fast communication system might be possible with increasing the usability of devices, namely with servicing faulty devices in a short period of time.

The Gendarmerie Signal Corps is especially paying attention to depot and intermediate repair in order to repair communication equipments and get the equipments ready in the task field. Therefore, it has been proposed to develop a multiobjective programming model which considers the various objectives and criteria like the minimum transportation time and cost, intensity of equipment and short repair cycle time, as to generate solutions for selecting the location of depot repair center and allocating the intermediate repair centers to the depot repair center.

The objective of this thesis study is to develop a modelling approach that can be used by the Gendarmerie Signal Corps in determining the location of the depot repair center and allocating the intermediate repair centers with respect to this center, while decreasing the transportation time and cost with repair cycle time and increasing the usability of devices. Thus, the communication service which is the responsibility of the Gendarmerie Signal Corps would be performed in a more effective and faster way and also the operational readiness of the Gendarmerie forces would be increased.

When the model solved for one center to minimize the maximum distance, the distance is found 1073 km. Whereas, in the existing system this distance is 1410 km. However, one depot repair center is not enough for decreasing the transportation time or the distance to 600 km., the distance accepted by the private cargo companies as one day' s transportation distance. When the model solved for two center the maximum distance could be decreased to 628 km. However, the one day' s transportation distance cannot be achieved by two depot facilities. So the model was solved for numbers of Depot Repair Center and various transportation distances have been found.

ÖZET

Jandarma Birliklerine daha etkin ve hızlı bir muhabere hizmeti vermek isteyen Jandarma Muhabere Sınıfı, muhabere cihazlarının bakım onarımına ve bu bakım onarım faaliyetlerinin gerçekleştirildiği bakım onarım merkezlerinin yerlerinin seçimine ayrı bir önem vermektedir. Etkin ve hızlı bir muhabere sistemi cihazların kullanılabilirliğinin arttırılması ile, yani arızalı cihazların daha kısa sürede onarılarak hizmete sunulmasıyla mümkün olacaktır.

Jandarma Muhabere Sınıfı kısa sürede muhabere cihazlarının onarımını yapmak ve cihazları görev yerinde hazır edebilmek için özellikle depo ve orta seviye onarımlarına önem vermektedir. Burada, depo onarım merkezlerinin yerlerinin seçimine ve orta seviye onarım merkezlerinin depo onarım merkezlerine tahsisine yönelik olarak, minimum taşıma süresi ve maliyeti ile cihaz yoğunluğu ve kısa sürede onarım gibi çeşitli kriterleri dikkate alan bir Çok Amaçlı Programlama Modeli önerilmektedir.

Bu tez çalışmasının amacı; Jandarma Muhabere Sınıfı için depo onarım merkezlerinin yerlerinin belirlenmesinde ve orta seviye onarım merkezlerinin bu merkezlere tahsisinde kullanabilecek olan, özellikle taşıma süre ve maliyetleri ile onarım süresini azaltan ve cihazların kullanılabilirliğini arttırmayı hedefleyen bir modelleme yaklaşımı geliştirmektir. Böylelikle; Jandarma Muhabere sınıfı sorumlu olduğu muhabere hizmetini en etkin ve hızlı bir şekilde gerçekleştirebilecek ve Jandarma birliklerinin verimlilikleri arttırılabilecektir.

Model maksimum mesafeyi azaltmak için tek merkezli çözüldüğünde mesafe 1073km. bulunmuştur. Oysa, mevcut sistemde bu mesafe 1410 km.dir. Ancak tek depo onarım merkezi taşıma süresini veya mesafeyi 600km.ye indirebilmek için yeterli değildir. Bu mesafe özel kargo şirketlerince bir günlük taşıma mesafesi olarak kabul edilmektedir. Model iki merkezli çözüldüğünde maksimum mesafe 628km.ye kadar azaltılabilmektedir. Yine de bir günlük taşıma mesafesi iki depo tesisiyle de elde edilememiştir. Bundan dolayı model çok sayıda depo onarım merkezi için çözülmüş ve çeşitli taşıma mesafeleri bulunmuştur.

1. INTRODUCTION

1.1. General information about Gendarmerie

1.1.1. History of the Gendarmerie

When we look at the history of Turkish people, we will see that the government's administrative, juridical and security services were carried out by commanders. In Orhun Epitaphs, it is told that law enforcement officers called Yargan were managed by the kings and they carried out security services. "Gendarmerie" was called "Surta" in the State of Seljukian, in Ottoman Empire it was "Subaşı" and then it was called "Zaptiye".

Gendarmerie was reorganized according to administrative divisions of Turkey after the declaration of the Republic and Gendarmerie had its current legal statute by putting into force the Law no: 1706, dated 10 June 1930. In 1988, with the Law no: 3497 The Command of Land Forces started to protect the land borders. However, some parts of Iran and Syria borders and Iraq border are still under the control of General Command of Gendarmerie (GCoG).

> "Gendarmerie is an army of law devoted to the country, nation and republic with love and fidelity, being a model of modesty, self sacrifice and abnegation." Mustafa Kemal ATATÜRK.

1.1.2. Regions of Responsibility

In general, the duty and responsibility area of the Gendarmerie is outside of Police duty zone. These are the places located outside the municipal boundaries of the provinces and districts. The Gendarmerie is responsible for the performance of the safety and public order in above mentioned zones and in places having no police organizations. The 91 % of the Turkey's area is under the responsibility of The Gendarmerie.

1.1.3. Duties of the Gendarmerie

The Gendarmerie of the Republic of Turkey, which is responsible for the maintenance of safety and public order as well as carrying out other duties assigned by laws and regulation, is an armed security and law enforcement force, having military nature.

As a part of Turkish Armed Forces the General Command of Gendarmerie is subordinated to The General Staff in matters relating to training and education in connection with the Armed Forces, and to the Ministry of Interior in matters relating to the performance of the safety and public order duties. In accordance with Law No 2803, the duties of The Gendarmerie fall in four main points as administrative, judicial, military and other duties.
(http://www.jandarma.tsk.mil.tr/ing/genel/gorevi.htm)

1.1.4. Goals of the Gendarmerie

The Turkish Gendarmerie, together with its growing structure of force and modern equipment, makes effort to ensure interior security, determine damages, establish civil defense structures, ensure the security of the main domestic supply routes, establish and train hunter units and defend critical, strategic and economic facilities and establish a peaceful environment.

The General Command of Gendarmerie tries its best to fulfill its duties effectively through the innovations of technology, in order to:

a. Serve all over the country from patrols to the posts, from the district to provincial commands

b. Ensure wide-spread deployment and an effective command and control system

c. Increase the level of service standards

d. Reorganize the cadres in compliance with the true needs of service

e. Ensure the correct and timely fulfillment of administrative, judicial, military and the other duties

f. Establish an effective instructional and motivating control mechanism.

(http://www.jandarma.tsk.mil.tr/ing/genel/moder.htm)

1.2. Organizational Structure

The Organization of the General Command of Gendarmerie is composed of;

1. The General Command of Gendarmerie Headquarters and its attached units,
2. Internal Security Units,
    a. Gendarmerie Regional Commands,
    b. City Center and District Gendarmerie Commands,
3. Border Units,
4. Schools, Training and Educational Units
5. Administrative and Logistics Support Units, and other units established in accordance with the characteristics of the duties.

1.2.1. Logistics Support Units

The logistic support of Gendarme Units is provided by means of Gendarme Logistics Command. The various workshops under this command are producing the need of official dresses, whereas the plants are aimed at responding to the other needs, in addition to supporting the 5^{th} level of repair and maintenance. The materials acquired by the Gendarmerie Headquarters are being sent to the Gendarme Units by means of the transportation fleet under this command. (http://www.jandarma.tsk.mil.tr/ing/diger/lojistik.htm)

1.2.2. General Command of The Gendarmerie Headquarters

The General Command of the Gendarmerie Headquarters is the highest organ assisting to the General Commander of Gendarmerie for the command and conduct of Gendarmerie units. It controls all the public order events throughout Turkey, and the larger units are charged by the Headquarters in parallel with the developing of the events.

The General Command of the Gendarmerie Headquarters has a sophisticated communication and computer network system with its subordinate units. These sophisticated communication systems are operated by the Gendarmerie Signal Corps, and its duty is not only to operate these systems but also repair and maintain the systems.

1.3. Gendarmerie Signal Corps

The ultimate goal of the Gendarmerie Signal Corps (GSC) is to maintain the highest communication readiness level for the General Command of Gendarmerie (GCoG) in order to defend public security and to guard the borders of its country. To maintain the communications of Gendarmerie forces, the Signal Corps (SC) depends on a supply and maintenance network composed of a main(primary) supply center, three maintenance levels (Depot, Intermediate and Organizational) and commercial manufacturers.

The primary supply center maintains an inventory of many items to support overhaul activities that consist of consumable spare parts, repairable components, subsystems, assemblies, equipment, general and special consumption materials and maintenance kits. The main supply center and other inventory control points maintain this inventory to satisfy the maintenance requirements of communication systems.

Signal Corps is one of the primary stanchions supporting the GCoG to maintain highest operation readiness. Its importance obliges high-tech communications systems including modern Radios, Computers, Switchboards and the related test equipments and reliable logistics support. The goal of GSC logistics support is to maintain the highest possible level of readiness, commonly expressed as operational availability.

There are two ways to increase operational availability. First, the reliability of the communication system can be increased, thereby improving the "mean time between maintenance". This option is normally fiscally constrained during the communication system's acquisition process, since the related budget does not allow the purchase of a more reliable communication system. Second, by reengineering the maintenance process, the SC can reduce the downtime related to repair time and administrative and logistics delays. This will save from infrastructure costs and communication system inventory costs in the long run.

Cycle time reduction in the gendarmerie logistics channel (repair depots, intermediate-level maintenance, inventory control points, and supply centers) causes a large number of communication equipments to be available on the fields, and also leads to significant savings in inventory costs.

1.3.1. Levels of Maintenance

The Signal Corps (SC) performs the maintenance activities in three levels: Organizational level (O-level) includes the 1^{st} and 2^{nd} Echelon Of Maintenance (EOM), Intermediate level (I-level) includes the 3^{rd} EOM for communication equipment only, and Depot level (D-level) includes the 5^{th} EOM, which is similar in structure to the multi-echelon logistics support systems of commercial firms.(Blanchard, 1998)

To achieve economies of scale in maintenance equipment and personnel, levels of maintenance are progressively more capable, with D-level being the most capable. Therefore, D-level repair and maintenance centers' location and the number of centers are very important issues that must be considered by managers and commanders.

1.3.1.1. Organizational level of Maintenance

This level of maintenance is composed of 1^{st} and 2^{nd} Echelon of Maintenance (EOM). The equipment operators perform 1^{st} EOM, which covers primarily Preventive Maintenance procedures (cleaning up, screwing etc.). 2^{nd} EOM is performed by the operating unit and includes maintenance that involves inspection and the replacement of modular components and requires technicians to perform only the disassembly of the equipment. They are deployed at city centers and District Gendarmerie Commands.

The redundancy of non-value added activities in the 2^{nd} EOM (e.g. inspections, quality control and transportation) has also increased Repair Cycle Time (RCT). Many 2^{nd} EOMs are very near to 3^{rd} EOMs and since we can't measure these processes, these are out of the scope of this research.

1.3.1.2. Intermediate level of Maintenance

This level of maintenance is composed of 3rd Echelon of Maintenance (EOM). 3rd EOM involves more difficult repairs and maintenance, including the repair and testing of modules that have failed at the O-level. 3rd echelon maintenance for communication equipment is done at 3rd echelon departments deployed at Gendarmerie Region Command level. This level of repair and maintenance is very important for Signal Corps.

Non-value added activities in the 3rd EOM (e.g. inspections, quality control and waiting for transportation) have increased RCT and in some districts the waiting time for transportation is very long. When a technician decides to send a faulty hand held radio (FHHR) to 5th EOM, he must wait some more FHHRs to accumulate, since many of the faulty communication devices (FCD) are transported by military cargo vehicles, military cargo plane and railroad. Due to the waiting time, overall RCT increases and sometimes one FHHR's repair time can take a couple of months. The private sector cargo vehicles are not commonly used in military. In this study, we suggest the use of private sector cargo transportation means especially for the unclassified FCDs like computers, switchboard cards, printers and some radio cards.

1.3.1.3. Depot level of Maintenance

This level of maintenance is composed of 5th Echelon of Maintenance (EOM). 5th EOM activities ensure the continued communication integrity. This involves performing maintenance beyond the capabilities of the lower levels, usually on equipment requiring major overhaul or rebuilding of end items, subassemblies, and parts. (Maintenance and Repair Directions)

The depot repair cycle begins when an unserviceable but D-level repairable equipment is turned into the O-level or I-level maintenance, and it ends when the item is recorded on the inventory control point records as being ready-for issue. Depot repair cycle time includes processing time, accumulation time, repair time, time awaiting for parts, and delivery time. Unserviceable items may remain in storage for extended times for various reasons.

The duration of the depot repair cycle is important to the SC for two reasons. First, timely depot repair of the failed radios is essential to maintain operational readiness and sustainability. For many repairable items, depot repair is the most responsive and least-costly option available to support the operating customers' requirements. Second, because of the high unit costs of radios, there is a significant inventory investment involved while the parts are being repaired within the depot repair cycle.

There exists only one depot repair center and the waiting time stated in 3rd EOM affects the depot repair cycle time, since the 3rd EOM accumulate FCDs and send in batches to the depot repair center at the same time.

1.3.2. Repair and Maintenance Period

In this study, the maintenance period is separated into two parts: Administrative Chores and Repair Cycle Time.

1.3.2.1. Administrative Chores

The system used to monitor communication equipment maintenance process is based on laborious paperwork. It requires the completion, coordination, and management of numerous hard copy documents. For example, if a hand held radio needs a repair, the Force Assets Accountant fills out an Service Request Order (SRO), which provides carbon backing to produce four copies and fills out a Refusal Document (RD), which provides carbon backing to produce three copies to send the FHHR to 2nd EOM. When the radio comes to 2nd EOM, it is controlled by a technician and waits for SRO and RD approval of Regiment Command. Sometimes this approval transactions take one or two days.

When all the inspections are finished, the FHHR waits until some more radios are collected in order to send in batches to upper echelon. Furthermore, in addition to the technician's daily duties of repairing radios or other communication systems, he is also responsible for collateral jobs. Most of these jobs are interrelated to daily operations of the shop. A good example is when a technician is assigned responsible for the Depot or Canteen. There are more transactions like these stated above in the current maintenance process and these delays increase the overall repair cycle time.

These non-value added activities and the laborious paperwork like others stated above could be solved by JNET. JNET is a computer network of gendarmerie, namely it is an intranet such that the maintenance personnel can do the strenuous paperwork by the help of this intranet so they can cut the time passed when doing the tiresome paperwork.

1.3.2.2. Repair Cycle Time

It is also important to explain the definition of repair cycle time (RCT). RCT extends from the time the radio system or component is first identified as "not mission capable" (NMC) until the time it is returned to the user or put back on the shelf as "ready for issue" (RFI). There are measurable and nonmeasurable time elements included in this definition. We cannot measure the time that elapses from when the operator identifies the equipment as NMC to the time the first job order is submitted. Nor can we measure the time spent at the organizational maintenance and supply level.

In this study, RCT is considered as the time that elapses between 3rd EOM and 5th EOM. So the RCT components are the following:

1. Time at the Intermediate Repair Center including:
    a. Time waiting for inspection in 3rd EOM,
    b. Time waiting for transportation to 5th EOM,
2. Transportation time to 5th EOM,
3. Time at the Depot Repair Center including:
    a. Time waiting for inspection approval at 5th EOM,
    b. Time waiting for a spare part to become available,
    c. Active maintenance time,
    d. Time waiting for transportation to 3rd EOM,
4. Transportation time to 3rd EOM.

Repair cycle time is very important for all the military parts, not only for SC. There exists many studies that have been made to reduce repair cycle time. Kang et al. (1998) described two simulation models for analyzing the repair processes of aircrafts in the navy, and suggested the ways to reduce cycle time and improve readiness.

The models illustrate the effects of material availability and process redesign on repair cycle time and work-in-process inventory levels for critical components. Their results indicate that the Navy could significantly reduce repair cycle times of the components by increasing inventory levels of relatively inexpensive repair parts and by slightly modifying current repair processes.

An important development that occurred in 1998 was the study conducted by RAND Arroyo Center. A new concept called as "Velocity Management" (VM) initiative was introduced to the military terminology. Through the VM, the Army is expected to work for adopting the best business practices to make its logistics processes operate faster, better and cheaper. The goal of VM is to improve the Army's ability to keep the equipments ready while reducing total support costs and enhancing mobility.

Alfredson and Verrijdt (1999) considered a two-echelon inventory system for service parts. To obtain high service levels at low cost, they allowed emergency supply options through lateral transshipments and direct deliveries, in addition to the normal supply of parts.

1.4. Outline of the Study

The rest of the thesis is organized as follows: Chapter 2 presents information about Multiobjective Programming Approach and Chapter 3 includes the literature review for Facility Location. The formulation and the results of a multiobjective programming model that has been developed for determining the best site for the Depot Repair Center is presented in Chapter 4. Chapter 5 includes the conclusions and recommendations.

2. MULTIOBJECTIVE PROGRAMMING APPROACH

2.1. Value of Multiobjective Approaches

Considering the growing complexity of today's decision processes, it is more and more essential to support decision makers. The key word here is "support": it is not about replacing the decision maker but it is about helping him/her to understand the problem, to identify the alternatives, to determine the relevant criteria involved and to use them to evaluate the alternatives. All of these aspects must be considered within the framework of a decision process (selecting the best alternative, ranking or classifying possible alternatives, etc.).

