Locating Search and Rescue Stations in the Aegean and Western Mediterranean Regions of Turkey

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LOCATING SEARCH AND RESCUE STATIONS IN THE AEGEAN AND WESTERN MEDITERRANEAN REGIONS OF TURKEY

THESIS

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This research does not contain the official policy of the Turkish Air Force about Search and Rescue concept. Furthermore, the maps to show the results in Chapter 5 are only for demonstration, not for implementation. I am solely responsible for any comment or critique that may be made about this study.

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M. Melih Başdemir

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Abstract

The service of present Search and Rescue (SAR) stations in the Aegean and the Western Mediterranean regions of Turkey are not sufficient to meet the demands of the Turkish Air Force. This research seeks to find the optimum location of new SAR stations. The number of SAR stations required to cover all areas of operation becomes a very decisive element in finding the optimal coverage of the operation area by these stations.

The problem of finding the optimum SAR locations can be modeled as a maximal covering location problem (MCLP). Additional constraints are added to set standards on various issues in the regions. Main emphasis is to given to finding the minimum number of SAR locations that achieves maximum coverage in the operation area. Bonus values that indicate the importance of covering demand points are also included for analysis purposes. The model is coded and solved with an optimization software.

The solution shows the location of SAR stations and the total coverage in the area based on the operational capacity of SAR units. Several scenarios are examined and the results are then analyzed and presented.

CHAPTER 1

I. INTRODUCTION

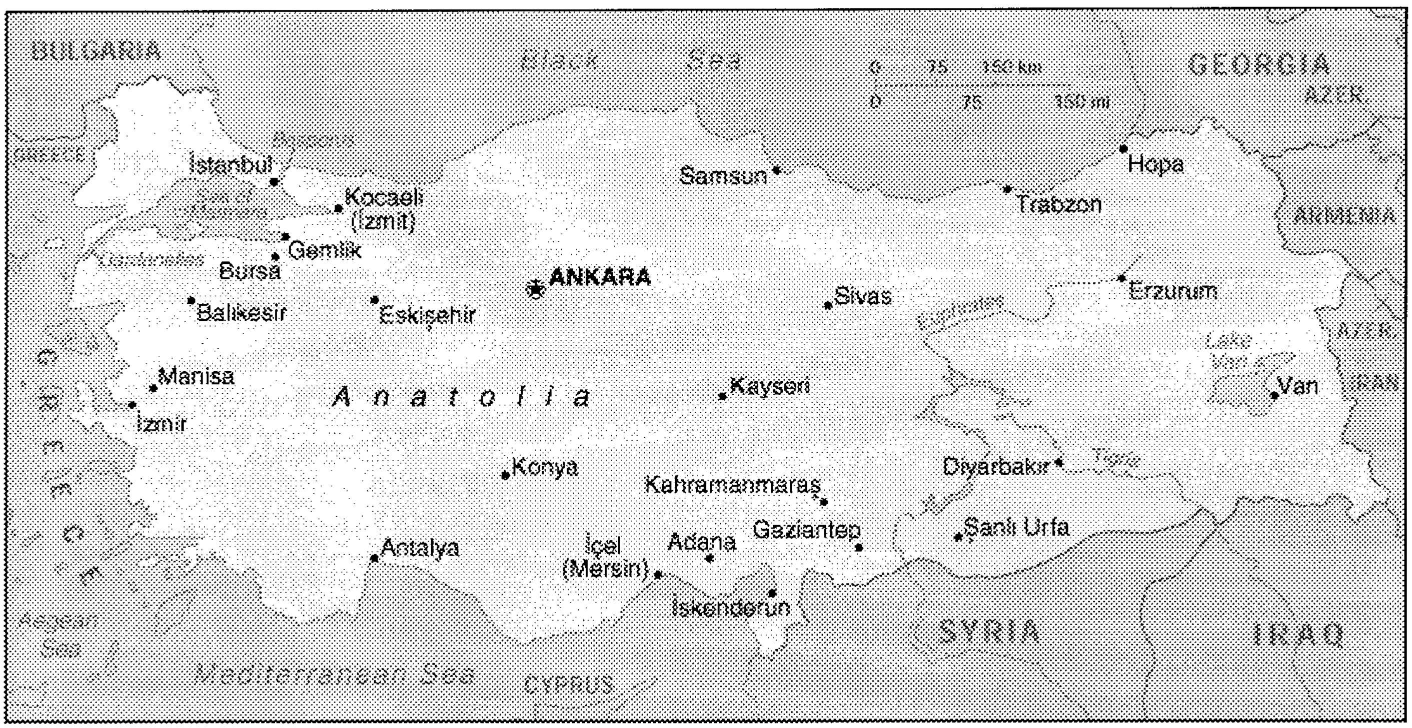
1.1 General Information About Turkey

A country of sun and history, Turkey is located where the three continents making up the old world, Asia, Africa and Europe, are closest to each other, and it straddles the point where Europe and Asia meet. Turkey has two European and six Asian neighbors, which are Bulgaria, Greece, Georgia, Armenia, Azerbaijan, Iran, Iraq, and Syria.

Because of its geographical location, the mainland, Anatolia, has witnessed the mass migration of diverse peoples shaping the course of history. The home of countless cultures, Anatolia has developed a unique synthesis of those cultures, each with its own distinct identity, yet each linked to its predecessors through insoluble threads. Anatolia has always found favor throughout history and is the birthplace of many great civilizations. It has also been prominent as a center of commerce because of its land connections to three continents and the sea surrounding it on three sides. Today, the total coastline (including islands) of Turkey is 8,372 km., (Aegean: 2,805 km. Mediterranean: 1,577 km. Black Sea: 1,695 km., and Marmara: 927 km)

The accomplishments of modern Turkey have been very impressive. After the National War in 1923, the main task was to create a democratic, independent society. In a time of imperialism, Turkey was one of the few nations to keep its independence, despite the great odds against it. First noted under Mustafa Kemal Atatürk for its campaign to educate and develop its people to live in the modern world, Turkey now is an economic success and a multiparty democracy. Today, Turkey is a bridge between the Middle East and the West, as well as a bridge between the West and the newly freed lands of Central Asia.

The success of Turkey is all the more remarkable because, as has been said, "Turkey is in a rough neighborhood." Turkey has some problems with neighboring countries such as Greece, Iran, Iraq and Syria. The problems with the southern neighbors, such as Iran, Iraq and Syria, are terrorism related. On the other hand, the problems with Greece are related with various issues such as the Aegean conflict, Cyprus and Thrace.



Turkey is generally divided into seven regions: Black Sea, Marmara, Aegean, Mediterranean, Central Anatolia, Eastern Anatolia and Southeastern Anatolia. The Aegean region extends from the Aegean coast to the inner parts of western Anatolia. In general, the mountains in the region fall perpendicularly into the sea, and the plains run from east to west.

In the Mediterranean region, located in the south of Turkey, the western and central Taurus Mountains suddenly rise behind the coastline. As in almost every region of Turkey, these regions have very rough terrain.[21] For the regional maps, one may refer to Appendix A.

1.2. Turkish Air Force

The Turkish Air Force has the responsibility of defending Turkey's national sky borders, deterring unfriendly actions and training its own personnel to keep up with the other modern air forces in the world. Today, the Turkish Air Force has modern airplanes and equipment, well-trained personnel, and outstanding combat-ready squadrons for any type of mission in the region. Along with other NATO countries, the Turkish Air Force has been involved in international operations in Bosnia and recently in Kosovo.

The Turkish Air Force has many fighter and cargo bases all over Turkey. Other branches of the Air Force, such as Logistics Command and Air Force Educational Training Command support the flight activities. The Turkish Air Force sponsors many projects like Unmanned Aerial Vehicle (UAV), CASA cargo airplane production (CASA is a Spanish made light cargo airplane produced in Turkey under a joint venture agreement between Spain and Turkey), F-16 production, plus F-5 and F-4 modernization efforts.

A majority of the sorties is flown in the Aegean region of Turkey. Turkey has national concerns about the Aegean Sea; therefore, this region is given major emphasis and attention. In addition, some missions are conducted in the international waters of the Aegean and Mediterranean Seas. Being an international territory makes these regions very important.

The Turkish Air Force is determined to protect Turkey's interests in the region. For this reason, flight activities are planned for deterring opposition. In many international summits, Turkey's rights were confirmed with respect to the Laussane agreement about Aegean national waters and skies. The Turkish Air Force is conducting daily flight missions to defend Turkey's rights according to international agreements.

Today, the Turkish Air Force is the best air force in the region. Turkey is leading many newly independent countries and trying to help them form their air force structures. Having the aviation spirit given by Turkey's founder, Ataturk, the Turkish Air Force will always be ready to serve the Turkish people and Turkey's friendly allies.

1.3. Search and Rescue (SAR)

Search and Rescue (SAR) is a vital issue to pilots, especially those who fly fighter airplanes for combat or training purposes in the international skies. Fighter pilots want to be rescued as soon as possible when their airplane is shot down or crushed into the ground because of a technical failure. In both cases, SAR teams play key roles in the rescue of downed personnel.

The Turkish Air Force states that personnel recovery activities, including SAR, represent "a critical element in the national defense ability to fulfill its moral obligation to protect its personnel, prevent exploitation of Turkish personnel by adversaries and reduce the potential of captured personnel being used as leverage against Turkey." [20]

If an aircrew goes down during any flight mission, SAR teams will execute the rescue mission. For this reason, SAR teams are trained for almost any situation, whether medical, military or just plain survival. Turkey has SAR units located at every air force base, and normal SAR activities are lead by these SAR units. Some new tools have been and are being developed to increase the effectiveness of SAR in order to meet today's real-life demands.

More information about SAR and its potential problem areas in the Turkish Air Force is presented in Chapter 2.

1.4 Conclusion

Chapter 2 discusses the background of the SAR mission and presents the scope and objectives of the research. Chapter 3 gives a literature review related the location problems and talks about the solution techniques for these types of problems. Chapter 4 explains the methodology, approach and the mathematical model. Chapter 5 is the results and analysis chapter. It interprets all the solution scenarios and the conclusions that can be derived from these solutions. Chapter 6 gives a general conclusion for this research and suggests some of the possible follow-on topics related to this study.

CHAPTER 2

II. BACKGROUND

2.1 SAR Activities

Turkey's National Search and Rescue (SAR) Plan is derived from international and domestic military agreements between authorities sharing a common interest. In practice, Search and Rescue is conducted with a spirit of cooperation between relevant authorities, and procedures exist to transfer a Search and Rescue incident between base authorities. The ideal arrangement is the seamless provision of Search and Rescue resources to an aircrew or unit in distress. The nature of Turkey's National Search and Rescue Plan demands a fairly flexible approach to Search and Rescue operations. Many Search and Rescue response units are dedicated to the task and are kept on stand-by at air bases.[20]

The purpose of SAR activities in the Turkish Air Force is to search for air crew and passengers in case of an accident, and execute any rescue mission as soon as possible. In wartime, however, this purpose includes bringing back the national and allied crew members from behind enemy lines to friendly territories where medical first aid can be supplied.[18]

Currently, the Turkish Air Force has SAR stations at all fighter bases; however, those SAR stations do not cover all areas of operation. For this reason, we need to locate more SAR stations. Currently there is no tool that evaluates the effectiveness of SAR activities. If we set aside the tactical details of the rescue operation, then the expected percentage of successful rescues is proportional to the survival probability. Any individual's chances of survival depend on the specifics of the situation, including local weather, geographical conditions, availability of cover and his/her own physical and mental condition. Moreover, if the crew member survives the initial period immediately after the incident the conditional probability of survival remains constant or decreases slightly over time.[17]

The Turkish Air Force conducts SAR missions using airplanes and helicopters. In case of an accident, the aircraft locates the crewmember, drops a SAR team into the area and passes this information to the nearest SAR station. Based on recent experiences, the current number of SAR stations in the Aegean and Western Mediterranean regions is not enough.

2.1.1 SAR Principles

- The purpose of SAR operation is to save lives. SAR action must be initiated as soon as possible by using all assets available for SAR activities.
- The regional SAR units are responsible for planning and executing SAR missions in their assigned areas. These SAR units report all incidents and SAR activities in their regions to the SAR Command as soon possible.
- All the SAR units must be ready to execute any SAR operation at any time.
- The SAR units may request additional supplies and further assistance from other units when it is necessary to commit the operation.
- SAR operations are executed using helicopters, airplanes, rescue boats and ships.
- Joint or separate SAR exercises must be carried out once every two months in order to ensure mission-readiness all the time.

- SAR personnel must be well trained, and tested regularly to determine their performance and knowledge levels.
- The equipment supplied to the SAR units must be well maintained and kept mission-ready.

2.1.2 SAR Plan

A SAR plan's objectives are:

- To detect the possible accident area along with the crewmembers.
- To decide the most suitable search area.
- To choose appropriate equipment, personnel and type of operation.
- To define target's condition, if possible.

These objectives are shown in 1.

The plan-maker should focus on the center of the accident area first, and enlarge the search area if the SAR units can not achieve any progress when they execute the operation. For this reason, the planner must maintain close contact with rescuers.

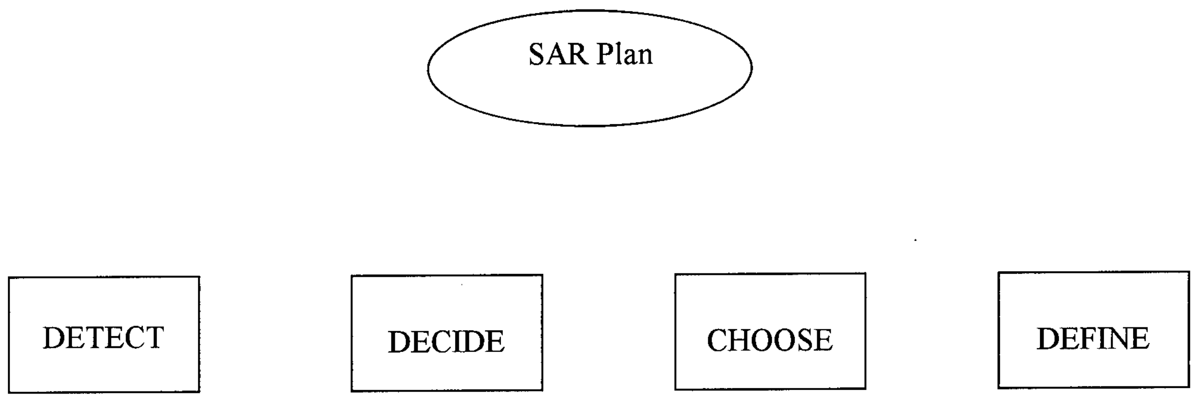


Figure 1: SAR PLAN OBJECTIVES

2.1.3 Search Factors

The following factors form the search guidelines;

- Verification and validation of current information.
- The knowledge level of the air crew being rescued.
- The dimensions of the search area.
- Meteorological conditions.
- Day and night conditions.
- The training and skill level of the SAR unit.
- Search and parachute deployment altitudes. Parametric data is given in Table 1.

Table 1 explains parachute-dragging distances by comparing parachute deployment altitude versus wind speed. The dragging distance increases when the parachute deployment altitude goes up and the wind is constant. In addition, wind also increases the dragging distance when it increases the speed.

Table 1: Parachute dragging distances (NM)

Parachute deployment altitude(feet)	WIND (KNOTS)						
	10	20	30	40	50	60	70
20,000	2.7	5.3					
10,000	1.4	2.8	4.2	5.7	7.0	8.3	9.7
6,000	0.9	1.7	2.6	3.5	4.4	5.2	6.1
4,000	0.6	1.2	1.8	2.4	3.0	3.5	5.1

2.1.4 SAR Operation Procedures

SAR units need detailed plans to ensure the success of rescue activities. The plan should be updated according to the developing circumstances. Search aircraft should take off immediately after the incident.

Before the rescue mission, SAR personnel should attend a briefing, if possible. In this briefing, all the information known about the accident is discussed among the SAR personnel. The search region and the possible clues are defined. Rescue type (sea, mountain, forest, etc), equipment, and report procedures are also defined. If possible, emergency frequencies, weather conditions and any national and international SAR agencies involved is reviewed.

After the rescue mission, the SAR personnel provide any information about regional conditions, survivors' medical conditions, responses, and the overall mission and its effectiveness.

2.1.5 SAR With Helicopters

Helicopters add flexibility to the SAR operation. They can be used in two forms:

- They can land on any flat ground, or on navy ships to transport equipment and rescue personnel in the accident region.
- They can be used without landing by simply using a crane or a portable ladder.

The first form is commonly used for mountain or ground rescue missions, while the second one is generally used for sea rescue missions. In the second case, SAR personnel may jump in the water to help the crewmember and apply medical first aid if it is necessary.[19]

2.2 Past Experience and Mishaps

Pilots in the Aegean and the Mediterranean regions fly in a very hot and vulnerable hostile environment. The missions called "Free Seas" are being conducted in the international waters of the Aegean and Mediterranean Seas. Sometimes unfriendly incidents take place with a neighboring country, Greece, and these missions become very serious and can evolve into a regional crisis like the Kardak crisis in early 1996 (Kardak crisis was an island conflict in the Aegean Sea between Turkey and Greece, and it was settled in peace by mutual negotiations).

Since this area has become very important, some aircraft accidents also have happened in previous years. After the latest incident, the Turkish Air Force developed new SAR models, but they are not very efficient. For instance, the latest model uses beacon signals. Each pilot carries a device that emits beacon signals in case of ejection. Meanwhile, the mobile SAR units are located somewhere that covers the mission area. Once the SAR units receive signals, they spot the pilot, and immediately initiate the rescue mission.

The new rescue methods certainly improve rescue success, however the SAR activities still are not enough to keep up with the current flight missions in the region. The Turkish Air Force has to find better ways to overcome this problem. For this reason, the idea of locating new SAR stations is introduced.