Methods for minimizing (or maximizing) a single objective has existed for a long time, but often they are of little practical use. The principle of multi-objective optimization is different from that in a single-objective optimization. In single-objective optimization, the goal is to find the best design solution, which corresponds to the minimum or maximum value of the objective function. On the contrary, in multi-objective optimization with conflicting objectives, there is no single optimal solution.

The interaction among different objectives gives rise to a set of compromised solutions, commonly known as the trade-off, nondominated, noninferior or Pareto-optimal solutions (Steuer, 1986). With the aid of multiple objective models, decision makers may grasp the conflicting nature and the trade-offs among the different objectives in order to select satisfactory compromise solutions.

Most real-life decision problems are multi-objective in nature; we always compare, rank, and order the object of our choice with respect to the criteria of choice. Multiple and conflicting objectives, for example, “minimize cost” and “maximize the quality of service” are the real stuff of the decision maker’s or manager’s daily concerns. Such problems are more complicated than the convenient assumptions of economics indicate. Improving achievement with respect to one objective can be accomplished only at the expense of another. (Zeleny, 1982)

Multiobjective programming (MOP) and planning represents a very useful generalization of more traditional, single-objective approaches to planning problems.

The consideration of many objectives in the planning process accomplishes three major improvements in problem solving. (Cohon, 1978)

1. MOP promotes more appropriate roles for the participants in the planning and decision-making process.
2. Models of a problem will be more realistic if many objectives are concerned.
3. When a multiobjective methodology is employed, a wider range of alternatives is usually identified.

MOP techniques have been applied to solve practical problems such as healthcare planning, production planning, transportation planning, traffic planning etc. Multiple objective problems are often hard even in the single objective case. For example, most vehicle routing problems are extensions of traveling salesperson problem which is already NP-hard. It is also worth mentioning that some combinatorial problems, which are easy in single objective case, turn hard when multiple objectives are considered. For example, the single objective shortest path problem is one of the simplest combinatorial problems while the corresponding multiple objective problem is NP-hard. (Serafini, 1987)

2.2. Planning Methodology for MOP

Multiobjective programming models can serve as a part of the planning process. Planning can be much more effective when models are the part of the methodology. A general methodology which consists of six steps for planning is displayed in Table 2.1. (Cohon, 1978)

Table 2.1.: Steps for a Planning Methodology

1. Identification and quantification of objectives
2. Definition of decision variables and constraints
3. Data collection
4. Generation and evaluation of alternatives
5. Selection of a preferred alternative
6. Implementation of the selected alternative

The methodology begins with the identification and quantification of objectives and definition of decision variables and constraints. That is, the determinants of what is important (the objectives), the controls which decision makers have available to them (the decision variables), and the limits on the range of the controls (the constraints) must be identified first in any planning exercise. If a mathematical model is to be used, then steps (1) and (2) correspond to model formulation.

After data are collected in step (3), alternatives that are feasible in terms of the constraints are generated and evaluated for their impact on the objectives. If a mathematical model is used, then generation and evaluation can be done in one step without a model this phase would require two steps.

In step (5), a preferred alternative is selected by decision makers through a political selection process. This can happen in several different ways, depending on the decision-making context: a single decision maker, such as the administrator of the U.S., may select an alternative; or a group of decision makers may select an alternative by consensus ;or a group of decision makers, such as a legislative body, may select through a voting mechanism.

In the final step of the methodology in Table 2.1, the chosen alternative is implemented. (Cohon,1978).

2.3. Formulation of the MOP Problem

Multiobjective programming deals with the optimization problems with two or more objective functions. The general multiobjective optimization problem with *n* decision variables, *m* constraints and *p* objectives is

$$\begin{aligned} \text{maximize } \mathbf{Z}(x_1, x_2, \ldots, x_n) &= [Z_1(x_1, x_2, \ldots, x_n), \\ &\quad Z_2(x_1, x_2, \ldots, x_n), \\ &\quad \ldots, Z_p(x_1, x_2, \ldots, x_n)] \\ \text{s.t. } g_i(x_1, x_2, \ldots, x_n) &\le 0, \quad i = 1,2,\ldots,m \\ x_j &\ge 0, \quad j = 1,2,\ldots,n \end{aligned}$$

where $\mathbf{Z}$ $(x_1, x_2, \ldots, x_n)$ is the multiobjective objective function and $Z_1(\ )$, $Z_2(\ ), \ldots Z_p(\ )$ are the *p* individual objective functions.(Cohon,1978)

A feasible solution to a multiobjective programming problem is non-inferior if there exist no other feasible solutions that will yield an improvement in one objective without causing a degradation in at least one other objective.

In single-objective problems, the optimal value of the objective function is unique. It allows the analyst and decision makers to restrict their attention to a single solution or a very small subset of solutions from among the much larger set of feasible solutions. But this notion of optimality must be dropped for multiobjective problems because a solution which maximizes one objective will not, in general, maximize any of the other objectives.

Non-inferior solution is the solution for which there exists no other feasible solution that will yield an improvement in one objective without causing a degradation in at least one other objective. *Best compromise solution* is the noninferior solution that is selected as the preferred alternative.

2.4. Categorization of MOP Techniques

The characteristics of the decision-making process which will be used in categorizing MOP methods are the information flows in the process and the decision making context. Information flows are important because they determine the role that the analyst must play in the planning process. The decision making context defines the goal of the analysis.

The analyst-decision maker or bottom-up information flow contains the results about the noninferior set or noninferior alternatives, their impacts on the objectives and the trade-offs among the objectives.

Techniques that incorporate preferences (preference-oriented methods) share the analytical goal of the generating methods, analysis of multiobjective problem without explicit consideration of the dynamics of the problem. Unlike the implicit treatment of preferences by the generating methods, however, preference-oriented methods require that decision makers articulate their preferences and pass that information on to the analyst.

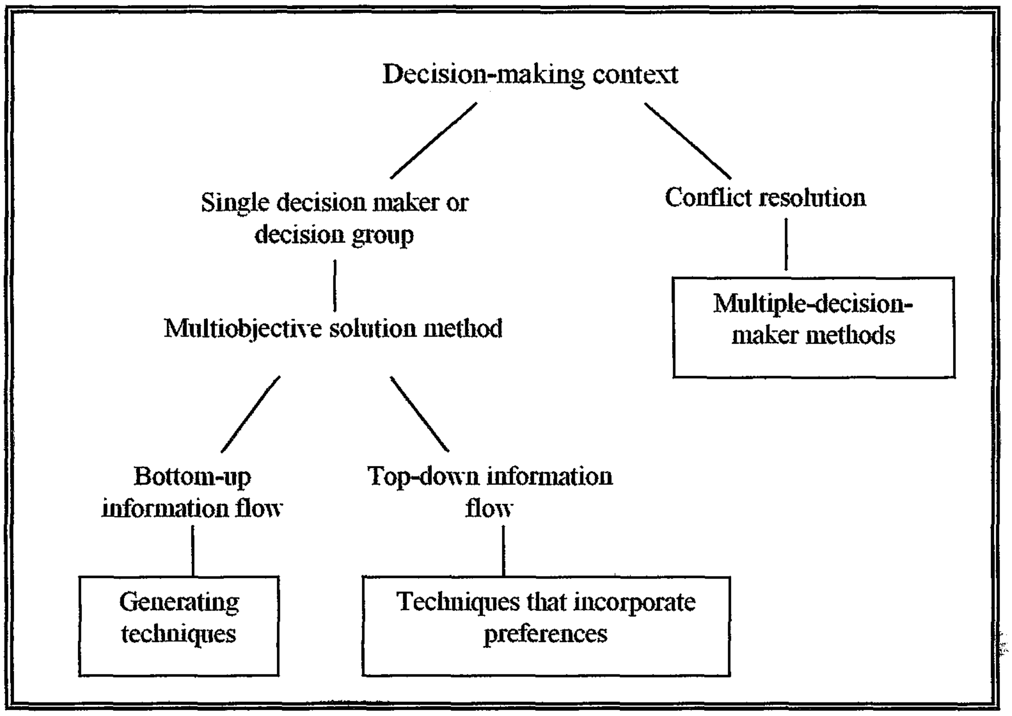

Figure 2.1.: Relationships between the categories of methods
(Source : Cohon, 1978, Multiobjective Programming and Planning, Academic Press, London)

The decision maker-analyst or top-down flow occurs when decision makers explicitly articulate preferences so that a best-compromise solution may be identified. There are many techniques that allow for only one of these types of information flows; some techniques (iterative methods) employ both types of flow during the solution process.

The range of analytical methods is segmented into three categories, depending on the decision-making setting for which they are best suited and on the information flows that their use requires. The categories are generating techniques, methods that incorporate preferences, and multiple-decision-maker methods. Figure 2.1 explains the relationships of the methods.(Cohon,1978)

2.5. Generating Techniques for Solving Multiobjective Problems

Generating techniques provide all of the information that one can extract from a multiobjective model and emphasized the development of information about a multiobjective problem that is presented to a decision maker in a manner that allows the range of choice and the tradeoffs among objectives to well understood.

This is accomplished without preference information from decision makers. In general, the generating techniques for solving multiobjective programming models can be classified into four categories: The weighting method, the constraint method, the non-inferior set estimation method, and the multiobjective simplex algorithm (Cohon, 1978).

2.5.1. The Weighting Method

This method is usually applied in situations when the decision maker provides his/her preference information before the problem is solved. Using the weighting method, the user can set two weights on the basis of his/her preference for two objective functions, then transfer the two objective functions into a weighted objective function.

The weighting method is generally used to approximate the non-inferior set; but it is not an efficient method for finding an exact representation of the non-inferior set. A number of different sets of weights are used until an adequate representation of the non-inferior set is obtained. Any sets of positive weights may be used in the weighting method but it makes sense to follow an orderly procedure.

First, objectives are optimized individually. After each objective is optimized individually, a systematic variation of the weights may be followed. That is, each weight may be varied from zero to some upper bound using a predetermined step size. The weighted problems solved for each new set of weights that is generated in this manner. Every non-inferior solution that is found with the weighting method requires the solution of a linear program. (Cohon, 1978)

The user can set the various weighting vectors, then solve for the optimal solution for each one. The optimal solution for a weighting vector is a non-dominated solution of the multiple objective problems. (Hwang and Masud, 1979)

2.5.2. The Constraint Method

The constraint method is perhaps the most intuitively appealing generating technique. It operates by optimizing one objective while all of the others are constrained to some value. For example: given a multiobjective problem with p objectives

$$\text{Maximize } \mathbf{Z}(x_1, x_2, x_3,\ldots\ldots,x_n)$$
$$= [Z_1(x1, x2, x3,\ldots\ldots,x_n), Z_2(x_1, x_2, x_3,\ldots\ldots,x_n)$$
$$,\ldots., Z_P(x_1, x_2, x_3,\ldots\ldots,x_n)] \qquad (2.1)$$
$$\text{s.t.} \quad (x_1, x_2, x_3,\ldots\ldots,x_n) \in F_d \qquad (2.2)$$

The form of the constrained problem is

$$\text{Maximize } Z_h(x_1, x_2, x_3,\ldots\ldots, x_n) \qquad (2.3)$$
$$\text{s.t.} \quad (x_1, x_2, x_3,\ldots\ldots,x_n) \in F_d \qquad (2.4)$$
$$Z_k(x_1, x_2, x_3,\ldots\ldots,x_n) \geq L_k$$
$$K = 1, 2,\ldots..,h-1, h+1,\ldots..p \qquad (2.5)$$

where the h^{th} objective was arbitrarily chosen for maximization. This formulation is a single-objective problem. The optimal solution to this problem is a noninferior solution to the original multiobjective problem if certain conditions are satisfied.

The condition that relates to our choice of the L^k is that all of the constraints on objectives should be binding at the optimal solution to the constrained problem. If this not the case and if there are alternative optima to the constrained problem, then some of these optimal solutions may be inferior alternatives for the original multiobjective problem. This situation is equivalent to the case of zero weights in the weighting method.

An algorithm for the application of the Constraint Method is stated below:

Step 1

a. Solve p individual maximization problems to find the optimal solution for each $x_k = (x_{1k}, x_{2k}, x_{3k},\ldots..,x_{nk})$. If there are alternative optima for any of these problems, then choose those solutions from among the alternative optima that are non-inferior.

b. Compute the value of each objective at each of the p optimal solutions: $Z_1(x_k)$, $Z_2(x_k)$,........, $Zp(x_k)$, k = 1,2,....,p. This gives us p values for each of the p objectives.

c. Array the p values of each of the p objectives in a table in which the rows correspond to x_1, x_2,......,x_p and the columns are labeled by the objectives as shown in the Table 2.2.

Table 2.2.: Payoff table for a Problem with p Objectives

	$Z_1(x^k)$ $Z_2(x^k)$ .... $Z_P(x^k)$
X^1	$Z_1(x^1)$ $Z_2(x^1)$ .... $Z_P(x^1)$
X^2	$Z_1(x^2)$ $Z_2(x^2)$ .... $Z_P(x^k)$
.	.
.	.
.	.
X^P	$Z_1(x^P)$ $Z_2(x^P)$ .... $Z_P(x^P)$

d. Find largest number in the k^{th} column; denote it by M_k. Find the smallest number in the k^{th} column; denote it by n_k. Do this for k =1, 2,...., p.

Step 2

Convert the multiobjective programming problem such as (2.1) and (2.2) to its corresponding constrained problem as in (2.3)-(2.5).

Step 3

The n_k and M_k from step 1 represent a range for objective k in the non-inferior set: $n_k \leq Z_k \leq M_k$. This range applies as well to L_k; the right hand side of the constraint on objective k. Choose the number of different values of L_k that will be used in the generation of non-inferior solutions. Call this r.

Step 4

Solve the constrained problem set up in step 2 for every combination of values for the L_k, k = 1, 2,......, h-1,h+1,.....,p, where

$$Lk = n_k + [t / (r-1)] (M_k - n_k), \quad t = 0, 1, 2,....,(r-1)$$

Since r values of each objective will be used in Step 4, there are r^{p-1} combinations of values of the L_k. Each of the r^{p-1} constrained problems that are feasible will yield a noninferior solution (if all the constraints are binding). These solutions are the desired approximation of the noninferior set.

The payoff table provides a systematic way for finding a range of values for each of the L_k. The approach is predicated on the belief that the optima for the p individual problems represent "endpoints" of the non-inferior set. This approach guarantees feasibility and non-inferiority of the constrained problem for two objectives. Higher dimensional problems will usually lead to some infeasible constrained problems.

In a problem with two objectives, Z_2 achieves its minimum in the non-inferior set at the solution that maximizes Z_1; a similar statement can be made for the minimum of Z_1 in the non-inferior set (Cohon, 1978).

2.5.3. The Noninferior Set Estimation Method

This method operates by finding a number of noninferior extreme points and evaluating the properties of the line segments between them.

The Noninferior Set Estimation Method algorithm begins by maximizing each objective individually, which yields two points in objective space. The slope of the line segment connecting these two points is used to compute weights for use in the weighted problem. When the new problem is solved, the resulting noninferior solution is used in the computation of the maximum possible error. The algorithm continues in this fashion until the maximum possible error in all parts of the noninferior set is less than or equal to the maximum allowable error (Cohon, 1978).

2.5.4. Multiobjective Simplex Method

The multiobjective simplex method can be used to generate an exact representation of the noninferior set. This is done by moving mathematically from one noninferior extreme point to adjacent noninferior extreme point until all noninferior extreme point have been found (Cohon, 1978).

Given an optimization problem with two or more objectives, multiobjective programming will give an *optimal trade-off* curve between those objectives. All points on this curve are optimal in the sense that it is not possible to improve one objective without worsening at least one other. After generation of the noninferior set the analyst may choose to pursue a structured or mathematical procedure for the articulation of preferences. It is sufficient in many applications simply to present the noninferior set and to explain the implications of the various alternatives.

Generation methods are particularly effective when the noninferior set exhibits a "kinked" shape, as in Figure 2.2. The best-compromise solution will usually be found in the vicinity of point B. On the parts of the curve a large amount of one objective must be sacrificed in order to gain relatively little of the other objective. For example, in going from B to A, $(Z_1^B - Z_1^A)$ of objective Z_1 is lost in order to gain only $(Z_2^A - Z_2^B)$ of objective Z_2 (Cohon, 1978).

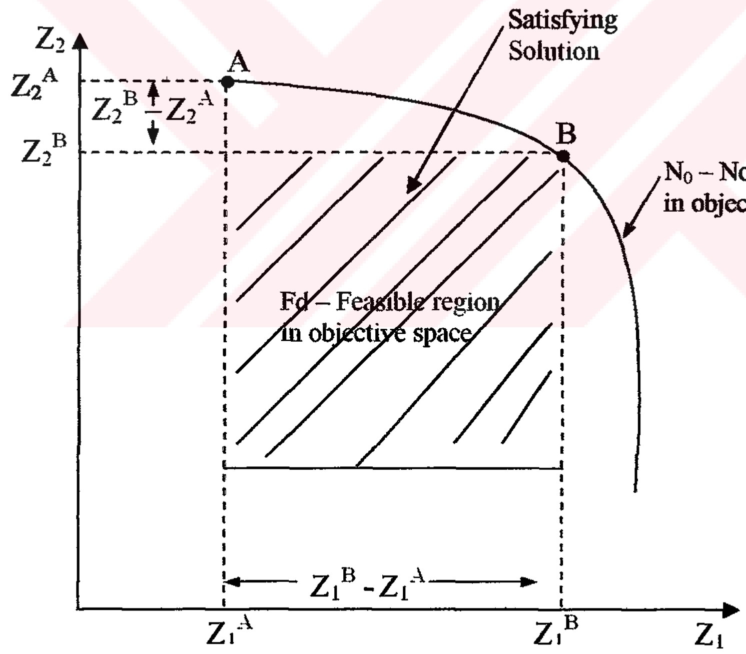

Figure 2.2.: A "kinked" noninferior set.
(Source : Cohon, 1978, Multiobjective Programming and Planning, Academic Press, London)

3. FACILITY LOCATION

An important strategical decision in today's decision processes is the selection of a location of a facility (a warehouse, a fire station, a dumping site etc.) such that some objective related to the distance to other known locations (customers, potential fire sites, cities) is minimized or maximized. To find realistic and efficiently solvable models including all the constraints in the real world problem is a big challenge.

3.1. Facility Location Problem

The location of facilities, where a facility can be any structure erected to manufacture, store, or distribute a product or provide service, is a common decision-making problem that is confronted by managers of wide range of activities.(Cohon,1978)
Basically, a location problem is characterized by four elements;

1. A set of locations where facilities may be built / opened. For every location, some information about the cost of building or opening a facility at that location is given.
2. A set of demand points (clients) that have to be assigned for service to some facilities. For every client, one receives some information regarding its demand and about the costs/profits incurred if he would be served by a certain facility.
3. A list of requirements to be met by the open facilities and by any assigment of demand points to these facilities.
4. A function that associates to each set of facilities the cost/profit incurred if one would open all the facilities in the set and would assign the demand points to them such that the requirements are satisfied. (Bumb, 2002)

Location models have been developed to answer questions such as; how many facilities to establish, where to locate them, and how to distribute the products to the customers in order to satisfy demand and minimize total cost. For excellent surveys of the related literature, see Meidan (1978), Krarup and Pruzan (1983), Aikens (1985) and Geoffrion et al. (1995). However, due to problem's complexity, very few papers consider dynamic, multi-echelon supply chain and multiobjective aspects.

Location problems encompass a wide range of problems such as the location of emergency services, location of hazardous materials, location of ATM bank machines, problems in telecommunication networks design, etc.

3.2. Types of Facility Location Problems

Most of the problems described in the facility location literature are concerned with finding a "desirable" facility location, where the goal is to minimize a distance function between the facility (service) and the sites (customers).

Just as important is the case of locating an "undesirable" or noxious facility. In this case instead of minimizing the largest distance between the facility and the destinations, we maximize the smallest distance (e.g. locating garbage dumps, dangerous chemical factories or nuclear power plants).

Facility location analysis has played a central role in the development of Operations Research. The factors to be considered in location problems can be classified as follows (Peters, 1999):

1. Number of facilities (single or multiple)
2. Capacitated or uncapacitated
3. Continuous or discrete location space
4. Distance metric
   a. Rectilinear
   b. Euclidean (provides a lower bound on distance)
   c. Actual distance
5. Objective criteria
   a. Single (usually total cost: fixed plus transportation)
   b. Multiple
6. Objective function
   a. Minisum
   b. Minimax

Another characteristic of the location problems is the variety in mathematical objectives, which can be listed as (Sule, 2001):

1. P-median problem
2. P-center problem
3. Uncapacitated facility location problem (UFLP)
4. Capacitated facility location problem (CFLP)
5. Quadratic assignment problem

The p-median problem has the objective of placing p facilities at p locations at minimum costs. The costs can be defined as value of time, money, distance, etc. This problem is also called minisum or Weber problem. The p-median problem is NP-hard. Many heuristics and exact methods have been proposed to solve it. Exact algorithms are provided by Beasley (1985) and Hanjoul and Peeters (1985), among others. The uncapacitated facility location problem (UFLP) has the same objective as the minisum problem, but the cost formula contains a fixed cost component, i.e. costs are related to the facilities themselves. Because the capacity of each facility is infinite, it is never optimal to allocate a specific demand to multiple facilities, and the capacitated facility location problem (CFLP) is the same as UFLP, except for the capacity constraint. The quadratic assignment problem defines problems where n facilities, such as n machines with their own production flow, at n locations at the same time have to be placed to minimize the costs (Harkness and ReVelle, 2003).

Location-allocation models simultaneously optimize facility locations and the allocations of demands to those locations. Solution techniques for location-allocation models have been formulated for problems represented in continuous and discrete space. Formulation in discrete space is based on a network which is made up of a series of node-link relationships. Links can be characterized as transportation routes, whereas nodes can represent route intersections, aggregate demand points and existing and potential facility locations. It has been demonstrated that many location-allocation problems have similar structure and that by editing the objective function coefficients, each can be derived from the well know p-median model. This forms the basis of location-allocation model.

P-median problem is considered as a classical normative location model. A set of linear constraints and a linear objective function describe the problem. By minimizing weighted distance, accessibility is maximized. As the weighted distance is minimized, so is the average distance that demand is away from the closest facility. The importance of location analysis has been growing rapidly over the last decades. This is due to increasing transportation costs and recent development of management science techniques that enable optimal solution of complex, realistic location models to be computed (Berman and Mandowsky, 1986)

3.2.1. Facility Location objectives

Two broad classes of facility location objectives can be distinguished. Much of the traditional location literature focuses on minimizing some function of the *average or total distance* between demand nodes and facilities to which they are assigned. The classic model in this class is the P-median problem stated above that seeks the location of P uncapacitated facilities to minimize the demand weighted total distance between the demand nodes and the nearest facility to each demand node. Distances are weighted by the demand at the nodes. Models that minimize the total or average distance are most appropriate for private sector facility location problems in which the total cost is often related directly to the total distance required to deliver the goods. (Sule, 2001)

A second class of location problems focuses on the *maximum distance* between any demand node and the facility to which the node is assigned. Such models are often referred to as covering models and the maximum distance is called the covering distance. The simplest of such models is the Set Covering Model (Toregas, et al., 1971) which seeks the location of the minimum number of facilities needed to cover all demand nodes within a specified coverage distance and Beasley and Chu (1996) applied in their genetic algorithms for covering problems. Batta (1989) presents a model to study the effect of using expected service time dependent queueing disciplines on optimal location of a single server. Some authors have criticized the fact that the repair process is modeled by an exponential distribution, as coefficient of variations of less than one are usually observed in reality (Diaz and Fu, 1997).

The set covering model fails to distinguish between large demand nodes and small demand nodes: all nodes simply have to be covered within the coverage distance. Often, the number of facilities needed to cover all demands within the specified distance is excessively large. In such cases, we can relax the requirement that all demands be covered within the coverage distance and locate a fixed number (P) of facilities to maximize the number of demands that are covered within the coverage distance. This is the Maximal Covering Problem (Church and ReVelle, 1974).

3.2.2. Maximal Covering Location Problem

This type of problem has been successfully cast as a discrete choice optimization problem and modelled as a linear integer program. In the Maximal Covering Location Problem (MCLP), the aim is to locate a fixed number (P) of facilities to maximize coverage of demand number. Coverage is defined as : Point i is said to be covered if there is a facility located within S miles of i, where S is the maximum service distance (Cohon,1978).

In the general statement of the MCLP there are two sets of points:

I is the set of all demand points;

J is the set of all potential facility locations;

The two sets may overlap partially or completely; i.e., points in the network may be both demand and potential facility points. We define x_j as a 0-1 integer variable that equals 1 if a facility is placed at point j and 0 otherwise. One constraint in the model is that exactly P facilities must be sited, where P is the prespecified number,

$$\sum_{j \in J} x_j = P \qquad (3.1)$$

The notion of coverage can be incorporated by defining y_i as a 0-1 variable that equals 1 if there is a facility within S miles of point i and 0 otherwise, and N_i, the set of all potential facility sites within S miles of point i.

The coverage constraints are:

$$y_i \leq \sum_{j \in N\mathrm{i}} x_j \qquad \forall i \in I \qquad (3.2)$$

$$y_i - \sum_{j \in N\mathrm{i}} x_j \leq 0 \qquad \forall i \in I \qquad (3.3)$$

$$y_i \text{ and } x_j \in \{0,1\} \qquad (3.4)$$

The constraint requires at least one x_j, $j \in N_i$, equal to 1 if y_i is equal to 1; namely, point i can be considered covered only if at least one facility is located within S miles of it.

The constraint (3.4) is the integrality constraint and is very important for the integer program. The objective function of the MCLP is to maximize coverage. In general, there may be some attribute of a demand point that should serve as a weight on the importance of covering it. Calling a_i the amount of the attribute, e.g., property value, at point i, the objective function is

$$\text{Maximize} \sum_{i \in I} a_i y_i \qquad (3.5)$$

The entire MCLP is the maximization of (3.5) subject to (3.1) - (3.4). Alternatively, we can relax the coverage distance and locate P facilities to minimize the endogenously determined coverage distance. This is called as the P-center problem.

3.2.3. P-Center Problem

The P-center problem or minimax problem has the objective of placing P facilities at P locations by minimizing the maximum distance from a facility to a point of demand. This type of an objective is typical for locating emergency services, such as fire stations, police stations and hospitals. (O'Kelly, 1995).

The P-center problem comes in two variants. The absolute P-center problem allows facilities to be located anywhere on a link of the network. Hakimi [1964] and Handler [1990] outline how the absolute P-center problem can be solved by considering only a subset of the nodes and local centers on the links. The vertex P-center problem is that of locating p facilities on the nodes of a network to minimize the maximum distance between a demand node and the facility to which the node is assigned. Daskin [2000] outlines how performing a binary search over the maximum distance can solve the problem.

The problem of optimally locating facilities and allocating the demand to the facilities has been of a great interest to researchers for a long time. Needless to say , most of the infrastructure planning activities involve decision making based on spatial location/allocation of facilities. Some practical examples are in locating hospitals, educational institutes, warehouses, general public amenities, retail outlets etc.

Though a lot of research has gone into developing location models , no single analytical model can solve all location problems. Most of the location decisions are still subjective today.

3.2.3.1. P-Center Problem Formulation

The p-center problem seeks to locate p facilities in order to minimize the maximum distance from a facility to a point of demand. P-center problem is formulated as an integer programming problem using the following notation:

- i, I are the index and set of demand nodes;
- j, J are the index and set of candidate facility sites;
- d_{ij} is the distance between demand node $i \in I$ and candidate site $j \in J$;
- P is the number of facilities to locate;
- X_j is a zero-one decision variable; it is 1 if a facility is located at candidate site j, and is 0 otherwise;
- Y_{ij} is a zero-one decision variable; it is 1 if demands at node i are assigned to a facility at node j, and is 0 otherwise;
- W is the maximum distance between a demand node and the facility to which it is assigned

With this notation, p-center problem can be stated as follows.

$$\text{Minimize} \quad W \tag{3.6}$$

$$\text{s.t.} \quad \sum_{j \in J} Y_{ij} = 1 \qquad \forall i \in I \tag{3.7}$$

$$Y_{ij} \leq X_j \qquad \forall i \in I; \forall j \in J \tag{3.8}$$

$$\sum_{j \in J} X_j = P \tag{3.9}$$

$$W \geq \sum_{j \in J} d_{ij} Y_{ij} \qquad \forall i \in I \tag{3.10}$$

$$X_j \in \{0, 1\} \qquad \forall j \in J \tag{3.11}$$

$$Y_{ij} \in \{0, 1\} \qquad \forall i \in I; \forall j \in J \tag{3.12}$$

The objective function (3.6) minimizes the maximum distance between a demand node and the facility to which it is assigned.

The constraint (3.7) ensures that each demand node is assigned. The constraint (3.8) stipulates that demand nodes can only be assigned to open facilities. Constraint (3.9) states that we are to locate exactly p facilities. Constraint (3.10) defines the maximum distance in terms of the assignment variables. Finally constraints (3.11) and (3.12) are standard integrality constraints.

As indicated above, this problem is generally solved by performing a binary search over the value of W. For each value of W, a set covering problem is solved. On the other hand Daskin [2000] proposes the maximal covering problem which is solved using Lagrangian relaxation that is embedded in a branch and bound algorithm as a subroutine instead of the set covering problem while solving this type of problem.

3.2.3.2. Partial Covering P-Center problem

The aim in this type of problem is to locate p facilities in order to minimize the maximum distance between a demand node and the facility to which it is assigned. So far, this sounds just like the standard p-center problem. However, in the partial covering p-center problem, not all the nodes but only a fraction of the nodes will contribute to the objective function. The other nodes can be farther than the endogenously determined coverage distance. The key is that at least α % of the total demand must be covered within the endogenously determined coverage distance. Thus, if α is 0.98 %, then up to 2 % of the total demand can be at a distance that exceeds the distance determined in the objective function for the partial covering p-center problem.(Oven and Daskin,1999)

The partial covering p-center problem is formulated as an integer programming problem using the following notations together with the ones stated in section 3.2.3.1.

h_{ij}	is the demand at node $i \in I$;
α	is the minimum fraction of the total demand that must be considered in the problem
W	is the maximum distance for α % of the total demand.

With this notation, partial p-center problem can be stated as follows;

$$\text{Minimize} \quad W$$

$$\text{s.t.} \quad \sum_{i \in I} \sum_{j \in J} h_{ij} Y_{ij} \geq \alpha \sum_{i \in I} h_{ij} \qquad \forall\, i \in I \qquad (3.13)$$

All other constraints are the same as (3.7) - (3.12), in the formulation stated in section (3.2.3.1). The constraint (3.13) means that we must assign enough demand nodes so that α % of the total demand is assigned.

The p-center problem differs from the p-median problems only in its objective: it uses a public sector objective function, i.e. minimizes the maximum distance between service facilities and demand points (Daskin, 2000). These two types of problems are used for solving the netwok or hub location problems at the same time.

3.3. Multiobjective Analysis of Facility Location Problems

Facility location is a natural framework for multiobjective analysis. The location of facilities, which can be any structure established to store, manufacture or distribute a product or provide a service, is a common decision-making problem that is confronted by managers or decision makers. Facility location is both a private and public sector concern, although the two application areas may present different types of problems.

Ordinary public facilities, such as libraries or health clinics, are established so as to provide a service to as many people as possible. Facilities that provide an emergency service, such as service centers, ambulance bases, hospitals, fire stations, civil defense, or accident rescue, must be located so as to provide as much coverage as possible; i.e., as many emergencies as possible must be covered. The location of noxious facilities, such as solid-waste disposal facilities, should be sensitive to their impact on neighbors.

In the private facility case, the objective is usually straightforward: Minimize cost while providing a given service, or maximize profit. The public facility problem is more complex in this respect in that the notion of payoff or benefits of a facility is dependent on the welfare gains from the facility.

In case of ordinary public facilities, e.g., libraries, a useful surrogate for welfare is to minimize average distance of people from the facility, thereby maximizing accessibility to the services provided.

While most of the optimization models developed to date have used single objective, it is clear that the location of each of the three facility types is an inherently multiobjective problem. In each case – ordinary, emergency, and noxious type - the facility's performance, which is measured by a nonmonetary criterion, must be compared to cost since all agencies –even critical ones such as fire and police departments- operate with fixed finite budgets.

The Baltimore study, which is a fire station location problem, gave rise to the multiobjective facility location (MOFLO) problem presented in Schilling (1976). MOFLO employs the same constraint set as the Maximal Covering Location Problem, but it allows for more than one coverage objective. Defining a_{ik} as the amount of the k^{th} attribute at point i, the objective function of MOFLO is

$$\text{maximize } Z = \left[\left(\sum_{i \in I} a_{i1} y_i \right), \left(\sum_{i \in I} a_{i2} y_i \right), \ldots, \left(\sum_{i \in I} a_{ip} y_i \right) \right]$$

where, in general, there are p objectives. (Cohon, 1978)

The multiobjective facility location problem is a 0-1 integer programming problem that has special constraint structure that accelerates its solution time. These two charecteristics of the problem as the integrality requirements and the special structure of the constraints, have important implications for the multiobjective solution technique that may be employed. Since the generating techniques find an approximation of the noninferior set; they focus on the range of choices available to the decision-maker. This emphasis on alternatives, without a recommendation of an optimal alternative from the analyst, appealed to the manager.

4. A MODEL FOR LOCATING THE REPAIR AND MAINTENANCE FACILITIES: AN APPLICATION IN GENDARMERIE SIGNAL CORPS

4.1. Repair and Maintenance Facilities Location Decisions

Both facilities location and communication equipment decisions have a significant effect on the maintenance level. The repair and maintenance facilities location decisions determine the distance between the maintenance facility and the operations starting point and affects directly the maintenance cycle times. Longer travel distances result in increased repair time and greater variability of maintenance cycle times. Ho and Pearl [1998] have shown that it is necessary to study the interdependence between location decision, fleet size, service quality and maintenance demand.

The repair and maintenance location decision also affects the communication equipment availability at the operations starting point due to the greater variability of leads and cycle times. There is a strong interdependence between maintenance facility location and communication equipment decisions. As Peri and Sirisoponsilp [1988] have shown, the number of warehouses affects the overall level of safety stock in the system: "As the number of warehouses increases, the safety stock at each warehouse decreases, but the total safety stock increases." The same statement is valid for the communication equipment maintenance network, when the size of the network requires more than one maintenance facility.

They have also shown that "the number and locations of warehouses affect the distances between plants and warehouses. Longer distances between plants and warehouses imply longer replenishment lead times and greater variance of replenishment lead times, both of which increase the level of safety stock at the warehouses." For the communication equipment maintenance network, this means that the farther away the maintenance facility from the point where the communication equipment is taken out of the operation to be brought in for maintenance, the higher is the number of communication equipment which is not used for military service but bound for maintenance.