2.3 Why Aegean and Mediterranean?

As mentioned above, Turkey is a peninsula surrounded by the Aegean, Mediterranean and Black Seas. The majority of past international issues have been centered in the Aegean and Mediterranean regions. There are a lot of problems in the region. Because of sensitive issues such as Cyprus and Aegean water borders, bordering countries concerned with these problems pay extra attention to the region. This condition makes the Turkish Air Force more concerned about daily regional missions.

In order to meet the Turkish Air Force demands and interests in the region, the Aegean and Mediterranean regions are selected for this study. The Air Force wants to rescue its downed personnel in any part of these regions.

2.4 Problem Definition

The following scenario describes the problem.

The Turkish Air Force wants to locate some new SAR stations to increase its capabilities in the Aegean and Western Mediterranean regions. The current capability is not adequate to meet air force demands. The major considerations are number of stations and the coverage area of those stations. The Air Force wants to obtain maximum coverage with a limited number of stations in the region.

There are some possible candidate points where the SAR stations can be located and certain demand points that must be served. Every candidate point has meteorological and geographical and logistics values. The Air Force has established standards for these values. Resources limit the number of additional stations. All stations use similar SAR helicopters. Each candidate point's coverage area is known. Every demand point has an importance value. Each demand point's importance value, known as the bonus value is based on the frequency of missions flown around that point. The region is a holiday resort for tourists from inside and outside Turkey, so the Air Force does not want to interfere with tourist issues in the region.

Given this scenario, the problem is to locate a limited number of SAR stations to obtain maximum coverage.

2.5. Scope and Objectives

Placing SAR stations may be regarded as a facility location problem. In a review of analytic models for locating facilities, Erkut and Neuman [10] state:

> ... we judge the site election stage to be too complex for accurate representation using an analytically tractable single-objective model.... Current models can be used to generate a small number of candidate sites, but the final selection of a site is a complex problem and should be approached using multi-objective decision making tools.... Further, reporting of such applications would benefit practitioners and researchers...

In this study there are two objectives. One is represented in the objective function, and the other one is modeled as a constraint. This partitioning of objectives makes the problem easier to solve. The basic objectives for this study are:

- Maximize coverage in the region.
- Limit the number of stations.

These objectives shape the objective function in the mathematical formulation and are explained in detail in Chapter 4.

In this study, the problem is dealt with by applying location problem techniques. An integer programming model is developed and solved. This study only reveals the location of SAR stations and it does not deal with the basing issues of the stations. Basically, the scope of this research is limited to the location stage of the problem. The research presents analysis of the results, makes recommendations and indicates potential extensions of the research.

2.6. Assumptions

The problem of locating SAR stations is a location problem and we do not plan to deal with basing issues. So, we make the following assumptions;

1. This research does not reflect the official policy of the Turkish Air Force. The author is responsible for any comments and critiques related to this research.

2. Since the cost of locating each candidate point is assumed the same, therefore cost is not included in this problem.

3. Similar helicopters are used at the SAR stations. Although their attributes are realistic, they are called Helicopter X

4. Fixed distances from the candidate points are defined to indicate demand points.

5. Demand points and candidate points are generic. In other words, they are notional points in the region.

6. Each demand point is the origin of 10 NM radius. The operation perimeter is based on this radius.

7. Basing issues are not included. The study examines only SAR location selection. It does not deal with personnel, equipment, design, or training issues at the stations.

8. There are a finite number of potential SAR station locations.

9. A demand point is covered if it is within the effective range of a SAR station.

10. Demand point coverage must be maximized.

11. The capacity and the performance of each SAR station are the same; however, their demand point coverage is different.

The next chapter presents a review of the literature pertinent to this research.

CHAPTER 3

III. LITERATURE REVIEW

3.1. Location Problems

Location problems seek the best locations for service facilities such as fire stations, military installations, airports, or warehouses. The mathematical structure of a location problem depends on the region available for the location and on how we judge the quality of a location. Consequently, there are many different kinds of location problems, and the literature offers a variety of solution techniques.[15]

Location theory was first formally introduced in 1909 for locating a single warehouse to minimize the total travel distance between the warehouse and a set of spatially distributed customers. A number of authors in the 1950s and 1960s considered the problem of facility layout and design. Before the mid-1960s, however, work in the field of location theory consisted primarily of a number of separate applications not tied together by a unified theory. Interest in location problems was sparked by Hakimi who considered the general problem of locating one or more facilities on a network to minimize the travel distances in the network. Since then, considerable research has been carried out in the field of location theory.[1]

Basing or coverage type problems often are treated as location problems. The goal in location problems is to locate service facilities to minimize some cost function or to maximize the amount of demand for service that can be satisfied. In addition, fundamental to modeling of location decisions is some measure of proximity. While specific point-to-point distances are often used, the concept of coverage is a well-known alternative. The norm of partitioning inter-point distances based on some distance standard has been employed extensively in location literature for over thirty years. Location models fit into two broad categories based on whether coverage is required or optimized.[10]

3.2. Definition and Solution Techniques

According to one general definition, a location problem is a spatial resource allocation problem. In the general location paradigm, one or more service facilities (servers) serve a spatially distributed set of demands (customers).[1] Another source states that the plant location problem represents an idealization of a variety of practical decision problems.[14]

When we look at the solution procedures, we see both optimization and heuristic techniques. Optimization techniques include mixed integer programming, which is the most straightforward of the methods for optimizing location problems. The objective here is to optimize a linear cost function subject to constraints describing available service. Another optimization technique used is Lagrangian optimization. These method results in a much smaller mathematical formulation than integer programming, but it may become more difficult to solve. Heuristic techniques, on the other hand, have been developed to provide feasible solutions quickly that are acceptably close to the optimum. Heuristic techniques are used when exact methods for finding optimum solutions to location problems become too time consuming.[11] The primary algorithm used today to solve integer programs is the simplex algorithm with branch-and-bound applied to the relaxed integer program. There are many commercially available linear solvers, such as LINDO and CPLEX. There are also many heuristic solution approaches to integer programming problems and large zero/one problems [10]. Table 2 shows solution and evaluation techniques for location models.

Table 2: Some Solution Techniques for Location Models

1. *Exact Solution Techniques*

- Analytical Solution/Optimality Result*
- Integer Programming/Branch and Bound
- Dynamic Programming/Backtrack Programming
- Convex Programming
- Other

2. *Heuristic Solution Techniques*

- Exchange Heuristics
- Greedy ("Add") Heuristics
- Drop Heuristics
- Sequential Location and Allocation
- Solution of an Approximate Problem
- Solution of a Relaxed Problem
- Solution of a Restricted Problem
- Tabu Search♦
- Genetic Algorithms
- Other

3. *Techniques for Evaluation of Heuristics*

- Bound on Optimal Solutions
- Worst Case Analysis
- Probabilistic Analysis
- Statistical Evaluation

- Stopping Rule

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* May be combined with numerical search methods

♦ More information about Tabu Search can be found in Appendix E.

3.3. Location Problem Types

Two versions of the location covering problem are the set covering problem (SCP) and the maximal covering location problem (MCLP). The SCP involves finding the minimum number of facilities required to cover a given set of demand points. The covering constraints are usually based on some easily determined metric such as distance or time-of-travel. On the other hand, the limited nature of most budgets can make covering all customers impractical. The MCLP attempts to address this problem by locating a limited number of facilities to cover the maximum number of, but not necessarily all, demand points. If all demand points are covered by the given number of facilities, the problem is equivalent to the SCP.[6] Table 3 presents the relationship between the SCP and MCLP

The SCP and the MCLP are extremely powerful tools in location analysis. Applications of these covering models include the location of daycare facilities, fire stations, bus stops, emergency services, computer service centers, airports, and military bases. Extensions to the original models may include multi-objective formulations, hierarchical location schemes, multiple or backup coverage, and facility capacity.[16]

Another version of location covering problems is the maximal expected covering location problem (MECLP). The MECLP has been used extensively in analyzing locations for public service facilities. The MECLP accounts for the possibility a covered demand point is not serviced since all facilities capable of covering the demand are engaged serving other demands. The formulation is an integer program. In industrial contexts, facilities may be unable to respond to demands due to inclement weather, labor conditions or facility maintenance needs.[2] To preclude this situation, we would therefore like to have more than one facility capable of covering each demand point or node, particularly those nodes that generate large numbers of demands. This idea is also applicable to the location of SAR stations. Here, the primary objective is to cover all the demands with the minimum number of facilities. Another objective of the SAR location problem is to maximize a measure of multiple coverage.[3]

Table 3: Relationships Between SCP and MCLP

Problem	Number of Facilities	% Demand Coverage	Coverage Distance
SCP	Objective function (min.)	100%	Exogenous
MCLP	Exogenous	Objective function (max.)	Exogenous

CHAPTER 4

IV METHODOLOGY

4.1 Formulation Background

The optimum location of SAR stations in the Aegean and Western Mediterranean regions of Turkey can be modeled as an MCLP with a number of additional constraints. In the problem, there are candidate points that model the location of SAR stations. The solution shows the number of demand points that can be covered and which candidate points should be selected. Each candidate point has a coverage area and each demand point has a priority (bonus) value. These bonus values show the importance of the demand points. Therefore, each demand point is given a value depending on its strategic and operational importance.