The findings regarding the lead times are also valid, because the longer the distance the communication equipment have to cover between maintenance facility and operational starting point the greater is the possibility of occurrences which negatively affect the time for the transfer.

4.2. The Structure of the Maintenance Network in Signal Corps

The Gendarmerie Signal Corps constitutes its own repair and maintenance network in order to repair and maintain its communication equipment. The network is composed of the Depot Repair Center (DRC) and Intermediate Repair Centers (IRC).

Depot Repair Center is responsible for the depot level or 5th echelon repair of communication equipment and systems, whereas Intermediate Repair Centers are responsible for the intermediate or 3rd echelon repair of communication equipment and systems.

IRC's repair authority is restricted by instructions and also this center can not store the whole inventory of spare parts which are used in repairing the equipment or systems. On the other hand, the technician who works in the repair center is responsible for many collateral works which are not related to the repairing and maintenance. Therefore, IRCs frequently send the repairable items to depot repair center because of the shortage of needed spare parts and plenty of tasks. Thus the repairable items in DRC are accumulating and the limited number of technicians is not sufficient for repairing the devices in a short period of time.

Signal Corps' repair and maintenance network diagrams are displayed in Figure 4.1 and Figure 4.2 for different scales.

In this study the network in Figure 4.1 has been considered, since the two levels are more important and more time consuming than the others. While computing total Repair Cycle Time, the flows between intermediate repair centers and depot repair center have been taken into consideration. In this study, the problem of generating the optimal location alternatives for depot repair center and the reallocation of intermediate repair centers to the newly located centers have been examined.

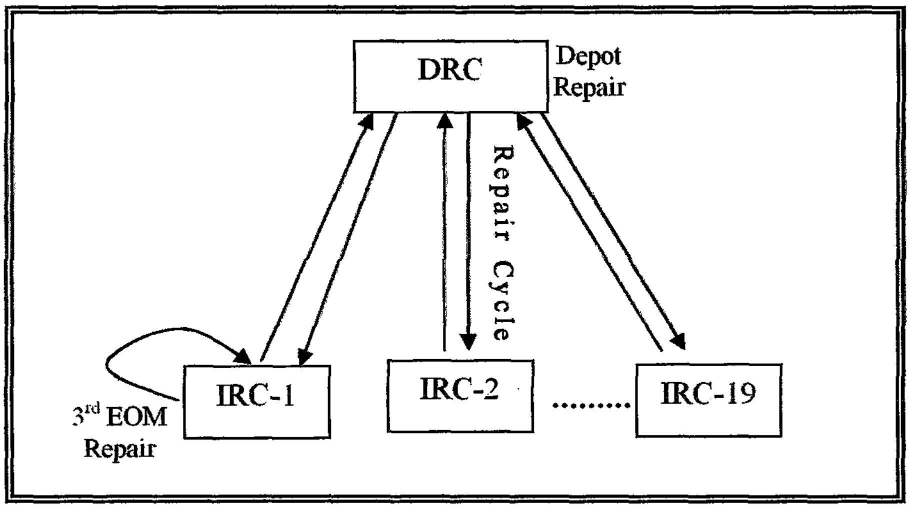

Figure 4.1.: Repair and Maintenance networks and flows (minimum scale)

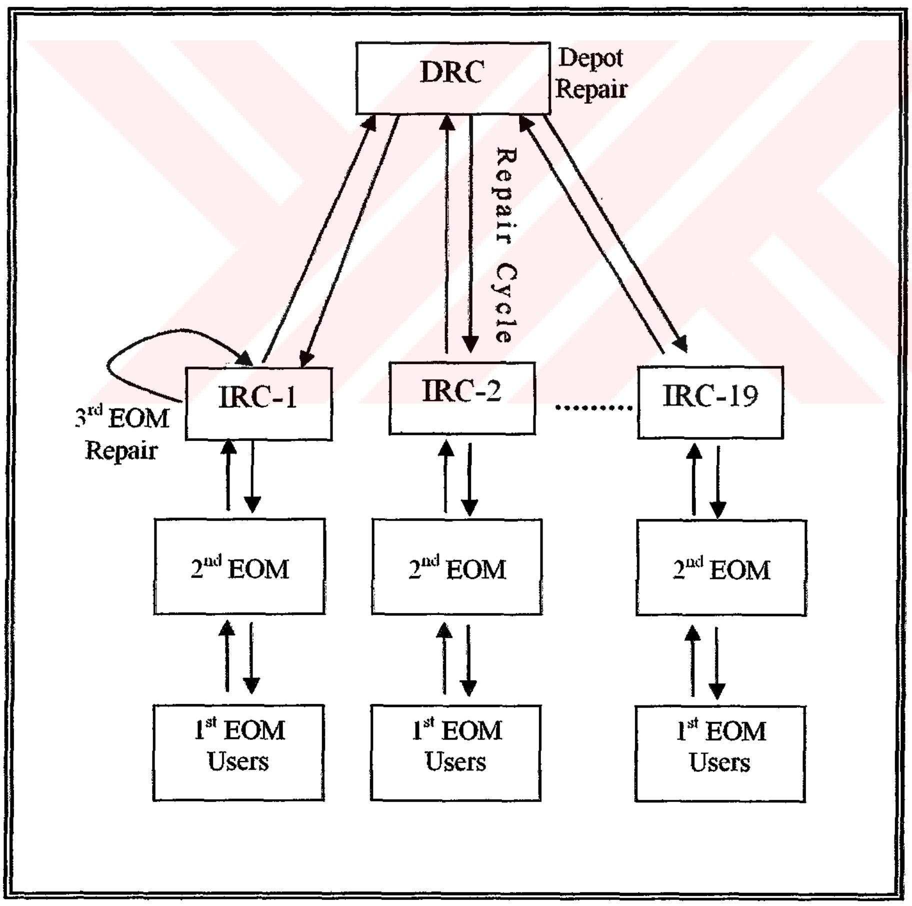

Figure 4.2.: Repair and Maintenance networks and flows (maximum scale)

4.3. Definition of the Existing Problem

The Gendarmerie Signal Corps (GSC) fulfills its repair and maintenance duties by means of its robust maintenance centers. By improving the depot service quality and repair and maintenance duration, the user's satisfaction level and the operational effectiveness can be increased.

The Gendarmerie Signal Corps, who wishes to provide a better service to the people who use communication equipment, is paying a particular attention to facility location and convenient construction of repair and maintenance centers. In the existing repair and maintenance network, only one DRC provides depot maintenance service to all IRCs. When Repair Cycle Time (RCT) which includes repair time, administrative and logistics delay times are examined, we see that especially the administrative and logistics delay times are very long. In addition to long RCT, total transportation cost is also high. Thus, in order to ensure and maintain the continuity of maintenance and repair, the GSC could decide either to establish a new repair and maintenance facility or a depot repair center within their sites of responsibility, or to move the existing facility centers to some other more effective sites.

The objective of this thesis study is to develop a modelling approach that can be used by The Gendarmerie Signal Corps in determining the best location of repair and maintenance facilities, which ensures the repair and maintenance services provided to its forces to be performed in a more effective way. While providing economic contributions by increasing the efficiency of investment, this will increase operational effectiveness and also repairing a large number of communication devices in a short time could increase the morale of Gendarmerie soldiers.

A multiobjective programming model has been formulated that aims to reduce repair cycle time and transportation costs by searching whether only one DRC that exists is enough for the desired performance of depot repair and maintenance activities.

In trying to reduce the repair cycle time and transportation cost, the questions to be answered are; **(a)** Is the existing DRC facility site optimal?, **(b)** How many depot repair centers should be opened in addition to the existing one?,

(c) Where should these new facilities be located?, and **(d)** Which intermediate repair centers should be allocated to each DRC facility?

4.4. The Characteristics of the Model

In constructing the framework of the model, firstly the candidate sites to locate the new depot repair centers have been determined. While doing this selection, four criteria have been considered:

1. The site must be available for air transportation,
2. The site must be available for railroad transportation,
3. The site must be available for cargo transportation,
4. The site must be within a military zone, namely, there must be a Gendarmerie Regional Command (GRC)

The list of all candidate sites for Depot Repair Center (DRC) location is given in Table 4.1.

Table 4.1.: The candidate sites for DRC location

Candidate sites	Cargo*	Railroad**	Air**	GRC
DRC-1	√	√	√	√
DRC-2	√	√	–	√
DRC-3	√	√	√	√
DRC-4	√	√	–	√
DRC-5	√	–	√	√
DRC-6	√	√	√	√
DRC-7	√	√	√	√
DRC-8	√	√	√	√
DRC-9	√	√	√	√
DRC-10	√	–	–	√
DRC-11	√	–	–	√
DRC-12	√	√	√	√
DRC-13	√	–	–	√
DRC-14	√	√	√	–
DRC-15	√	√	–	–
DRC-16	√	√	–	–
DRC-17	√	–	–	–
DRC-18	√	–	–	–
DRC-19	√	√	√	–
* Domestic Cargo standards,	**http://www.Gezzi.com			

The nominee sites which do not meet the four criteria have been eliminated and the final form of the list for the nominee sites as given in Table 4.2. has been obtained. The data in Table 4.2 was used in the model to locate the new depot repair centers.

Table 4.2.: The sites for DRC location.

Candidate sites	Cargo*	Railroad	Air	GRC
DRC-1	√	√	√	√
DRC-3	√	√	√	√
DRC-6	√	√	√	√
DRC-7	√	√	√	√
DRC-8	√	√	√	√
DRC-9	√	√	√	√
DRC-12	√	√	√	√
* Domestic Cargo standards.				

Two objectives are considered in the MOP model. The first one is to minimize the maximum distance between the intermediate repair centers and the depot repair center in order to minimize travel time, together with the repair cycle time and transportation costs. The second objective is to minimize the risk of being non-functional for the communication equipments, which aims to increase the availability of the communication equipment and the level of operational readiness.

The multiobjective programming model developed for the location of repair and maintenance facilities includes two objective functions, 174 constraints and 140 binary variables for 7 nominee sites for DRC location and 19 discrete demand points for IRC. The problem was solved with the WinQSB 1.0 computer package program.

4.5. Formulation of the MOP Model

The problem considered is similar to the p-center problem explained in 3.2.3. The p-center problem or the minimax problem has the objective of placing p facilities at p locations for minimizing the maximum distance from the facility to the points of demand.

Four different scenarios have been tried in order to answer the questions stated in 4.3. The model has been solved for {P= 1, 2, 3, 4} and while solving the {P=1} scenario, the condition of being open of the existing Depot Repair Center (DRC) was omitted. For the other scenarios {P= 2, 3, 4}, this condition was included in the model.

The symbols which represent the candidate DRCs and IRCs are demonstrated in Table 4.3 and Table 4.4, respectively.

Table 4.3.: Symbols of candidate DRCs

Candidate DRCs*	DRC 1	DRC 3	DRC 6	DRC 7	DRC 8	DRC 9	DRC 12
Symbols	X_1	X_2	X_3	X_4	X_5	X_6	X_7

Table 4.4.: Symbols of IRCs

Symbols	IRCs**
Y_1	IRC-1
Y_2	IRC-2
Y_3	IRC-3
Y_4	IRC-4
Y_5	IRC-5
Y_6	IRC-6
Y_7	IRC-7
Y_8	IRC-8
Y_9	IRC-9
Y_{10}	IRC-10
Y_{11}	IRC-11
Y_{12}	IRC-12
Y_{13}	IRC-13
Y_{14}	IRC-14
Y_{15}	IRC-15
Y_{16}	IRC-16
Y_{17}	IRC-17
Y_{18}	IRC-18
Y_{19}	IRC-19

The formulation of the model is presented below.

a. Decision Variables

X_j is the set of zero-one decision variables; 1 if the depot repair center (DRC) is located at candidate site j, and 0 otherwise

Y_{ij} is the set of zero-one decision variables; 1 if the demand at intermediate repair center (IRC) i is allocated to DRC located at candidate site j, and 0 otherwise

P is the number of DRCs to locate (P = 1, 2, 3, 4)

* The Depot Locations' names are not given in the study due to the secrecy.

** The districts' names are not given in the study due to the secrecy.

b. Parameters

i, I are the index and set of intermediate repair centers (IRC)

$I \{i = 1, 2, 3, \ldots, 19\}$

j, J are the index and set of nominee facility nodes of depot repair centers (DRC)

$J \{j = 1, 2, 3, \ldots, 7\}$

r_i : mean inspection time at IRC i

r_j : mean inspection and repair time at DRC j

t_{ij} : transportation time from IRC i to DRC j

k_i : mean number of incidents of IRC i (regional risk coefficient)

h_i : mean faulty devices at IRC i

f_i : total number of devices at IRC i

d_{ij} : distance from IRC i to DRC j

R_{ij} : total repair cycle time

$$R_{ij} = \{ r_i + r_j + (2 * t_{ij}) \}$$

W_{ij} : the risk of being nonfunctional of devices

$$W_{ij} = \{ k_i * (h_i / f_i) * R_{ij} \}$$

c. Constraints

1. Existing DRC is already open and used.

$$X_1 = 1 \qquad \text{(for } P = 2, 3, 4) \qquad (4.1)$$

2. Each demand at IRC i must be assigned to a DRC located at candidate site j

$$\sum_{j=1}^{7} Y_{ij} = 1 \qquad \forall i \in I \qquad (4.2)$$

3. Demands at IRC i cannot be assigned to a DRC at j unless a facility is located at j.

$$X_j \geq Y_{ij} \qquad \forall i \in I;\ j \in J \qquad (4.3)$$

4. P facilities are to be located (P = 1,2,3,4)

$$\sum_{j=1}^{7} X_j = P \qquad \forall i \in I \qquad (4.4)$$

5. Integrality constraints

$$X_i \in \{0,1\} \qquad \forall j \in J \qquad (4.5)$$

$$Y_{ij} \in \{0,1\} \qquad \forall i \in I;\ j \in J \qquad (4.6)$$

d. Objective Functions

1. Minimize the risk of being nonfunctional for the devices at IRC sites:

$$\text{Min. } Z = \sum_{i=1}^{19} \sum_{j=1}^{7} W_{ij} Y_{ij} \qquad \forall i \in I;\ j \in J \qquad (4.7)$$

2. Minimize the maximum distance between IRCs and DRCs:

$$\text{Min. } D = \sum_{j=1}^{7} d_{ij} Y_{ij} \qquad \forall i \in I \qquad (4.8)$$

The objective function (4.7) minimizes the risk of being nonfunctional for the communication devices at the Gendarmerie Regional Command (IRC) sites by increasing the availability and decreasing the repair cycle time of the faulty devices.

The objective function (4.8) minimizes the maximum distance between the Gendarmerie Regional Command (IRC) sites and the depot repair center (DRC) in order to decrease both the repair cycle time of the faulty devices and the total transportation costs.

4.6. Solution and Results of the MOP Model

The constraint method was used in the study which provides complete control of the spacing and coverage of the non-inferior set. Constraint method is used to generate non-inferior solutions by changing the right hand sides of the constraints on the objectives. Operating with the right hand sides is more straightforward than altering the objective function coefficients.

The solution steps of the constraint method are presented below.

In step 1, the payoff table is constructed which provides a systematic way for finding a range of values for each objective function. Each objective is optimized individually and the extreme points of the solution set are obtained.

In step 2, the problem is converted into a multiobjective programming problem. In order to solve the multiobjective programming model with the constraint method, one of the objectives is defined as the primary objective to be optimized and the other objectives are converted into constraints.

In step 3, different values of the right-hand sides of the constraints, which are obtained from the payoff table values for the objectives, are used to generate the non-inferior solution set. The constrained problem is solved for all the selected values of right hand sides and the non- inferior solution set is obtained.

4.6.1. Minimization of the Risks of being Non-functional for the Devices

The primary objective to be optimized is selected as Z, "the minimization of the risk of being non-functional for the communication devices" (4.7.), and solutions have been obtained for various numbers of depot repair centers: (P=1), (P=2), (P=3) and (P=4).

The objective function D (4.8.) is included in the model as constraint. The problem formulation is given below.

$$\text{Min. } Z = \sum_{i=1}^{19}\sum_{j=1}^{7} W_{ij} Y_{ij}$$

s.t.

$$\sum_{j=1}^{7} d_{ij} Y_{ij} - D \leq 0 \qquad \forall i \in I$$

$$X_1 = 1 \qquad (4.9)$$

$$\sum_{j=1}^{7} Y_{ij} = 1 \qquad \forall i \in I \qquad (4.10)$$

$$X_j - Y_{ij} \geq 0 \qquad \forall i \in I;\ j \in J \qquad (4.11)$$

$$\sum_{j=1}^{7} X_j = P \qquad \forall i \in I \qquad (4.12)$$

$$X_i \in \{0,1\} \qquad \forall j \in J \qquad (4.13)$$

$$Y_{ij} \in \{0,1\} \qquad \forall i \in I;\ j \in J \qquad (4.14)$$

W_{ij} is the risk of being non-functional for the devices at IRC sites and given by

$W_{ij} = k_i * (h_i / f_i) * R_{ij}$, or

W_{ij} = mean number of incidents at IRC i * (mean faulty devices at IRC i / total number of devices at IRC i) * total repair cycle time

The calculation of the W for DRC-1 is as follows:

W_{11} = 8869 * (264 / 2348) * 33

W_{11} = 32,906

Table 4.5.: The data for the risk of being non-functional of devices (W_{ij})

W_{ij}	DRC 1	DRC 3	DRC 6	DRC 7	DRC 8	DRC 9	DRC 12
IRC-1	32.906	34.900	36.894	34.900	34.900	34.900	36.894
IRC-2	38.006	38.006	38.006	38.006	35.952	38.006	38.006
IRC-3	53.401	50.350	56.453	56.453	53.401	53.401	56.453
IRC-4	3.374	3.374	3.192	3.374	3.374	3.374	3.192
IRC-5	21.304	21.304	22.522	21.304	21.304	22.522	22.522
IRC-6	16.074	16.074	14.336	16.074	16.074	16.074	15.205
IRC-7	59.555	62.958	62.958	56.152	62.958	62.958	62.958
IRC-8	31.555	31.555	33.358	33.358	29.752	31.555	33.358
IRC-9	27.977	27.977	29.576	29.576	27.977	26.379	29.576
IRC-10	9.284	9.815	9.284	9.815	9.284	9.284	9.284
IRC-11	35.142	35.142	35.142	35.142	35.142	33.243	33.243
IRC-12	17.165	17.165	16.237	17.165	17.165	17.165	15.309
IRC-13	7.549	7.549	7.141	7.549	7.549	7.141	7.141
IRC-14	7.803	8.249	8.249	7.803	7.803	8.249	8.249
IRC-15	1.278	1.351	1.351	1.278	1.278	1.351	1.351
IRC-16	2.920	3.087	3.087	2.920	2.920	2.920	3.087
IRC-17	2.534	2.534	2.397	2.534	2.534	2.534	2.397
IRC-18	3.315	3.315	3.136	3.315	3.315	3.315	3.315
IRC-19	9.544	9.544	9.028	9.544	9.544	9.544	9.028

R_{ij} is the total repair cycle time and given by

$R_{ij} = r_i + r_j + 2 * t_{ij}$, or

R_{ij} = mean inspection time at IRC I + mean inspection and repair time at DRC j + (2 * transportation time from IRC i to DRC j)

The calculation of the R for IRC-1 is as follows:

$R_{11} = 10^{*} + 23^{**} + (2 * 0^{***})$; $R_{11} = 33$ days.

Table 4.6.: The data for the total repair cycle time (R_{ij})

R_{ij}	DRC 1	DRC 3	DRC 6	DRC 7	DRC 8	DRC 9	DRC 12
IRC-1	33	35	37	35	35	35	37
IRC-2	37	37	37	37	35	37	37
IRC-3	35	33	37	37	35	35	37
IRC-4	37	37	35	37	37	37	35
IRC-5	35	35	37	35	35	37	37
IRC-6	37	37	33	37	37	37	35
IRC-7	35	37	37	33	37	37	37
IRC-8	35	35	37	37	33	35	37
IRC-9	35	35	37	37	35	33	37
IRC-10	35	37	35	37	35	35	35
IRC-11	37	37	37	37	37	35	35
IRC-12	37	37	35	37	37	37	33
IRC-13	37	37	35	37	37	35	35
IRC-14	35	37	37	35	35	37	37
IRC-15	35	37	37	35	35	37	37
IRC-16	35	37	37	35	35	35	37
IRC-17	37	37	35	37	37	37	35
IRC-18	37	37	35	37	37	37	37
IRC-19	37	37	35	37	37	37	35

Z is considered as the primary objective function to be optimized, whereas objective D is written as constraints. The optimal solutions for this problem for various values of P are given in Tables 4.7 through 4.10. The model has been solved for (P=1), (P=2), (P=3) and (P=4) separately, and while solving for (P=1) condition, the first constraint (X_1 =1) was omitted.

* Maximum time (days) allowed at Intermediate Repair Center (IRC) to inspect and repair.
** Maximum time (days) allowed at Depot Repair Center (DRC) to inspect and repair.
*** If DRC is at the same site with IRC, the transportation time is taken as zero.

The solutions for the model are presented below. For P = 1 (Table 4.7), the current site of DRC has been evaluated for being an optimal location.

Table 4.7.: Objective Z minimized for P = 1.

P = 1	Evaluation of the Current Situation	
Objective D Max. distance (km.)	Location of DRC (X*j)	Allocation of IRCs
1410	X_1	All IRCs allocated to X_1
Objective Function	Min. Z	380,686

The minimum risk of being non-functional of devices was found as 380,686. All the demand points are allocated to DRC-1, which means that the current site is optimal for Z.

Table 4.8.: Objective Z minimized for P = 2.

P = 2		
Objective D Max. distance (km.)	Location of DRC (X*j)	Allocation of IRCs
622	X_1 - X_7	$X_1 = Y_1, Y_2, Y_3, Y_5, Y_7, Y_8, Y_9, Y_{10}, Y_{14}, Y_{15}, Y_{16}$
		$X_7 = Y_4, Y_6, Y_{11}, Y_{12}, Y_{13}, Y_{17}, Y_{18}, Y_{19}$
Objective Function	Min. Z	374,819

The minimum risk of being non-functional of devices was found as 374,819. 11 demand points are allocated to DRC-1 and 8 demand points are allocated to DRC-12.

Table 4.9.: Objective Z minimized for P = 3.

P = 3		
Objective D Max. distance (km.)	Location of DRC (X*j)	Allocation of IRCs (Y*ij)
622	X_1-X_5-X_7	$X_1 = Y_1, Y_3, Y_5, Y_7, Y_9, Y_{15}, Y_{16}$
		$X_5 = Y_2, Y_8, Y_{10}, Y_{14}$
		$X_7 = Y_4, Y_6, Y_{11}, Y_{12}, Y_{13}, Y_{17}, Y_{18}, Y_{19}$
Objective Function	Min. Z	370,962

The minimum risk of being non-functional of devices was found as 370,962. 7 demand points are allocated to DRC-1, 4 demand points are allocated to DRC-8 and 8 demand points are allocated to DRC-12.

Table 4.10.: Objective Z minimized for P = 4.

P = 4		
Objective D Max. distance (km.)	Location of DRC (X^*j)	Allocation of IRCs (Y^*ij)
622	X_1 - X_4 - X_5 - X_7	$X_1 = Y_1, Y_3, Y_9, Y_{10}, Y_{14}$
		$X_4 = Y_7$
		$X_5 = Y_2, Y_5, Y_8, Y_{15}, Y_{16}$
		$X_7 = Y_4, Y_6, Y_{11}, Y_{12}, Y_{13}, Y_{17}, Y_{18}, Y_{19}$
Objective Function	Min. Z	367,559

The minimum risk of being non-functional of devices was found as 367,559. 5 demand points are allocated to DRC-1, 1 demand points are allocated to DRC-7, 5 demand points are allocated to DRC-8 and 8 demand points are allocated to DRC-12.

4.6.2. Minimization of the Maximum Distance

Now, the primary objective to be optimized is selected as D, "minimization of the maximum distance between IRCs and DRCs" (4.8.), and solutions have been obtained for various numbers of depot repair centers: (P=1), (P=2), (P=3) and (P=4).

The objective function Z (4.7.) is included in the model as a constraint. The problem formulation is given below.

$$\text{Min. } D = \sum_{j=1}^{7} d_{ij} Y_{ij} \qquad \forall i \in I$$

s.t.

$$\sum_{i=1}^{19} \sum_{j=1}^{7} W_{ij} Y_{ij} - Z \leq 0$$

and the constraints (4.9) - (4.14).

The data for the distance matrix are presented in Appendix A.2. D is considered as the primary objective function to be optimized, whereas objective Z is written as a constraint.

The optimal solutions for the problem for various values of P are given in Tables 4.11 through 4.15. The model has been solved for (P=1), (P=2), (P=3) and (P=4) separately, and while solving for (P=1) condition, the first constraint (X_1 =1) was omitted.

The solutions for the model are presented below. For P = 1 (Table 4.11), the current site of DRC has been evaluated for being an optimal location.

Table 4.11.: Objective D minimized for P = 1.

P = 1	Evaluation of the Current Situation	
Objective Z	Location of DRC (X*j)	Allocation of IRCs
384,249	X_2	All IRCs allocated to X_2
Objective Function	Min. D	1073

The maximum distance between the demand nodes (IRCs) and the center (DRC) was found as 1073 km. All demand points are allocated to DRC-3. This means that the current DRC site is optimal for Z, but it is not optimal for the objective D.

Table 4.12.: Objective D minimized for P = 2.

P = 2		
Objective Z	Location of DRC (X*j)	Allocation of IRCs
379,650	X_1 - X_3	$X_1 = Y_1, Y_2, Y_5, Y_7, Y_8, Y_9, Y_{10}, Y_{11}, Y_{14}, Y_{15}, Y_{16}$
		$X_3 = Y_3, Y_4, Y_6, Y_{12}, Y_{13}, Y_{17}, Y_{18}, Y_{19}$
Objective Function	Min. D	628

The maximum distance between the demand nodes (IRC) and the center (DRC) was found as 628 km. 11 demand points are allocated to DRC-1 and 8 demand points are allocated to DRC-6.

Table 4.13.: Objective D minimized for P = 3.

P = 3		
Objective Z	Location of DRC (X*j)	Allocation of IRCs (Y*ij)
374,699	$X_1 - X_3 - X_6$	$X_1 = Y_1, Y_2, Y_3, Y_5, Y_7, Y_8, Y_9, Y_{10}, Y_{14}, Y_{15}, Y_{16}$
		$X_3 = Y_4, Y_6, Y_{12}, Y_{13}, Y_{17}, Y_{18}, Y_{19}$
		$X_6 = Y_{11}$
Objective Function	Min. D	604

The maximum distance between the demand nodes (IRC) and the center (DRC) was found as 604 km. 11 demand points are allocated to DRC-1, 7 demand points are allocated to DRC-6 and one demand point is allocated to DRC-9.

Table 4.14.: Objective D minimized for P = 4.

P = 4		
Objective Z	Location of DRC (X*j)	Allocation of IRCs (Y*ij)
372,645	$X_1 - X_3 - X_5 - X_7$	$X_1 = Y_1, Y_3, Y_5, Y_7, Y_8, Y_9, Y_{10}, Y_{15}, Y_{16}$
		$X_3 = Y_4, Y_6, Y_{12}, Y_{13}, Y_{17}, Y_{18}, Y_{19}$
		$X_5 = Y_2, Y_{14}$
		$X_7 = Y_{11}$
Objective Function	Min. D	551

The maximum distance between the demand nodes (IRC) and the center (DRC) was found as 551 km. 9 demand points are allocated to DRC-1, 7 demand points are allocated to DRC-6, 2 demand points are allocated to DRC-8 and one demand point is allocated to DRC-12.

4.6.3. The Non-Inferior Solution Set for the Objectives Z and D

If the availability of communication equipment and the transportation time or distance are considered as the two important factors (objectives) when considering the characteristics of the repair and maintenance activities, then the payoff table can be constructed based on these objectives so that the commander decides effectively.

The constraint method was applied to the model for the evaluation of the current situation (P=1), and for (P = 2), (P = 3), (P = 4).

$$\text{Min. } Z = \sum_{i=1}^{19} \sum_{j=1}^{7} W_{ij} Y_{ij}$$

$$\text{Min. } D = \sum_{j=1}^{7} d_{ij} Y_{ij} \qquad \forall i \in I$$

s.t.

$$X_1 = 1 \qquad (4.15)$$

$$\sum_{j=1}^{7} Y_{ij} = 1 \qquad \forall i \in I \qquad (4.16)$$

$$X_j - Y_{ij} \geq 0 \qquad \forall i \in I; j \in J \qquad (4.17)$$

$$\sum_{j=1}^{7} X_j = P \qquad \forall i \in I \qquad (4.18)$$

$$X_i \in \{0,1\} \qquad \forall j \in J \qquad (4.19)$$

$$Y_{ij} \in \{0,1\} \qquad \forall i \in I; j \in J \qquad (4.20)$$

A. (P = 1)

Step 1:

$$\text{Min. } Z = \sum_{i=1}^{19} \sum_{j=1}^{7} W_{ij} Y_{ij}$$

s.t.

$$\sum_{j=1}^{7} d_{ij} Y_{ij} - D \leq 0 \qquad \forall i \in I$$

and (4.16) - (4.20)

Step 2: Payoff table is constructed.

a. Z is considered as the primary objective and D is written as a constraint. The optimal solution for the problem is:

Z = 380,686

D = 1410 km.

Location of DRC (X*j): X_1 or DRC1.

b. D is considered as the primary objective and Z is written as a constraint. The optimal solution for the problem is:

D = 1073 km

Z = 384,249

Location of DRC (X*j): X_2 or DRC3.

Table 4.15.: Payoff table for the objectives (P = 1).

P = 1				
	Objective Z	Objective D (km.)	Location of DRC (X*j)	Allocation of IRCs (Y*ij)
Z^*	380,686	1410	X_1	All IRCs allocated to X_1
D^*	384,249	1073	X_2	All IRCs allocated to X_2

B. (P = 2)

Step 1:

$$\text{Min.. } Z = \sum_{i=1}^{19}\sum_{j=1}^{7} W_{ij} Y_{ij}$$

s.t.

$$\sum_{j=1}^{7} d_{ij} Y_{ij} - D \leq 0 \qquad \forall i \in I$$

and (4.15) - (4.20).

Step 2: Payoff table is constructed.

a. Z is considered as the primary objective and D is written as a constraint. The optimal solution for the problem is:

Z = 374,819

D = 622 km.

Location of DRC (X*j): X_1 and X_7, or DRC1 and DRC12

b. D is considered as the primary objective and Z is written as a constraint. The optimal solution for the problem is:

D = 628 km.

Z = 379,650

Location of DRC (X*j): X_1 and X_3 , or DRC1 and DRC6.

Table 4.16.: Payoff table for the objectives (P = 2).

P = 2				
	Objective Z	Objective D (km.)	Location of DRC (X*j)	Allocation of IRCs (Y*ij)
Z^*	374,819	622	X_1 and X_7	$X_1 = Y_1, Y_2, Y_3, Y_5, Y_7, Y_8, Y_9, Y_{10}, Y_{14}, Y_{15}, Y_{16}$
				$X_7 = Y_4, Y_6, Y_{11}, Y_{12}, Y_{13}, Y_{17}, Y_{18}, Y_{19}$
D^*	379,650	628	X_1 and X_3	$X_1 = Y_1, Y_2, Y_5, Y_7, Y_8, Y_9, Y_{10}, Y_{11}, Y_{14}, Y_{15}, Y_{16}$
				$X_3 = Y_3, Y_4, Y_6, Y_{12}, Y_{13}, Y_{17}, Y_{18}, Y_{19}$

C. (P = 3)

Step 1:

$$\text{Min. } Z = \sum_{i=1}^{19}\sum_{j=1}^{7} W_{ij} Y_{ij}$$

s.t.

$$\sum_{j=1}^{7} d_{ij} Y_{ij} - D \leq 0 \qquad \forall i \in I$$

and (4.15) - (4.20).

Step 2: Payoff table is constructed.

a. Z is considered as the primary objective and D is written as a constraint. The optimal solution for the problem is:

Z = 370,962

D = 622 km.

Location of DRC (X*j): X_1, X_5 and X_7 , or DRC1, DRC8 and DRC12.

b. D is considered as the primary objective and Z is written as a constraint. The optimal solution for the problem is:

D = 604 km

Z = 374,699

Location of DRC (X*j): X_1, X_3 and X_6 , or DRC1, DRC6 and DRC9.

Table 4.17.: Payoff table for the objectives (P = 3).

P = 3				
	Objective Z	Objective D (km.)	Location of DRC (X*j)	Allocation of IRCs (Y*ij)
Z^*	370,962	622	X_1 - X_5 - X_7	$X_1 = Y_1, Y_3, Y_5, Y_7, Y_9, Y_{15}, Y_{16}$
				$X_5 = Y_2, Y_8, Y_{10}, Y_{14}$
				$X_7 = Y_4, Y_6, Y_{11}, Y_{12}, Y_{13}, Y_{17}, Y_{18}, Y_{19}$
D^*	374,699	604	X_1 - X_3 - X_6	$X_1 = Y_1, Y_2, Y_3, Y_5, Y_7, Y_8, Y_9, Y_{10}, Y_{14}, Y_{15}, Y_{16}$
				$X_3 = Y_4, Y_6, Y_{12}, Y_{13}, Y_{17}, Y_{18}, Y_{19}$
				$X_6 = Y_{11}$

D. (P = 4)

Step 1:

$$\text{Min } Z = \sum_{i=1}^{19} \sum_{j=1}^{7} W_{ij} Y_{ij}$$

s.t.

$$\sum_{j=1}^{7} d_{ij} Y_{ij} - D \leq 0 \qquad \forall i \in I$$

and (4.15) - (4.20)

Step 2: Payoff table is constructed.

a. Z is considered as the primary objective and D is written as a constraint. The optimal solution for the problem is:

Z = 367,559

D = 622 km.

Location of DRC (X*j): X_1, X_4, X_5 and X_7 , or DRC1, DRC7, DRC8 and DRC12

b. D is considered as the primary objective and Z is written as a constraint. The optimal solution for the problem is:

D = 551 km.

Z = 372,645

Location of DRC (X*j): X_1, X_3, X_5 and X_7 , or DRC1, DRC6, DRC8 and DRC12.

Table 4.18.: Payoff table for the objectives (P = 4).