Demand coverage is handled in two ways. At first, demand points are covered once, and then, with a minor modification, the coverage is increased to more than one. At this time, bonus values for each demand point cause the objective function to encourage covering each demand point more than once. Bonus points are used to prioritize the demand points. Different demand points have different bonus values based on their operation tempo like more flights, more risk, and etc. A complete bonus value list is in Appendix B. Each demand point does not have to be covered; however, any uncovered demand point does not contribute to the value of the objective function. Furthermore, there are constraints on the maximum number of SAR locations, weather, geography and logistics.

There are two types of decision variables; one for demand points and one for candidate points. First, both types are introduced as binary integer variables. This covers the demand points only once. Then the variables for the demand points are treated as general integer variables while the decision variables for the candidate points remain binary. This approach allows us to vary the constraint parameters and analyze results regarding these variations. In order to form some regional constraints, each candidate point is given a logistics, weather and geography value. These values are based on the candidate point's conditions with respect to these areas. For the solution, selected candidate points have to be above the average value for these areas. In other words, the sum of candidate point values for each additional constraint has to be above some level for the candidate point to be feasible. This level is a reasonable numerical value based on the conditions of that area. The logistics, weather, and geography values for each candidate point are in Appendix B.

4.2 Approach

This location problem is formulated as an integer program and solved using LINGO 5. Candidate point selection strategy is based on current military facilities and potential sites. We prefer to use facilities that are ready to use when applicable, but in this study, facility construction is not an issue. On the other hand, demand point selection depends on the areas of operation.

4.2.1 Candidate Point Inclusion

Candidate point inclusion strategy is based on regional issues, and the various advantages and disadvantages of the selected points. There is no strict guideline that depicts this inclusion process. One major issue is the proximity of candidate points. There are many sites that can be included as candidate points, and each one has different characteristics. Therefore, we try to include those points close to each other in order to evaluate their coverage capabilities and regional issues such as geographical, logistical and meteorological advantages.

Although there may be a considerable number of points in a given region, each point provides different coverage and has different pertinent regional issues. For this reason, there are more candidate points than demand points. The coverage is varied, and is examined for 150 NM, 120 NM and 80 NM radii. These are derived from the operation capabilities of Helicopter X. The specifications of Helicopter X are shown in Table 4. Under normal conditions, Helicopter X has an operational range of 300 NM. This includes take-off, enroute, rescue and RTB (Return to Base). Therefore, 150 NM coverage is considered normal. 120 NM coverage is for abnormal conditions such as poor visibility or in-flight emergency. 80 NM coverage is the worst case scenario. Coverage data is provided separately for each of these distances.

Table 4: Helicopter X

Aircraft Specifications	
Cruise Speed:	135 kts
Max. Passengers:	Twelve
Max. Take Off Weight:	4,765 kg
Range (internal tanks):	3.50 hrs
External Load Capacity:	1,500 kg

4.2.2 Demand Point Selection

Demand point selection is vital to this research, since demand points define the coverage of operation areas. Selecting the demand points defines possible rescue points. Since, an accident may happen anywhere; demand points must represent all areas.

Each demand point represents a specific area for coverage, and each one represents a circle with a radius of 10NM. Collectively, these represent the entire area of operation. In our model there are 100 demand points. The model tries to maximize the coverage of these demand points. The relationship between the candidate point and the demand point variables is shown in Figure 2.

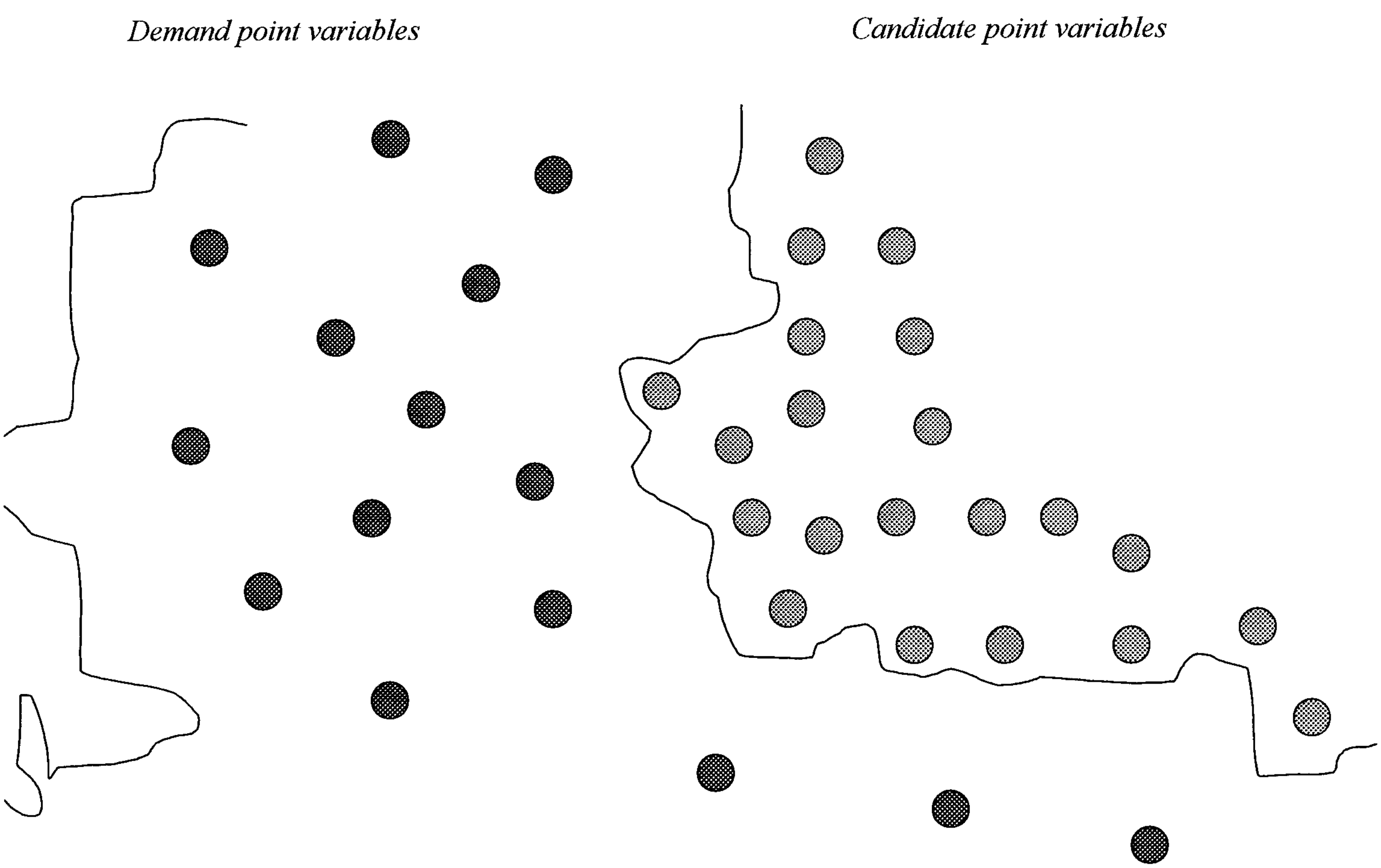


Figure 2: Candidate points and Demand points

4.3 The Mathematical Model

The mathematical model can be described as an MCLP with additional constraints and variables.[16] A typical MCLP is formulated mathematically as :

Maximize $Z = \sum a_i \bullet y_i$ $\quad i \in I$

Subject To:

$\sum x_j \geq y_i$ $\quad \forall i \in I, \quad j \in Ni$

$\sum x_j \leq P$ $\quad j \in J$

$x_j \in \{ 0,1 \}$ $\quad \forall j \in J$

$y_i \in \{ 0,1 \}$ $\quad \forall i \in I$

where I = set of demand points, J = set of candidate facility location sites.

x_j (candidate points) = 1 if site at location j is occupied, 0 otherwise.

y_i (demand points) = 1 If demand point at i is covered, 0 otherwise.

a_i = the value of covering demand point i for i = 1,.....m

P = the number of facility location sites that can be occupied.

4.3.1 Model Formulation :

Our formulation of the SAR location problem is:

$$\text{Maximize} \quad Z = \sum a_i \bullet y_i \qquad i \in I \qquad (1)$$

S.T.

$$\sum x_j \geq y_i \qquad \forall i \in I, \quad j \in Ni \qquad (2)$$

$$\sum x_j \leq P \qquad j \in J \qquad (3)$$

$$\sum L_j \bullet x_j \geq N_L \bullet \sum x_j \qquad j \in J \qquad (4)$$

$$\sum G_j \bullet x_j \geq N_G \bullet \sum x_j \qquad j \in J \qquad (5)$$

$$\sum W_j \bullet x_j \geq N_W \bullet \sum x_j \qquad j \in J \qquad (6)$$

$J = \{1\ldots152\}$, $I = \{1\ldots100\}$

$$x_j \in \{0,1\} \qquad \forall j \in J,$$

$$y_i \in \{0,1\} \qquad \forall i \in I,$$

where :

I = set of demand points

J = set of candidate SAR location sites

$x_j = 1$ if SAR site at location j is occupied, 0 otherwise.