<table>
<tr><td colspan="5">P = 4</td></tr>
<tr><td></td><td>Objective Z</td><td>Objective D (km.)</td><td>Location of DRC (X*j)</td><td>Allocation of IRCs (Y*ij)</td></tr>
<tr><td rowspan="4">Z^*</td><td rowspan="4">367.559</td><td rowspan="4">622</td><td rowspan="4">X_1- X_4- X_5-X_7</td><td>X_1 = Y_1, Y_3, Y_9, Y_{10}, Y_{14}</td></tr>
<tr><td>X_4 = Y_7</td></tr>
<tr><td>X_5 = Y_2, Y_5, Y_8, Y_{15}, Y_{16}</td></tr>
<tr><td>X_7 = Y_4, Y_6, Y_{11}, Y_{12}, Y_{13}, Y_{17}, Y_{18}, Y_{19}</td></tr>
<tr><td rowspan="4">D^*</td><td rowspan="4">372.645</td><td rowspan="4">551</td><td rowspan="4">X_1- X_3-X_5-X_7</td><td>X_1= Y_1, Y_3, Y_5, Y_7, Y_8, Y_9, Y_{10}, Y_{15}, Y_{16}</td></tr>
<tr><td>X_3= Y_4, Y_6, Y_{12}, Y_{13}, Y_{17}, Y_{18}, Y_{19}</td></tr>
<tr><td>X_5= Y_2, Y_{14}</td></tr>
<tr><td>X_7= Y_{11}</td></tr>
</table>

In order to define the noninferior solution sets for P=1, P = 2, P = 3 and P = 4, the problem was solved for a number of points within the range of values for Z and D, with various step lengths. The decision maker would select the best solution among the set of noninferior solutions. In order to obtain the noninferior solution set, the objective Z was minimized and the objective D was taken as the constraint. The non-inferior solution sets for the two objectives are given in Tables 4.19 through 4.22., and the graphical representation of the non-inferior solution sets are given Figure 4.3 through 4.6.

Table 4.19.: Non-inferior solutions for Z and D for P=1.

P = 1	Evaluation of the Current Situation			
Points	Objective Z	Objective D (km.)	Location of DRC (X*j)	Allocation of IRCs (Y*ij)
1	380,686	1410	X_1	All IRCs allocated to X_1
2	383,915	1343	X_6	All IRCs allocated to X_6
3	383,915	1275	X_6	All IRCs allocated to X_6
4	383,915	1208	X_6	All IRCs allocated to X_6
5	384,249	1140	X_2	All IRCs allocated to X_2
6	384,249	1073	X_2	All IRCs allocated to X_2

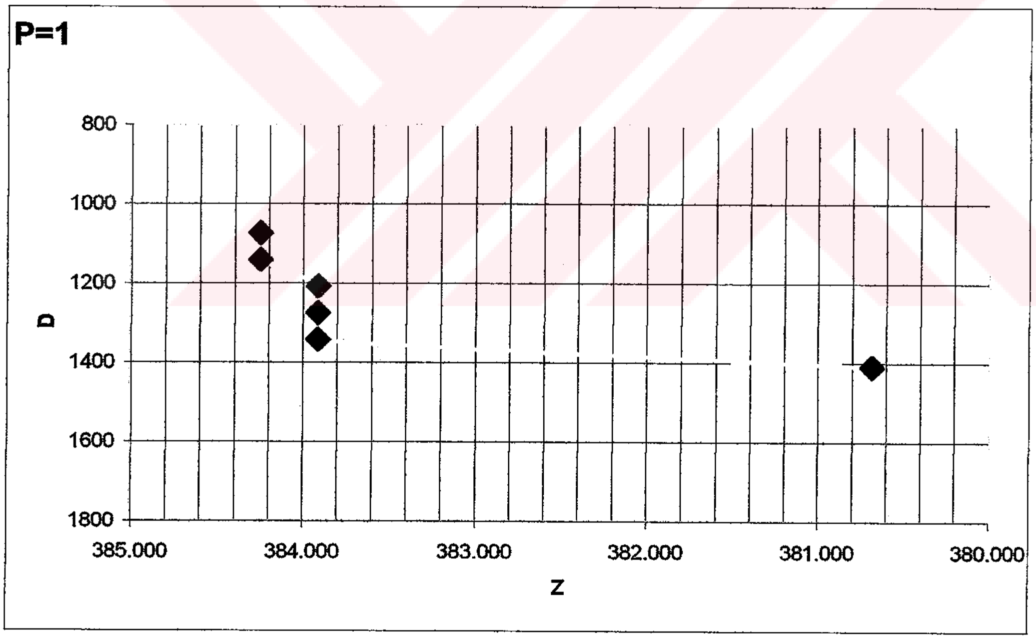

Figure 4.3.: Graphical representation of the non-inferior solution set for P = 1

Table 4.20.: Non-inferior solutions for Z and D for P=2

P = 2				
Points	Objective Z	Objective D (km.)	Location of DRC (X*j)	Allocation of IRCs (Y*ij)
1	374,819	622	X_1 and X_7	$X_1 = Y_1, Y_2, Y_3, Y_5, Y_7, Y_8, Y_9, Y_{10}, Y_{14}, Y_{15}, Y_{16}$
				$X_7 = Y_4, Y_6, Y_{11}, Y_{12}, Y_{13}, Y_{17}, Y_{18}, Y_{19}$
2	374,819	623	X_1 and X_7	$X_1 = Y_1, Y_2, Y_3, Y_5, Y_7, Y_8, Y_9, Y_{10}, Y_{14}, Y_{15}, Y_{16}$
				$X_7 = Y_4, Y_6, Y_{11}, Y_{12}, Y_{13}, Y_{17}, Y_{18}, Y_{19}$
3	374,819	624	X_1 and X_7	$X_1 = Y_1, Y_2, Y_3, Y_5, Y_7, Y_8, Y_9, Y_{10}, Y_{14}, Y_{15}, Y_{16}$
				$X_7 = Y_4, Y_6, Y_{11}, Y_{12}, Y_{13}, Y_{17}, Y_{18}, Y_{19}$
4	374,819	626	X_1 and X_7	$X_1 = Y_1, Y_2, Y_3, Y_5, Y_7, Y_8, Y_9, Y_{10}, Y_{14}, Y_{15}, Y_{16}$
				$X_7 = Y_4, Y_6, Y_{11}, Y_{12}, Y_{13}, Y_{17}, Y_{18}, Y_{19}$
5	374,819	627	X_1 and X_7	$X_1 = Y_1, Y_2, Y_3, Y_5, Y_7, Y_8, Y_9, Y_{10}, Y_{14}, Y_{15}, Y_{16}$
				$X_7 = Y_4, Y_6, Y_{11}, Y_{12}, Y_{13}, Y_{17}, Y_{18}, Y_{19}$
6	379,650	628	X_1 and X_3	$X_1 = Y_1, Y_2, Y_5, Y_7, Y_8, Y_9, Y_{10}, Y_{11}, Y_{14}, Y_{15}, Y_{16}$
				$X_3 = Y_3, Y_4, Y_6, Y_{12}, Y_{13}, Y_{17}, Y_{18}, Y_{19}$

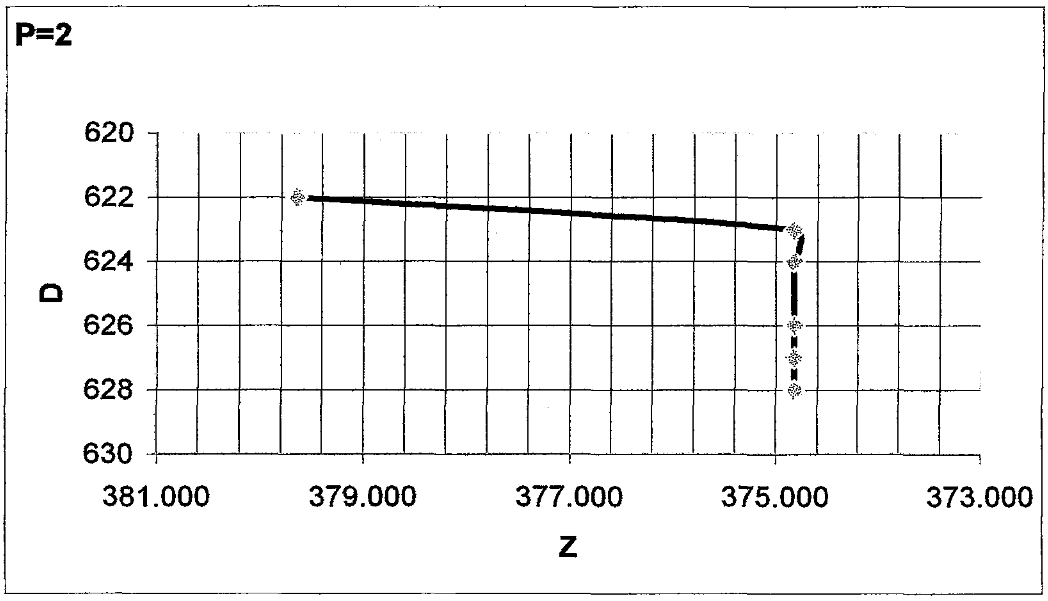

Figure 4.4.: Graphical representation of the non-inferior solution set for P = 2

Table 4.21.: Non-inferior solutions for Z and D for P=3.

P = 3				
Points	Objective Z	Objective D (km.)	Location of DRC (X*j)	Allocation of IRCs (Y*ij)
1	370,962	622	X_1 - X_5 - X_7	$X_1 = Y_1, Y_3, Y_5, Y_7, Y_9, Y_{15}, Y_{16}$
				$X_5 = Y_2, Y_8, Y_{10}, Y_{14}$
				$X_7 = Y_4, Y_6, Y_{11}, Y_{12}, Y_{13}, Y_{17}, Y_{18}, Y_{19}$
2	373,101	618	X_1 - X_3 - X_6	$X_1 = Y_1, Y_2, Y_3, Y_5, Y_7, Y_8, Y_{10}, Y_{14}, Y_{15}$
				$X_3 = Y_4, Y_6, Y_{12}, Y_{13}, Y_{17}, Y_{18}, Y_{19}$
				$X_6 = Y_9, Y_{11}, Y_{16}$
3	373,101	615	X_1 - X_3 - X_6	$X_1 = Y_1, Y_2, Y_3, Y_5, Y_7, Y_{10}, Y_{14}, Y_{15}$
				$X_3 = Y_4, Y_6, Y_{12}, Y_{13}, Y_{17}, Y_{18}, Y_{19}$
				$X_6 = Y_8, Y_9, Y_{11}, Y_{16}$
4	373,101	611	X_1 - X_3 - X_6	$X_1 = Y_1, Y_2, Y_3, Y_5, Y_7, Y_8, Y_{10}, Y_{14}, Y_{15}$
				$X_3 = Y_4, Y_6, Y_{12}, Y_{13}, Y_{17}, Y_{18}, Y_{19}$
				$X_6 = Y_8, Y_9, Y_{11}, Y_{16}$
5	373,101	608	X_1 - X_3 - X_6	$X_1 = Y_1, Y_2, Y_3, Y_5, Y_7, Y_8, Y_{10}, Y_{14}, Y_{15}$
				$X_3 = Y_4, Y_6, Y_{12}, Y_{13}, Y_{17}, Y_{18}, Y_{19}$
				$X_6 = Y_8, Y_9, Y_{11}, Y_{16}$
6	374,699	604	X_1 - X_3 - X_6	$X_1 = Y_1, Y_2, Y_3, Y_5, Y_7, Y_8, Y_9, Y_{10}, Y_{14}, Y_{15}, Y_{16}$
				$X_3 = Y_4, Y_6, Y_{12}, Y_{13}, Y_{17}, Y_{18}, Y_{19}$
				$X_6 = Y_{11}$

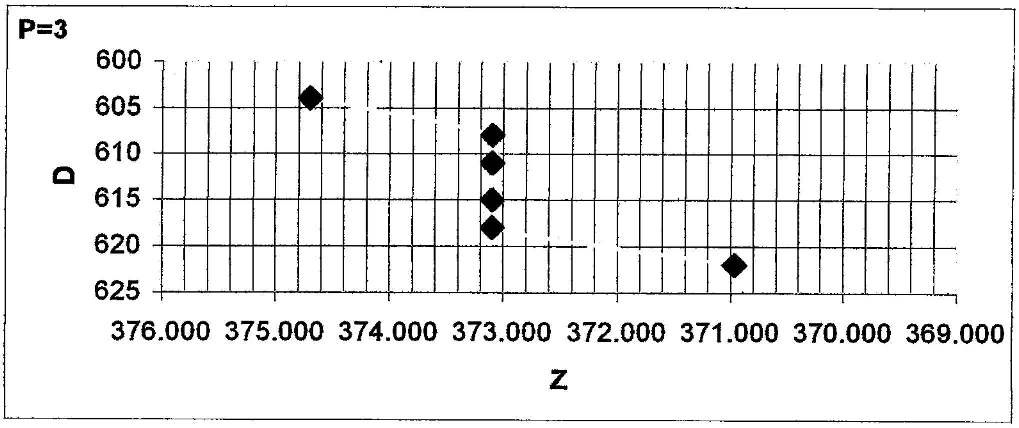

Figure 4.5.: Graphical representation of the non-inferior solution set for P = 3

Table 4.22.: Non-inferior solutions for Z and D for P=4

P = 4				
Points	Objective Z	Objective D (km.)	Location of DRC (X*j)	Allocation of IRCs (Y*ij)
1	367.559	622	X_1- X_4- X_5-X_7	X_1 = Y_1, Y_3, Y_9, Y_{10}, Y_{14} X_4 = Y_7 X_5 = Y_2, Y_5, Y_8, Y_{15}, Y_{16} X_7 = Y_4, Y_6, Y_{11}, Y_{12}, Y_{13}, Y_{17}, Y_{18}, Y_{19}
2	369,244	608	X_1- X_3-X_5-X_6	X_1= Y_1, Y_3, Y_7, Y_{10}, Y_{14}, Y_{15} X_3= Y_4, Y_6, Y_{12}, Y_{13}, Y_{17}, Y_{18}, Y_{19} X_5= Y_2, Y_5, Y_8 X_6= Y_9, Y_{11}, Y_{16}
3	369,244	594	X_1- X_3-X_5-X_6	X_1= Y_1, Y_3, Y_7, Y_{10}, Y_{14}, Y_{15} X_3= Y_4, Y_6, Y_{12}, Y_{13}, Y_{17}, Y_{18}, Y_{19} X_5= Y_2, Y_5, Y_8 X_6= Y_9, Y_{11}, Y_{16}
4	369,244	579	X_1- X_3-X_5-X_6	X_1= Y_1, Y_3, Y_5, Y_7, Y_{10}, Y_{15} X_3= Y_4, Y_6, Y_{12}, Y_{13}, Y_{17}, Y_{18}, Y_{19} X_5= Y_2, Y_8, Y_{14},Y_{16} X_6= Y_9, Y_{11}
5	369,914	565	X_1- X_3-X_5-X_7	X_1= Y_1, Y_3, Y_5, Y_7, Y_9, Y_{10}, Y_{15}, Y_{16} X_3= Y_2, Y_4, Y_6, Y_{13}, Y_{17}, Y_{18}, Y_{19} X_5= Y_8, Y_{14} X_7= Y_{11}, Y_{12}
6	372.645	551	X_1- X_3-X_5-X_7	X_1= Y_1, Y_3, Y_5, Y_7, Y_8, Y_9, Y_{10}, Y_{15}, Y_{16} X_3= Y_4, Y_6, Y_{12}, Y_{13}, Y_{17}, Y_{18}, Y_{19} X_5= Y_2, Y_{14} X_7= Y_{11}

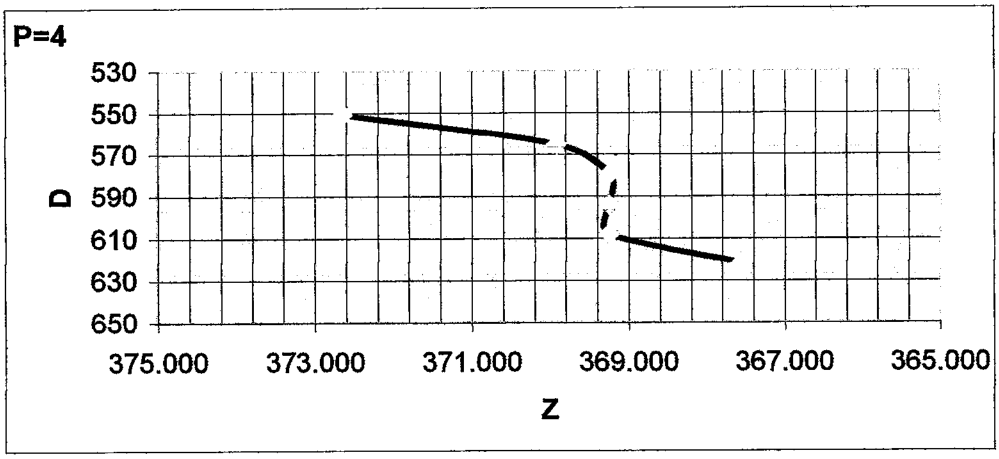

Figure 4.6.: Graphical representation of the non-inferior solution set for P = 4

4.6.4. Noninferior solutions and the Number of Depot Repair Centers

By considering the solutions obtained, the most significant factor has been determined as P (the number of Depot Repair Centers). That's why, the various values will be obtained for the objectives Z and D for the various values of P, respectively. The relations between P and Z, P and D are given in Table 4.23 and Table 4.24.

Table 4.23.: Relations between P and Z.

P and Z			
Number of DRC (P)	Objective Z*	Objective D (km.)	Location of DRC (X*j)
1	380.686	1410	X_1
2	374.819	622	$X_1 - X_7$
3	370.962	622	$X_1 - X_5 - X_7$
4	367.559	622	$X_1 - X_4 - X_5 - X_7$

Table 4.24.: Relations between P and D.

P and D			
Number of DRC (P)	Objective Z	Objective D* (km.)	Location of DRC (X*j)
1	384.249	1073	X_2
2	379.650	628	$X_1 - X_3$
3	374.699	604	$X_1- X_3-X_6$
4	372.645	551	$X_1- X_3-X_5-X_7$

The graphical representation of relations between P and Z, P and D and all solutions are given in Figure 4.7. and 4.9. respectively.