$y_i = 1$ if demand point i is covered, 0 otherwise.

a_i = the value of covering demand point i for $i = 1, \ldots\ldots m$

P = the number of SAR sites that can be occupied.

S = maximum covering distance

d_{ij} = distance from each demand point i to each SAR site j.

$N_i = \{ j \in J \mid d_{ij} \leq S \} \quad \forall i \in I$

N_L = the minimum value that has to be met by limiting constraint (4), to set the standard for logistics.

N_G = the minimum value that has to be met by limiting constraint (5), to set the standard for geography.

N_W = the minimum value that has to be met by limiting constraint (6), to set the standard for weather.

L_j = the individual logistics value that SAR site j takes.

G_j = the individual geography value that SAR site j takes.

W_j = the individual weather value that SAR site j takes.

Decision variable demand points (y_i) can be changed to general integer to allow multiple coverage of the demand. This increases the objective function value and effectiveness of the SAR stations. The effects of this change are compared and analyzed.

Constraint (2) is the coverage constraint. The candidate SAR location sites cover the fixed demand points. Each candidate point has a certain number of demand points it can cover; likewise, each demand point has a set of candidate points which cover it.

Constraint (3) shows the limit on the number of SAR sites. In other words, it indicates how many points may be assigned as SAR sites.

Constraints (4), (5), and (6) are the limiting constraints for logistics, geography and weather. As we have mentioned before, each candidate point has its own characteristics for these issues. Therefore, last three constraints set a standard on each one of these characteristics. The complete LINGO formulation of this model is in appendix C.

4.3.2 Model Restrictions and the Solution

There are some restrictions in the model that we need to explain. These restrictions affect the model and its solution. The restrictions are on the number of SAR stations, coverage, and regional considerations. The main emphasis should be given to the coverage restriction because it may change the optimal solution.

Demand point coverage is not fixed. It may change due to operational conditions. Helicopter X may have a range limit, but this is not a fixed value. Therefore, restrictions on variations in helicopter range require us to take a parametric approach. By changing parameter values we can investigate the differences caused by variations in the helicopter range.

The parametric approach starts with variables and then expands to the constraints. At first, we have the solution without bonus values (a_i). We solve the model after relaxing the binary restriction on the demand points and allow them to be general integer. Then we include bonus values in the objective function and solve the model again. Then, we examine the impact of having bonus values and analyze the resulting differences.

The constraints also change with the coverage distances. Thus, we examine the problem in three stages. First, we solve the problem with the normal coverage distance, then we reduce the coverage distance to abnormal coverage distance, and finally we apply the worst-case scenario. Since the coverage of demand points change in each case, coverage rates differ, and we analyze the differences. Some additional information about application of the methodology is also presented in Chapter 5.

4.4 Computer Representation of the Model

LINGO 5 is used to represent the model and to report the solution. This software can handle 800 integer variables and 4000 constraints.[12] For problems that contain similar sets of constraints; the user needs to code the mathematical formulation to take advantage of LINGO's capabilities. LINGO gives a separate report output that shows all the details and also has functions to generate different formats of the formulation (i.e., algebraic, MPS, LINDO, spreadsheet formats). In our problem, a code is devised to make the optimizer engine create the formulation's constraints and variables. The complete code and its brief explanation is found in Appendix D.

4.5 Solution Steps

As we have mentioned, we created different scenarios. Since there are several parameters involved with the problem, changing these parameters yields new formulations. Solutions of the new formulations are obtained, and differences and relationships among these solutions are examined. A main scenario is solved for location of the SAR sites.

In the main scenario, coverage is the major concern. The main scenario produces three different solutions, which are related to the coverage range of SAR sites. As we have already mentioned, this range has three values: 150, 120, and 80 NM coverage distances. By varying the scenario, various solutions with binary and general integer variables are produced. The main purpose of this application is to show the levels of coverage that can be obtained for these distances. A coverage flow chart is shown in Figure 3.

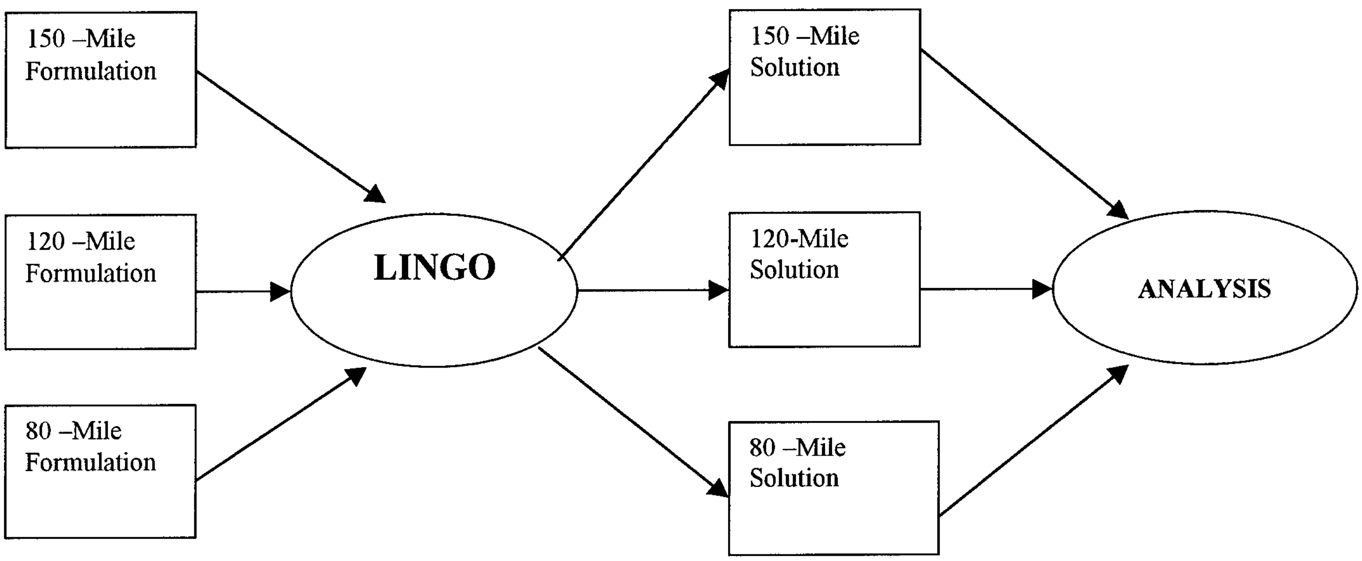


Figure 3: Coverage Flow Chart

Having found the solutions of the three main scenarios, parametric analysis is accomplished. In the parametric analysis there are several sub-scenarios. An extensive examination of these scenarios is presented. The flow of the solution process is shown in Figure 4.

Once we formulate the three basic models for the different coverage distances (150, 120,80 NM), we solve those models with all variables binary. Then we change the demand variables from binary to general integer, and solve them again. After these steps, we include bonus values for each demand variable and solve the models again.

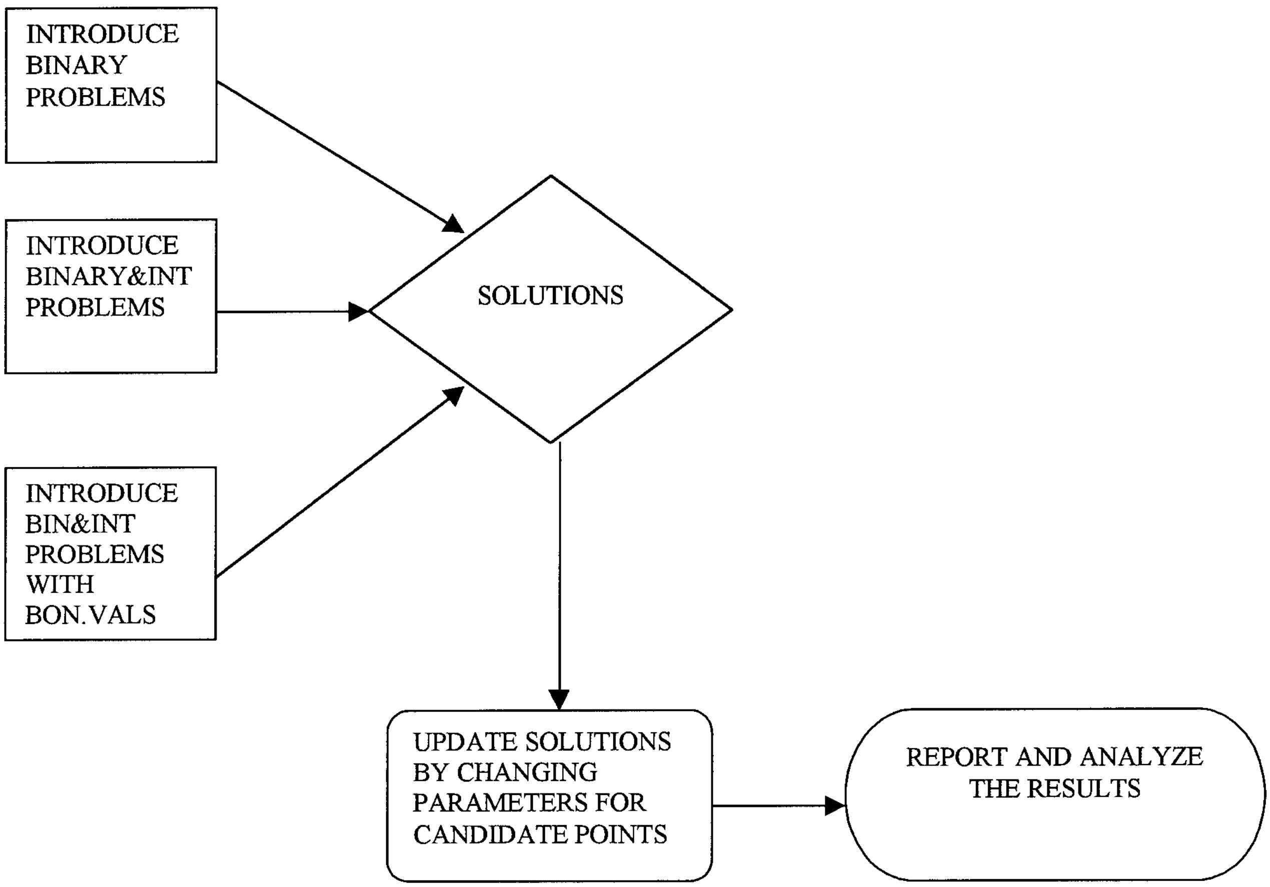


Figure 4 : Solution and Analysis Process

We start with an arbitrary number of 30 for the maximum number of SAR sites and then note solution changes as we decrease SAR sites to 1. The number of candidate SAR locations that provide the maximum coverage is emphasized as we decrease this number to 1. All these results are reported and analyzed after examining different parametric values.

Once these steps are finished, sensitivity analysis is conducted. Essential candidate points that are in the solution are removed from the solution space. Then their impact on the solution is examined. More information about these analyses is presented in Chapter 5.

CHAPTER 5

V. RESULTS AND ANALYSIS

5.1 Introduction

In this chapter, we present the results and analyze the outputs of the model. Results are examined under three basic scenarios. These scenarios differ by coverage distances. In each solution, the maximum coverage with the minimum number of SAR stations is found. After finding these solutions, a combined solution is produced. The combined solution is devised to achieve the separate solutions' maximum coverage rates under one solution. Furthermore, for each scenario, demand point variables are first treated as binary variables and then as general integer. The effect of having a general integer representation of the demand points is examined with and without having bonus values in the objective function. However, the main emphasis is given to the solutions with binary demand point variables. Binary solution applies to the solutions where the demand points are covered at least once. The general integer solution gives credit to demand points covered more than once. Bonus points encourage covering more important demand points.

This model was created to help the decision-maker. Since the 150-mile scenario has the most extensive formulation, one such approach suggests an application of the 150-mile solution to the other scenarios. We also examine an application of the combined 150-mile and 120-mile solutions to the 80-mile scenario. Consecutively, we produce three options for the decision-maker to examine. We also conduct a sensitivity analysis to show the impact of changing certain constraints of the model. Sensitivity analysis is applied to the combined solution with 150-mile formulation. The details of these solutions can be found in the appendices.

5.2 Solutions for Each Scenario (Separate Solutions)

There are three basic scenarios based on helicopter coverage distances: 80-mile, 120-mile, and 150-mile scenarios. We find solutions for each scenario with all demand point variables binary and general integer, with and without bonus values for target coverage. We first examine each scenario separately and then compare their results. The main emphasis is given to the solutions with binary variables for each case, because it is easy to evaluate the rate of coverage when using binary variables, and coverage is important to pilots. Bonus values may be used when each demand point is provided a separate importance level.

5.2.1 80-Mile Solution

The goal is to find the maximum coverage with the minimum number of SAR stations for an 80-mile scenario. Table 5 shows the parametric analysis for this scenario.

The best coverage rate is 52% (52 of 100 demand points) and can be achieved using 9 SAR stations. Naturally, as we increase the number of SAR stations in the model, the redundant coverage increases as seen in the GIN SOL column.

Table 5: Solution Report for 80-Mile Scenario

# of SAR Stations	BIN SOL	GIN SOL	BONUS BIN SOL.	BONUS GIN SOL
30	52	291	446	2647
25	52	255	446	2306
20	52	215	446	1944
15	52	171	446	1556
10	52	121	446	1099
9	**52**	**110**	**446**	**1003**
8	51	99	439	905
7	50	95	432	803
5	47	65	403	597
3	34	41	293	375
1	13	13	121	121

If the redundant coverage is important, 9 SAR stations may not be adequate as only 28% of the demand points get covered even tough demand points are covered totally 110 times. Clearly, the form of the objective function drives which SAR stations are picked and thus which demand points have any coverage.

When bonus values are included, the total number of covered demand points is still 52. However, it produces the solution among the demand points having the greater bonus values. Frankly, this does not have a broad effect on the binary solution but it implies a big impact on the general integer solution. Figures 5 and 6 plot the data taken from Table 5. Figure 5 excludes bonus values while Figure 6 includes bonus values. The general trends are the same.

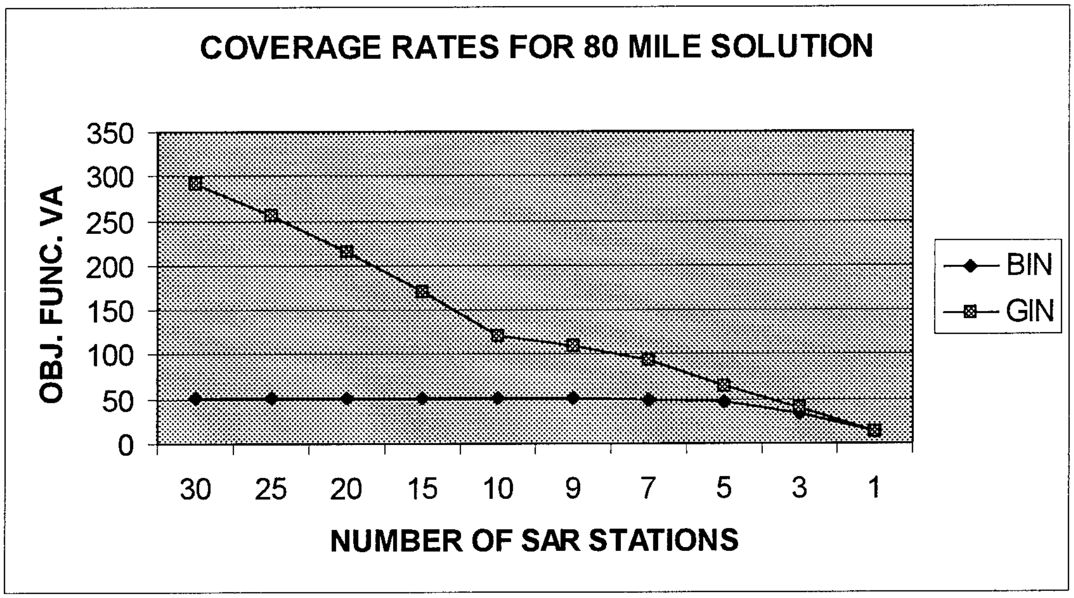


Figure 5: Objective Function Values vs. Number of SAR Stations

In Figure 5, binary solution shows a stable solution structure of 52, while the general integer solution's objective value constantly decreases as the number of SAR stations decreases. Binary solution's coverage is the same until the number of SAR stations is reduced to nine. After nine stations, coverage decreases. A single SAR station has a coverage rate of 13%.

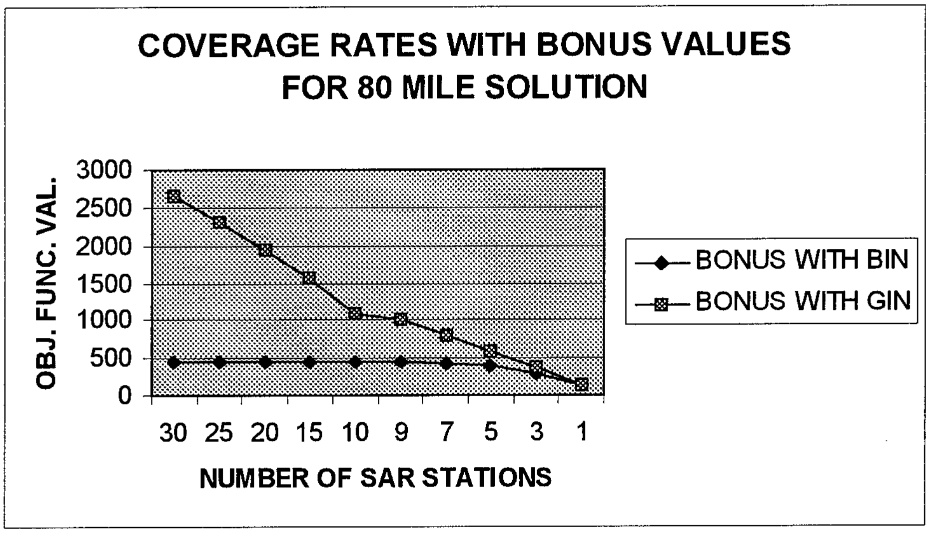


Figure 6: Objective Function Values with Bonus Points vs. Number of SAR Stations

5.2.2 120-Mile Solution

This scenario increases SAR station range from 80 miles to 120 miles. Table 6 summarizes the solutions with different numbers of SAR stations. Increased range means increased coverage with fewer SAR stations; 77% coverage using 8 SAR stations.