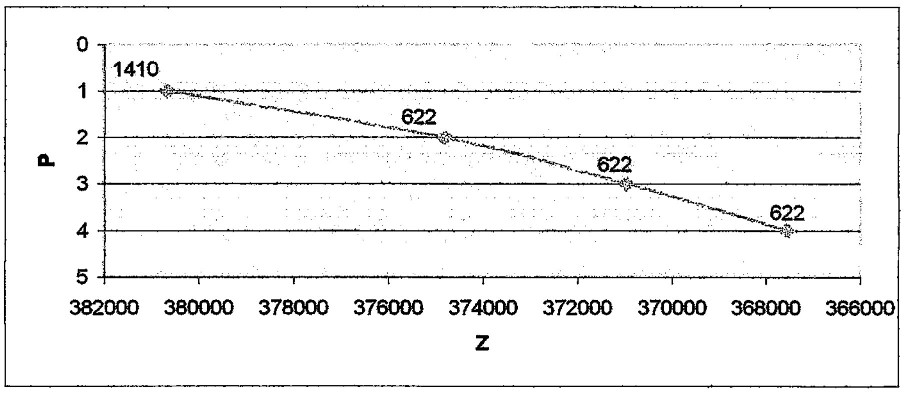

Figure 4.7.: Graphical representation of the relations between P and Z.

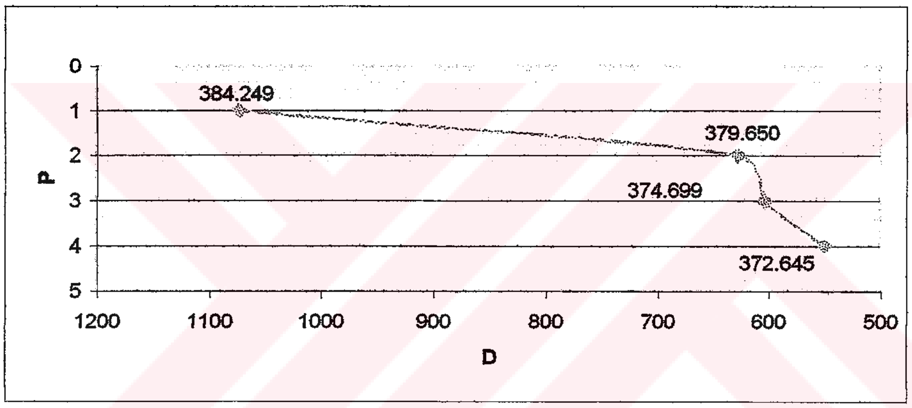

Figure 4.8.: Graphical representation of the relations between P and D.

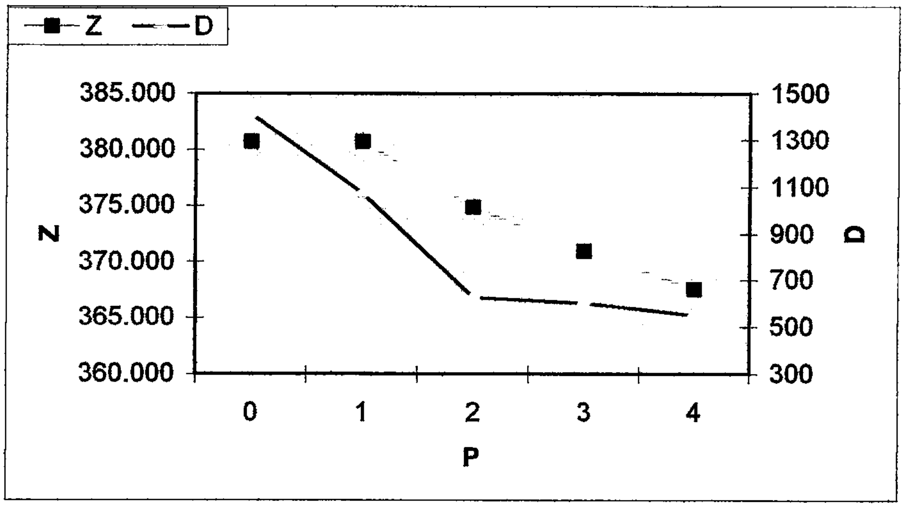

Figure 4.9.: Graphical representation of all solutions

4.7. Evaluation of the Results

In applying the first stage of the solution methodology, the developed multiobjective programming model has been solved for the individual optimization of the selected primary objective for various number of facilities (depot repair centers), while the other objective was considered as a constraint. By considering the approximations of the noninferior solution sets obtained for the two objectives Z and D, the decision maker is expected to choose the most reasonable solution, namely the "best compromise solution".

When the non-inferior solution set obtained by solving the model with the objectives Z and D for P = 1 is examined, it is seen that different alternatives are found. If the decision maker or the commander wants to minimize the maximum distance between IRCs and DRC, he must choose X_2 - DRC3. By selecting this site, the maximum distance between IRCs and DRC could be decreased to 1073 km., whereas in the existing system this distance is 1410 km. If the decision maker or the commander wants to minimize the risk of being non-functional for the communication devices, then the existing site (X_1 - DRC1) is optimal. However, one depot facility is not enough for decreasing the transportation time or the distance to 600 km., the distance accepted by the private cargo companies as one day' s transportation distance.

When the non-inferior solution set obtained by solving the model with the objectives Z and D for P = 2 is examined, it is seen that different alternatives are found. If the decision maker or the commander wants to minimize the maximum distance between IRCs and DRC, he must choose X_1 and X_3 together, namely DRC1 and DRC6. By selecting these sites, the maximum distance between IRCs and DRC could be decreased to 628 km. On the other hand, if the decision maker or the commander wants to minimize the risk of being non-functional for the communication devices, he must choose X_1 and X_7 together, namely DRC1 and DRC12.

When the two Depot Repair Centers are opened the savings in total transportation distances are stated in Tables 4.25. Namely, if commanders select the objective function D (minimization of maximum distance between IRCs and DRC) they could decrease total transportation distance at 45,60 %.

Table 4.26.: Savings in Total Transportation Cost

	The existing situation		
	DRC-1		
IRC-1	625.494.500 TL	0 TL	
IRC-2	649.214.500 TL	649.214.500 TL	
IRC-3	1.246.825.000 TL	1.246.825.000 TL	
IRC-4	2.145.870.000 TL		1.550.586.000 TL
IRC-5	518.075.000 TL	518.075.000 TL	
IRC-6	1.574.813.000 TL		0 TL
IRC-7	1.383.300.000 TL	1.383.300.000 TL	
IRC-8	1.007.000.000 TL	1.007.000.000 TL	
IRC-9	1.332.950.000 TL	1.332.950.000 TL	
IRC-10	364.375.000 TL	364.375.000 TL	
IRC-11	1.101.217.500 TL	1.101.217.500 TL	
IRC-12	857.942.000 TL		789.700.000 TL
IRC-13	1.463.971.500 TL		1.347.525.000 TL
IRC-14	1.099.750.000 TL	1.099.750.000 TL	
IRC-15	348.475.000 TL	348.475.000 TL	
IRC-16	695.625.000 TL	695.625.000 TL	
IRC-17	3.616.012.500 TL		3.027.625.000 TL
IRC-18	5.478.615.000 TL		4.587.150.000 TL
IRC-19	4.446.825.000 TL		3.723.250.000 TL
Total Transportation Cost	**29.956.350.500 TL**	**24.772.643.004 TL**	
	Decrease in total transportation cost		**17,30%**

Besides these savings stated in tables above the new situation can ensure other benefits like social improvements, operational effectiveness, boost in the morale of soldiers and economic contributions. Opening of the new depot repair center maybe increase the number of technicians who works in repairing but this can also decrease the redundancy of devices used for changing the faulty device with non-defective one. Because when second depot repair center is opened the repair cycle time decreases and a large number of devices are repaired in a short period of time.

Table 4.25.: Savings in Total Distance

	The existing situation		
	DRC-1		
IRC-1	0	0	-
IRC-2	604	604	-
IRC-3	490	490	
IRC-4	1057	-	134
IRC-5	382	382	-
IRC-6	923	-	0
IRC-7	453	453	-
IRC-8	258	258	-
IRC-9	319	319	-
IRC-10	399	399	-
IRC-11	628	628	-
IRC-12	877	-	323
IRC-13	819	-	276
IRC-14	580	580	-
IRC-15	313	313	-
IRC-16	268	268	-
IRC-17	1187	-	290
IRC-18	1410	-	551
IRC-19	1249	-	378
Total Distance	12216 KM.	6646 KM.	
	Decrease in total distance		45,60%

Thus, the one day' s transportation distance cannot be achieved by two depot facilities. Since increasing the number of facilities would result in higher costs, the model was solved for P=1, P=2, P=3, and P=4 and various transportation distances have been found. The decision maker or the commander could determine the best configuration for the maintenance network and select the "best compromise" solution.

Nevertheless, when we evaluate the situation in point of the trasportation cost which the two Depot Repair Centers are opened they could decrease total transportation cost at 17,30 % and this savings are stated in Table 4.26. When computing the Transportation Cost the faulty devices sended annually from Intermediate Repair Centers to Depot Repair Center and private cargo transportation costs are used.

5. CONCLUSION AND RECOMMENDATIONS

The Gendarmerie Signal Corps operates the maintenance network which is composed of three maintenance levels: Depot Level, Intermediate Level and Organizational Level. There exists one depot repair center where the depot level of maintenance and repair are done, 19 intermediate repair centers where the intermediate level of maintenance and repair are done and 81 organizational levels which consist of 1st and 2nd echelon of maintenance in the network. The Signal Corps is responsible for the repair and maintenance of various types of communication equipment. When the responsibility of the Signal Corps depot repair center is considered, the importance of the subject will be grasped clearly.

Signal Corps maintenance activities are organized to provide the gendarmerie forces with the maximum number of safe and mission-capable communication equipments. These activities must be dedicated to fast, continuous and reliable communication maintenance support in the highly mobile and integrated responsibility areas. The best maintenance decisions and actions are proactive, and they help us to perform our duties more effectively while getting a better return on the investment. The efficient and effective allocation of scarce resources is the key to the successful management of the country resources.

The problem with respect to the responsibility of the Signal Corps depot repair center is to provide fast and reliable repair and maintenance service to its lower echelon. While giving the service it takes into account the minimum transportation time and cost.

In the existing system, the service distances and the effectiveness factors are not taken into consideration completely while making the location and construction plans of the depot repair center. The importance of the problem is obvious when the high level of construction costs and the irretrievable results of a wrong site selection are considered. In this study, it is aimed at contributing to the development of a decision-support system for the command ranks who will decide for the structuring of the Gendarmerie Signal Corps maintenance network.

In this study, a multiobjective mathematical model has been developed that provides the determination of the best site(s) for the depot repair center, the allocations of lower echelons to these centers, and the number of depot repair centers, by considering the basic characteristics of the maintenance network system. The decision makers or commanders must analyze the changing conditions, the characteristics of the maintenance network and then determine the best depot repair center site(s) that would affect their repair and maintenance missions in a positive way.

In the study, the primary question considered was "How could the depot repair cycle time (RCT) be decreased?" As obtained from the interviews with the experts, there are several ways to decrease RCT, and one way is to increase the number of depot repair centers. There exist many different criteria affecting the location of the depot repair centers: the equipment density, transportation distance, the regional risk coefficient, failure rates and the total number of the communication equipments. Therefore in evaluating the depot repair center location, the model was solved for different numbers of facilities (P = 1, 2, 3, and 4).

In the model, two objectives have been considered, both of which directly affect the repair cycle time of the Signal Corps depot repair center. According to the objectives, the number and sites of depot repair centers and the allocations of lower echelons to these centers would change.

The criteria for depot repair center location discussed above should be taken into account when designing a location model for the DRC. There are also certain operational aspects of a DRC, which are not a part of the location policy, but have a major influence on the quality of security provided.

Payoff tables and graphics presented above display the number of DRCs to be located together with the affects on repair cycle time and transportation costs. The decision maker should incorporate his/her experience with these value paths and the non-inferior solution sets, and then determine the best number of DRC for the success of the repair and maintenance activities.

The presented multiobjective model provides the decision maker with the ability of determining the best number of DRCs according to the alternative scenarios. The commander does not have to decide in terms of a single objective. As in the real world problems, the commander can evaluate multiple objectives at the same time and make decisions in a more realistic way. The imposition of a single-objective approach on such problems will be restrictive and unrealistic. Also this model will indicate the decision maker a range of choice rather than a single "optimal" solution. The decision maker will have a chance to select the most suitable location among the solution set according to his/her experience.

All the regions of the country should be evaluated, than according to the characteristics of these regions, 2nd echelon of maintenance center's allocations should be determined. If the existing network of maintenance and the number of the depot repair center are found not sufficient, then the maintenance network should be planned in terms of the results obtained.

If we want to decrease the repair cycle times and transportation costs, while contrarily increase the availability of the equipment or the usability ratio, then the number of the depot repair centers should be increased. Not only increasing the number of depot repair center is not enough but also structuring a robust information network.

The important issues for the maintenance of communication equipment; like the maintenance personnel and spare parts availability, means of military transportation, equipment reliability, non-value added activities and repair costs are not considered in this study. Future research considering these issues as well for planning the location of the Gendarmerie Signal Corps depot repair centers would be helpful in achieving a better design of the maintenance network system.

However considering the transportation cost, repairing cost, opportunity cost and construction cost as well for planning the location of the Gendarmerie Signal Corps depot repair centers in future research will improve the study.

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APPENDICES

A1 : Cargo transportation times

A2 : Distance between Depot Repair Centers and Intermediate Repair Centers.

B1 : The Solution of the model for P = 2

B2 : Variable Coefficients of minimum Z for P = 2

B3 : Variable Coefficients of minimum D for P = 2

A1. Cargo transportation times

*t_{ij}	DRC 1	DRC 3	DRC 6	DRC 7	DRC 8	DRC 9	DRC 12
IRC-1	0	1	2	1	1	1	2
IRC-2	2	2	2	2	1	2	2
IRC-3	1	0	2	2	1	1	2
IRC-4	2	2	1	2	2	2	1
IRC-5	1	1	2	1	1	2	2
IRC-6	2	2	0	2	2	2	1
IRC-7	1	2	2	0	2	2	2
IRC-8	1	1	2	2	0	1	2
IRC-9	1	1	2	2	1	0	2
IRC-10	1	2	1	2	1	1	1
IRC-11	2	2	2	2	2	1	1
IRC-12	2	2	1	2	2	2	0
IRC-13	2	2	1	2	2	1	1
IRC-14	1	2	2	1	1	2	2
IRC-15	1	2	2	1	1	2	2
IRC-16	1	2	2	1	1	1	2
IRC-17	2	2	1	2	2	2	1
IRC-18	2	2	1	2	2	2	2
IRC-19	2	2	1	2	2	2	1

*This list is available on site http://www.yurticikargo.com.tr.

A2. Distance between Depot Repair Centers (DRC) and Intermediate Repair Centers (IRC).

d_{ij}	DRC 1	DRC 3	DRC 6	DRC 7	DRC 8	DRC 9	DRC 12
IRC-1	0	490	923	453	258	319	877
IRC-2	604	893	1415	693	542	864	1481
IRC-3	490	0	522	939	356	333	810
IRC-4	1057	656	134	1507	1012	738	405
IRC-5	382	834	1295	243	484	691	1235
IRC-6	923	522	0	1373	878	604	323
IRC-7	453	939	1373	0	665	772	1225
IRC-8	258	356	878	665	0	327	954
IRC-9	319	333	604	772	327	0	627
IRC-10	399	607	588	785	561	301	493
IRC-11	628	884	703	946	838	578	430
IRC-12	877	810	323	1225	954	627	0
IRC-13	819	625	276	1167	896	569	242
IRC-14	580	896	1418	566	546	867	1457
IRC-15	313	765	1226	250	415	622	1179
IRC-16	268	754	1188	331	522	587	1040
IRC-17	1187	712	290	1640	1068	868	523
IRC-18	1410	1073	551	1818	1429	1103	622
IRC-19	1249	900	378	1642	1256	930	417

*Gizlilik nedeniyle, Cihaz miktar ve isimleri ile Olay sayıları ve adları verilmemiştir.