The general integer formulation encourages extra coverage. When we encourage multiple coverage of the demand points, we still cover 56% of the demand points with 8 SAR stations.

Table 6: Solution Report for 120-Mile Scenario

# of SAR Stations	BIN SOL.	GIN SOL	BON BIN SOL.	BON GIN SOL
30	77	560	614	4904
25	77	481	614	4230
20	77	401	614	3523
15	77	314	614	2767
10	77	221	614	1944
8	77	**179**	**614**	**1592**
7	76	158	607	1405
5	74	116	590	1029
3	56	72	466	639
1	23	23	207	207

Figures 7 and 8 plot the data from Table 6; Figure 7 does not include bonus values, while Figure 8 includes bonus values. The trends mirror those in Figures 5 and 6. More SAR stations can increase redundant coverage but not the percentage of coverage. A single SAR station covers 23% of the demand points.

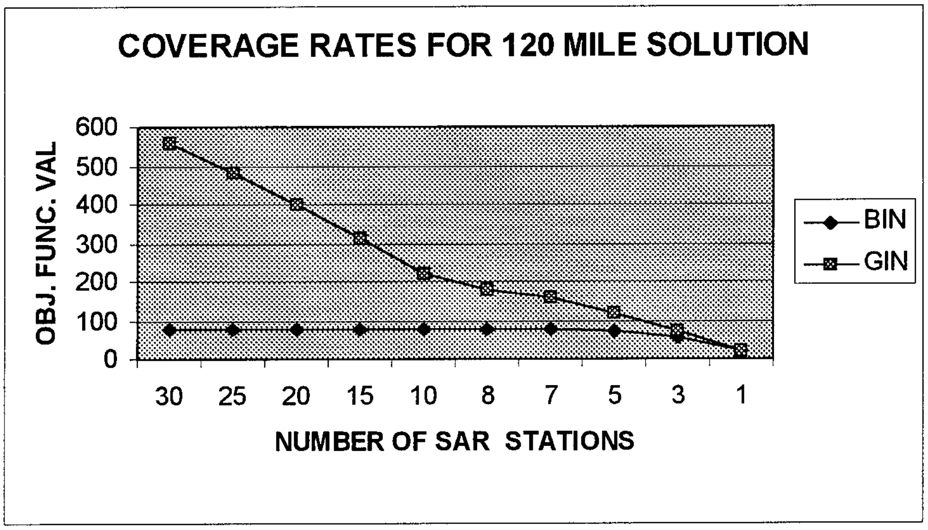


Figure 7: Objective Function Values vs. Number of SAR Stations

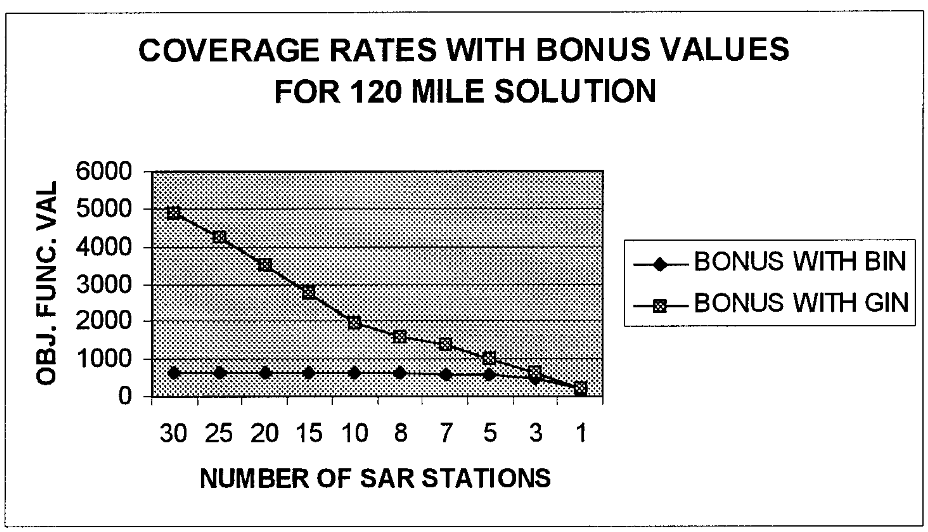


Figure 8: Objective Function Values with Bonus Points vs. Number of SAR Stations

5.2.3 150-Mile Solution

In this scenario, SAR units have a coverage distance of 150 NM. Table 7 shows the results with different numbers of SAR stations.

Table 7: Solution Report for 150-Mile Scenario

# of SAR Stations	BIN SOL.	GIN SOL	BON BIN SOL.	BON GIN SOL
30	100	970	737	8014
25	100	837	737	6877
20	100	698	737	5708
15	100	548	737	4449
10	100	385	737	3100
6	**100**	**243**	**737**	**1935**
5	99	205	731	1628
3	87	126	659	1000
1	43	43	334	334

In this scenario, 100% coverage is obtained using 6 SAR stations and this is the accepted solution. Solving with 8 SAR stations, and rewarding multiple coverage, the demand points are covered 243 times. However, the operation area's coverage rate drops to just 55%. This is not likely to be acceptable. Figures 9 and 10 plot the data from Table 7, yielding the same insights as gleaned from Figures 5 and 6 and Figures 7 and 8.

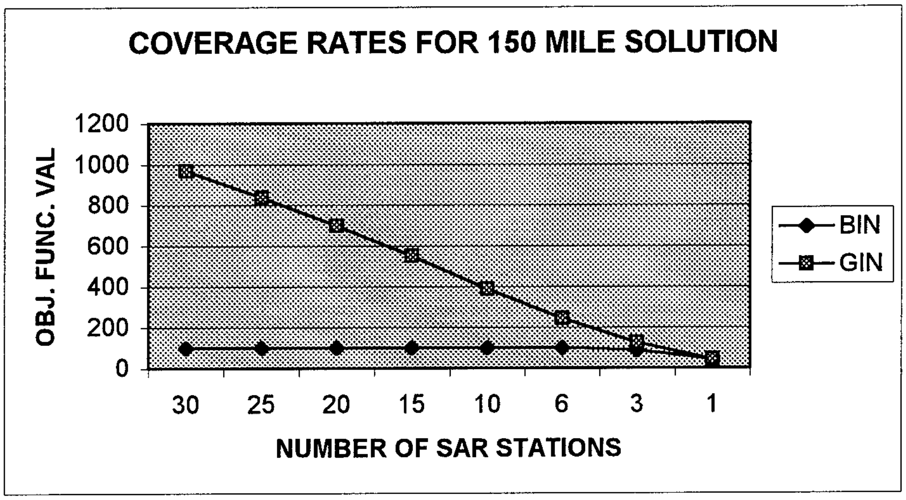


Figure 9: Objective Function Values vs. Number of SAR Stations

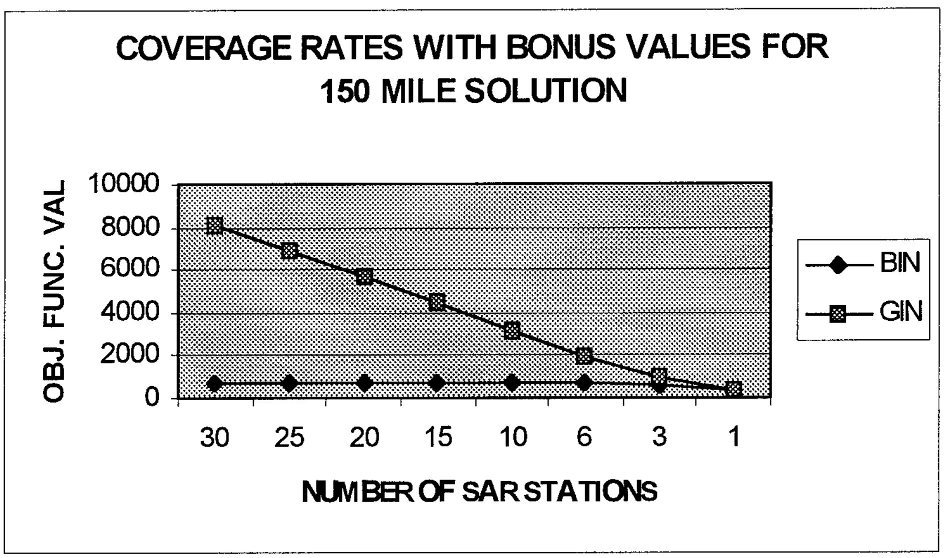


Figure 10: Objective Function Values with Bonus Points vs. Number of SAR Stations

5.2.4 Summary of the Individual Scenario Results

The main purpose of these results is to show the maximum coverage for each scenario. The objective function form drives the SAR station selection and coverage Table 8 summarizes the best results obtained. Favoring multiple coverage reduces percentage coverage. Next, we must find a solution to maximize coverage in all scenarios.