B1. The Solution of the model for P = 2

Minimize the risk of being non-functional for the devices of IRC

$$\text{Min. } Z = \sum_{i=1}^{19}\sum_{j=1}^{7} W_{ij} Y_{ij}$$

Min. Z = $32906Y_{11}+ 34900Y_{12}+ 36894Y_{13}+ 34900Y_{14}+ 34900Y_{15}+ 34900Y_{16}+ 36894Y_{17}+ 38006Y_{21}+ 38006Y_{22}+ 38006Y_{23}+ 38006Y_{24}+ 35952Y_{25}+ 38006Y_{26}+ 38006Y_{27}+ 53401Y_{31}+ 50350Y_{32}+ 56453Y_{33}+ 56453Y_{34}+ 53401Y_{35}+ 53401Y_{36}+ 56453Y_{37}+ 3374Y_{41}+ 3374Y_{42}+ 3192Y_{43}+ 3374Y_{44}+ 3374Y_{45}+ 3374Y_{46}+ 3192Y_{47}+ 21304Y_{51}+ 21304Y_{52}+ 22522Y_{53}+ 21304Y_{54}+ 21304Y_{55}+ 22522Y_{56}+ 225222Y_{57}+ 16074Y_{61}+ 16074Y_{62}+ 14336Y_{63}+ 16074Y_{64}+ 16074Y_{65}+ 16074Y_{66}+ 15205Y_{67}+ 59555Y_{71}+ 62958Y_{72}+ 62958Y_{73}+ 56152Y_{74}+ 62958Y_{75}+ 62958Y_{76}+ 62958Y_{77}+ 31555Y_{81}+ 31555Y_{82}+ 33358Y_{83}+ 33358Y_{84}+ 29752Y_{85}+ 31555Y_{86}+ 33358Y_{87}+ 27977Y_{91}+ 27977Y_{92}+ 29576Y_{93}+ 29576Y_{94}+ 27977Y_{95}+ 26379Y_{96}+ 29576Y_{97}+ 9284Y_{101}+ 9815Y_{102}+ 9284Y_{103}+ 9815Y_{104}+ 9284Y_{105}+ 9284Y_{106}+ 9284Y_{107}+ 35142Y_{111}+ 35142Y_{112}+ 35142Y_{113}+ 35142Y_{114}+ 35142Y_{115}+ 33243Y_{116}+ 33243Y_{117}+ 17165Y_{121}+ 17165Y_{122}+ 16237Y_{123}+ 17165Y_{124}+ 17165Y_{125}+ 17165Y_{126}+ 15309Y_{127}+ 7549Y_{131}+ 7549Y_{132}+ 7141Y_{133}+ 7549Y_{134}+ 7549Y_{135}+ 7141Y_{136}+ 7141Y_{137}+ 7803Y_{141}+ 8249Y_{142}+ 8249Y_{143}+ 7803Y_{144}+ 7803Y_{145}+ 8249Y_{146}+ 8249Y_{147}+ 1278Y_{151}+ 1351Y_{152}+ 1351Y_{153}+ 1278Y_{154}+ 1278Y_{155}+ 1351Y_{156}+ 1351Y_{157}+ 2920Y_{161}+ 3087Y_{162}+ 3087Y_{163}+ 2920Y_{164}+ 2920Y_{165}+ 2920Y_{166}+ 3087Y_{167}+ 2534Y_{171}+ 2534Y_{172}+ 2397Y_{173}+ 2534Y_{174}+ 2534Y_{175}+ 2534Y_{176}+ 2397Y_{177}+ 3315Y_{181}+ 3315Y_{182}+ 3136Y_{183}+ 3315Y_{184}+ 3315Y_{185}+ 3315Y_{186}+ 3315Y_{187}+ 9544Y_{191}+ 9544Y_{192}+ 9028Y_{193}+ 9544Y_{194}+ 9544Y_{195}+ 9544Y_{196}+ 9028Y_{197}$

s.t.

1. $\sum_{j=1}^{7} d_{ij} Y_{ij} - D \leq 0$ $\forall i \in I$

$0Y_{11}+ 490Y_{12}+ 923Y_{13}+ 453Y_{14}+ 258Y_{15}+ 319Y_{16}+ 877Y_{17} - D \leq 0$
$604Y_{21}+ 893Y_{22}+ 1415Y_{23}+ 693Y_{24}+ 542Y_{25}+ 864Y_{26}+ 1481Y_{27} - D \leq 0$
$490Y_{31}+ 0Y_{32}+ 522Y_{33}+939Y_{34}+356Y_{35}+333Y_{36}+810Y_{37} - D \leq 0$
$1057Y_{41}+ 656Y_{42}+ 134Y_{43}+ 1507Y_{44}+ 1012Y_{45}+ 738Y_{46}+ 405Y_{47} - D \leq 0$
$382Y_{51}+ 834Y_{52}+ 1295Y_{53}+ 243Y_{54}+ 484Y_{55}+ 691Y_{56}+ 1235Y_{57} - D \leq 0$
$923Y_{61}+ 522Y_{62}+ 0Y_{63}+ 1373Y_{64}+ 878Y_{65}+ 604Y_{66}+ 323Y_{67} - D \leq 0$
$453Y_{71}+ 939Y_{72}+ 1373Y_{73}+ 0Y_{74}+ 665Y_{75}+ 772Y_{76}+ 1225Y_{77} - D \leq 0$
$258Y_{81}+ 356Y_{82}+ 878Y_{83}+ 665Y_{84}+ 0Y_{85}+ 327Y_{86}+ 954Y_{87} - D \leq 0$
$319Y_{91}+ 333Y_{92}+ 604Y_{93}+ 772Y_{94}+ 327Y_{95}+ 0Y_{96}+ 627Y_{97} - D \leq 0$
$399Y_{101}+ 607Y_{102}+ 588Y_{103}+ 785Y_{104}+ 561Y_{105}+ 301Y_{106}+ 493Y_{107} - D \leq 0$
$628Y_{111}+ 884Y_{112}+ 703Y_{113}+ 946Y_{114}+ 838Y_{115}+ 578Y_{116}+ 430Y_{117} - D \leq 0$
$877Y_{121}+ 810Y_{122}+ 323Y_{123}+ 1225Y_{124}+ 954Y_{125}+ 627Y_{126}+ 0Y_{127} - D \leq 0$
$819Y_{131}+ 625Y_{132}+ 276Y_{133}+ 1167Y_{134}+ 896Y_{135}+ 569Y_{136}+ 242Y_{137} - D \leq 0$
$580Y_{141}+ 896Y_{142}+ 1418Y_{143}+ 566Y_{144}+ 546Y_{145}+ 867Y_{146}+ 1457Y_{147} - D \leq 0$
$313Y_{151}+ 765Y_{152}+ 1226Y_{153}+ 250Y_{154}+ 415Y_{155}+ 622Y_{156}+ 1179Y_{157} - D \leq 0$

$268Y_{161} + 754Y_{162} + 1188Y_{163} + 331Y_{164} + 522Y_{165} + 587Y_{166} + 1040Y_{167} - D \leq 0$
$1187Y_{171} + 712Y_{172} + 290Y_{173} + 1640Y_{174} + 1068Y_{175} + 868Y_{176} + 523Y_{177} - D \leq 0$
$1410Y_{181} + 1073Y_{182} + 551Y_{183} + 1818Y_{184} + 1429Y_{185} + 1103Y_{186} + 622Y_{187} - D \leq 0$
$1249Y_{191} + 900Y_{192} + 378Y_{193} + 1642Y_{194} + 1256Y_{195} + 930Y_{196} + 417Y_{197} - D \leq 0$

2. $\sum_{j=1}^{7} X_j = 2$

$X_1 = 1$

$X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_7 = 2$

3. $\sum_{j=1}^{7} Y_{ij} = 1 \qquad \forall i \in I$

$Y_{11} + Y_{12} + Y_{13} + Y_{14} + Y_{15} + Y_{16} + Y_{17} = 1$
$Y_{21} + Y_{22} + Y_{23} + Y_{24} + Y_{25} + Y_{26} + Y_{27} = 1$
$Y_{31} + Y_{32} + Y_{33} + Y_{34} + Y_{35} + Y_{36} + Y_{37} = 1$
$Y_{41} + Y_{42} + Y_{43} + Y_{44} + Y_{45} + Y_{46} + Y_{47} = 1$
$Y_{51} + Y_{52} + Y_{53} + Y_{54} + Y_{55} + Y_{56} + Y_{57} = 1$
$Y_{61} + Y_{62} + Y_{63} + Y_{64} + Y_{65} + Y_{66} + Y_{67} = 1$
$Y_{71} + Y_{72} + Y_{73} + Y_{74} + Y_{75} + Y_{76} + Y_{77} = 1$
$Y_{81} + Y_{82} + Y_{83} + Y_{84} + Y_{85} + Y_{86} + Y_{87} = 1$
$Y_{91} + Y_{92} + Y_{93} + Y_{94} + Y_{95} + Y_{96} + Y_{97} = 1$
$Y_{101} + Y_{102} + Y_{103} + Y_{104} + Y_{105} + Y_{106} + Y_{107} = 1$
$Y_{111} + Y_{112} + Y_{113} + Y_{114} + Y_{115} + Y_{116} + Y_{117} = 1$
$Y_{121} + Y_{122} + Y_{123} + Y_{124} + Y_{125} + Y_{126} + Y_{127} = 1$
$Y_{131} + Y_{132} + Y_{133} + Y_{134} + Y_{135} + Y_{136} + Y_{137} = 1$
$Y_{141} + Y_{142} + Y_{143} + Y_{144} + Y_{145} + Y_{146} + Y_{147} = 1$
$Y_{151} + Y_{152} + Y_{153} + Y_{154} + Y_{155} + Y_{156} + Y_{157} = 1$
$Y_{161} + Y_{162} + Y_{163} + Y_{164} + Y_{165} + Y_{166} + Y_{167} = 1$
$Y_{171} + Y_{172} + Y_{173} + Y_{174} + Y_{175} + Y_{176} + Y_{177} = 1$
$Y_{181} + Y_{182} + Y_{183} + Y_{184} + Y_{185} + Y_{186} + Y_{187} = 1$
$Y_{191} + Y_{192} + Y_{193} + Y_{194} + Y_{195} + Y_{196} + Y_{197} = 1$

4. $X_i \in \{0,1\}, Y_{ij} \in \{0,1\}$

5. $X_j - Y_{ij} \geq 0 \qquad \forall i \in I; j \in J$

$X_1 - Y_{11} \geq 0$
$X_1 - Y_{21} \geq 0$
$X_1 - Y_{31} \geq 0$
$X_1 - Y_{41} \geq 0$
$X_1 - Y_{51} \geq 0$
$X_1 - Y_{61} \geq 0$
$X_1 - Y_{71} \geq 0$
$X_1 - Y_{81} \geq 0$
$X_1 - Y_{91} \geq 0$
$X_1 - Y_{101} \geq 0$
$X_1 - Y_{111} \geq 0$
$X_1 - Y_{121} \geq 0$
$X_1 - Y_{131} \geq 0$
$X_1 - Y_{141} \geq 0$
$X_1 - Y_{151} \geq 0$
$X_1 - Y_{161} \geq 0$
$X_1 - Y_{171} \geq 0$
$X_1 - Y_{181} \geq 0$
$X_1 - Y_{191} \geq 0$

$X_2 - Y_{12} \geq 0$
$X_2 - Y_{22} \geq 0$
$X_2 - Y_{32} \geq 0$
$X_2 - Y_{42} \geq 0$
$X_2 - Y_{52} \geq 0$
$X_2 - Y_{62} \geq 0$
$X_2 - Y_{72} \geq 0$
$X_2 - Y_{82} \geq 0$
$X_2 - Y_{92} \geq 0$
$X_2 - Y_{102} \geq 0$
$X_2 - Y_{112} \geq 0$
$X_2 - Y_{122} \geq 0$
$X_2 - Y_{132} \geq 0$
$X_2 - Y_{142} \geq 0$
$X_2 - Y_{152} \geq 0$
$X_2 - Y_{162} \geq 0$
$X_2 - Y_{172} \geq 0$
$X_2 - Y_{182} \geq 0$
$X_2 - Y_{192} \geq 0$

$X_3 - Y_{13} \geq 0$
$X_3 - Y_{23} \geq 0$
$X_3 - Y_{33} \geq 0$
$X_3 - Y_{43} \geq 0$
$X_3 - Y_{53} \geq 0$
$X_3 - Y_{63} \geq 0$
$X_3 - Y_{73} \geq 0$
$X_3 - Y_{83} \geq 0$
$X_3 - Y_{93} \geq 0$
$X_3 - Y_{103} \geq 0$
$X_3 - Y_{113} \geq 0$
$X_3 - Y_{123} \geq 0$
$X_3 - Y_{133} \geq 0$
$X_3 - Y_{143} \geq 0$
$X_3 - Y_{153} \geq 0$
$X_3 - Y_{163} \geq 0$
$X_3 - Y_{173} \geq 0$
$X_3 - Y_{183} \geq 0$
$X_3 - Y_{193} \geq 0$

$X_4 - Y_{14} \geq 0$
$X_4 - Y_{24} \geq 0$
$X_4 - Y_{34} \geq 0$
$X_4 - Y_{44} \geq 0$
$X_4 - Y_{54} \geq 0$
$X_4 - Y_{64} \geq 0$
$X_4 - Y_{74} \geq 0$
$X_4 - Y_{84} \geq 0$
$X_4 - Y_{94} \geq 0$
$X_4 - Y_{104} \geq 0$
$X_4 - Y_{114} \geq 0$
$X_4 - Y_{124} \geq 0$
$X_4 - Y_{134} \geq 0$
$X_4 - Y_{144} \geq 0$
$X_4 - Y_{154} \geq 0$
$X_4 - Y_{164} \geq 0$
$X_4 - Y_{174} \geq 0$
$X_4 - Y_{184} \geq 0$
$X_4 - Y_{194} \geq 0$

$X_5 - Y_{15} \geq 0$
$X_5 - Y_{25} \geq 0$
$X_5 - Y_{35} \geq 0$
$X_5 - Y_{45} \geq 0$
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$X_5 - Y_{65} \geq 0$
$X_5 - Y_{75} \geq 0$
$X_5 - Y_{85} \geq 0$
$X_5 - Y_{95} \geq 0$
$X_5 - Y_{105} \geq 0$
$X_5 - Y_{115} \geq 0$
$X_5 - Y_{125} \geq 0$
$X_5 - Y_{135} \geq 0$
$X_5 - Y_{145} \geq 0$
$X_5 - Y_{155} \geq 0$
$X_5 - Y_{165} \geq 0$
$X_5 - Y_{175} \geq 0$
$X_5 - Y_{185} \geq 0$
$X_5 - Y_{195} \geq 0$

$X_6 - Y_{16} \geq 0$
$X_6 - Y_{26} \geq 0$
$X_6 - Y_{36} \geq 0$
$X_6 - Y_{46} \geq 0$
$X_6 - Y_{56} \geq 0$
$X_6 - Y_{66} \geq 0$
$X_6 - Y_{76} \geq 0$
$X_6 - Y_{86} \geq 0$
$X_6 - Y_{96} \geq 0$
$X_6 - Y_{106} \geq 0$
$X_6 - Y_{116} \geq 0$
$X_6 - Y_{126} \geq 0$
$X_6 - Y_{136} \geq 0$
$X_6 - Y_{146} \geq 0$
$X_6 - Y_{156} \geq 0$
$X_6 - Y_{166} \geq 0$
$X_6 - Y_{176} \geq 0$
$X_6 - Y_{186} \geq 0$
$X_6 - Y_{196} \geq 0$

$X_7 - Y_{17} \geq 0$
$X_7 - Y_{27} \geq 0$
$X_7 - Y_{37} \geq 0$
$X_7 - Y_{47} \geq 0$
$X_7 - Y_{57} \geq 0$
$X_7 - Y_{67} \geq 0$
$X_7 - Y_{77} \geq 0$
$X_7 - Y_{87} \geq 0$
$X_7 - Y_{97} \geq 0$
$X_7 - Y_{107} \geq 0$
$X_7 - Y_{117} \geq 0$
$X_7 - Y_{127} \geq 0$
$X_7 - Y_{137} \geq 0$
$X_7 - Y_{147} \geq 0$
$X_7 - Y_{157} \geq 0$
$X_7 - Y_{167} \geq 0$
$X_7 - Y_{177} \geq 0$
$X_7 - Y_{187} \geq 0$
$X_7 - Y_{197} \geq 0$

B2. Variable Coefficients of minimum Z

P=2	DRC 1	DRC 3	DRC 6	DRC 7	DRC 8	DRC 9	DRC 12
IRC-1	1	0	0	0	0	0	0
IRC-2	1	0	0	0	0	0	0
IRC-3	1	0	0	0	0	0	0
IRC-4	0	0	0	0	0	0	1
IRC-5	1	0	0	0	0	0	0
IRC-6	0	0	0	0	0	0	1
IRC-7	1	0	0	0	0	0	0
IRC-8	1	0	0	0	0	0	0
IRC-9	1	0	0	0	0	0	0
IRC-10	1	0	0	0	0	0	0
IRC-11	0	0	0	0	0	0	1
IRC-12	0	0	0	0	0	0	1
IRC-13	0	0	0	0	0	0	1
IRC-14	1	0	0	0	0	0	0
IRC-15	1	0	0	0	0	0	0
IRC-16	1	0	0	0	0	0	0
IRC-17	0	0	0	0	0	0	1
IRC-18	0	0	0	0	0	0	1
IRC-19	0	0	0	0	0	0	1

B3. Variable Coefficients of minimum D

P=2	DRC 1	DRC 3	DRC 6	DRC 7	DRC 8	DRC 9	DRC 12
IRC-1	1	0	0	0	0	0	0
IRC-2	1	0	0	0	0	0	0
IRC-3	0	0	1	0	0	0	0
IRC-4	0	0	1	0	0	0	0
IRC-5	1	0	0	0	0	0	0
IRC-6	0	0	1	0	0	0	0
IRC-7	1	0	0	0	0	0	0
IRC-8	1	0	0	0	0	0	0
IRC-9	1	0	0	0	0	0	0
IRC-10	1	0	0	0	0	0	0
IRC-11	1	0	0	0	0	0	0
IRC-12	0	0	1	0	0	0	0
IRC-13	0	0	1	0	0	0	0
IRC-14	1	0	0	0	0	0	0
IRC-15	1	0	0	0	0	0	0
IRC-16	1	0	0	0	0	0	0
IRC-17	0	0	1	0	0	0	0
IRC-18	0	0	1	0	0	0	0
IRC-19	0	0	1	0	0	0	0

CV

CURRICULUM VITAE OF THE AUTHOR

Personnel Details

Birth of Date	: 01 July 1974
Birth of Place	: UŞAK
Marital Status	: Married

Education

High School	: 1989-1993 Kuleli Military High School / İstanbul
Bachelor's Degree	: 1993-1997 Military Academy / Ankara

Work Experience

1998 -	: The General Command of Gendarmerie / the Signal Corps.