Table 8: Summary of the Results

Scenarios	**# of Stations**	**Objective Function Value**	**Coverage Rate in the Operation Area (%)**	**Bonus Solutions**
80-mile (bin)	9	52	**52**	446
80-mile (gin)	9	110	**13**	1099
120-mile (bin)	8	77	**77**	614
120-mile (gin)	8	179	**56**	1592
150-mile (bin)	6	100	**100**	737
150-mile (gin)	6	243	**55**	1935

5.3 Combined Solutions

The different scenarios produced different answers based on different candidate points. In order to locate SAR stations, we need some combined solution that maximizes coverage in all scenarios with some minimum number of SAR stations.

To find a single solution, we take the candidate points that satisfy the maximum coverage for each scenario, and the alternative optimal solutions. We take the union of these sets and find a solution set that maximizes coverage in all scenarios with the minimum number of SAR stations. Table 9 shows these sets and the combined solution set. These solutions show coverage first and then minimize the number of SAR stations.

Table 9: Solution Sets

Solutions	Selected Candidate Points (X)	# of Stations	Coverage Rate (%)
80-Mile	6, 33, 34, 56, 72, 98, 118, 123, 142	9	52
120-Mile	8, 31, 33, 62, 64, 72, 118, 142	8	77
150-Mile	6, 34, 70, 72, 105, 141	6	100
Combined	1, 6, 33, 34, 56, 63, 72, 73, 118, 123, 142	11	100, 77, 52

The main structure of the model produces several alternative optimal solutions. In the combining process, the main emphasis is given to the coverage issue. Second consideration is to keep the number of SAR stations as low as possible. Therefore, the solution basis is different from those found in the scenarios. Nonetheless, in order to maximize the coverage for each scenario in the combined solution, the number of SAR stations has to be at least 11.

Table 9 shows the combined solution set with the coverage rates. Table 10 summarizes the results of the combined solution for binary and general integer models with and without bonus values.

Table 10: Summary of the Combined Solution Results

Scenarios	# of Stations	Objective Function Value	Coverage Rate in the Operation Area (%)	Bonus Solutions
80-mile (bin)	11	52	**52**	446
80-mile (gin)	11	105	**52**	927
120-mile (bin)	11	77	**77**	614
120-mile (gin)	11	192	**77**	1620
150-mile (bin)	11	100	**`100**	737
150-mile (gin)	11	328	**100**	2556

A very nice feature of the combined solution is that, there is no degradation in coverage rate when redundant coverage is encouraged. There are also some differences between the separate and combined solutions of the scenarios. For the combined solution, the number of SAR stations is the same for each model. Objective function values and coverage rates may differ for each solution type as well as the bonus values. Figures 11, 12, and 13 show these differences. Since the results of binary solutions are the same for combined and separate solutions, they are not represented in the figures.

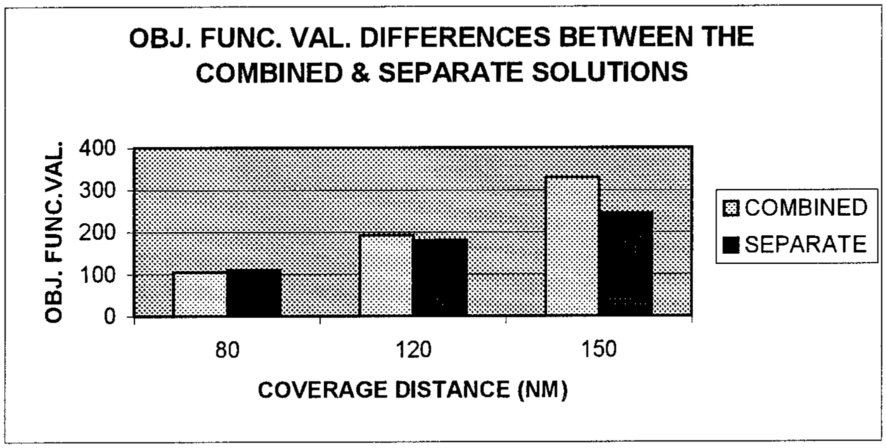


Figure 11: GIN Objective Function Value Differences (Without Bonus Values)

The separate solution for 80 NM has more total multiple coverage than that of combined solution. On the other hand the combined solution surpasses the separate solutions for 120 NM and 150 NM coverage distances. This reflects the change in the number of times each demand point is covered.

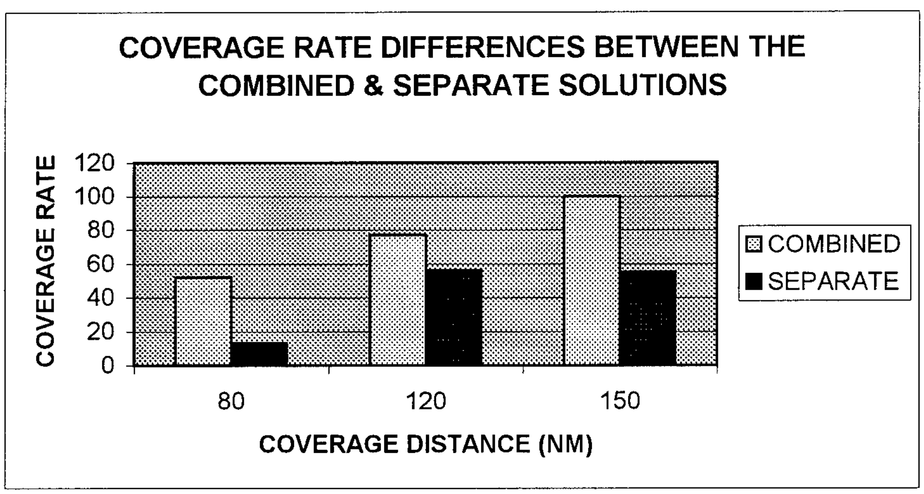


Figure 12: GIN Coverage Rate Differences(Without Bonus Values)

In Figure 12 combined solution coverage in the general integer problems are better than the separate solution results for all coverage distances. They all obtain the maximum coverage they can get for the given distance.

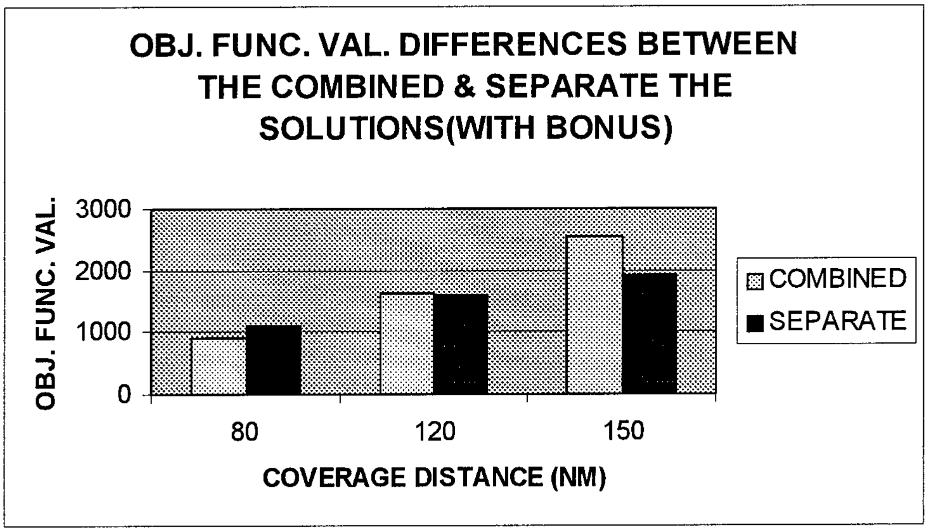


Figure 13: GIN Objective Function Value Differences (Bonus Points Included)

For 80 NM and 120 NM solutions, objective function values are very close for combined and separate solutions when the bonus points are included. As for the 150 NM solution, the combined solution clearly overshadows the separate solution.

When we combine the solutions, we need more SAR stations to maintain the maximum coverage for each scenario. However, for almost all cases the combined solution results are better than the separate solution results. Particularly, Figure 12 shows a drastic difference for the coverage rates. For instance, for the 150-mile scenario we get only 55% coverage in the separate solution; however, this rate goes up to 100% in the combined solution. More analysis is included in sensitivity analysis section for the combined solution.

Finally, we would like to show the results on the map in Figure 14. The map shows the approximate location of the SAR sites based on the results. This representation presents a better understanding of the solution. In addition, they are only for demonstration, not for implementation.

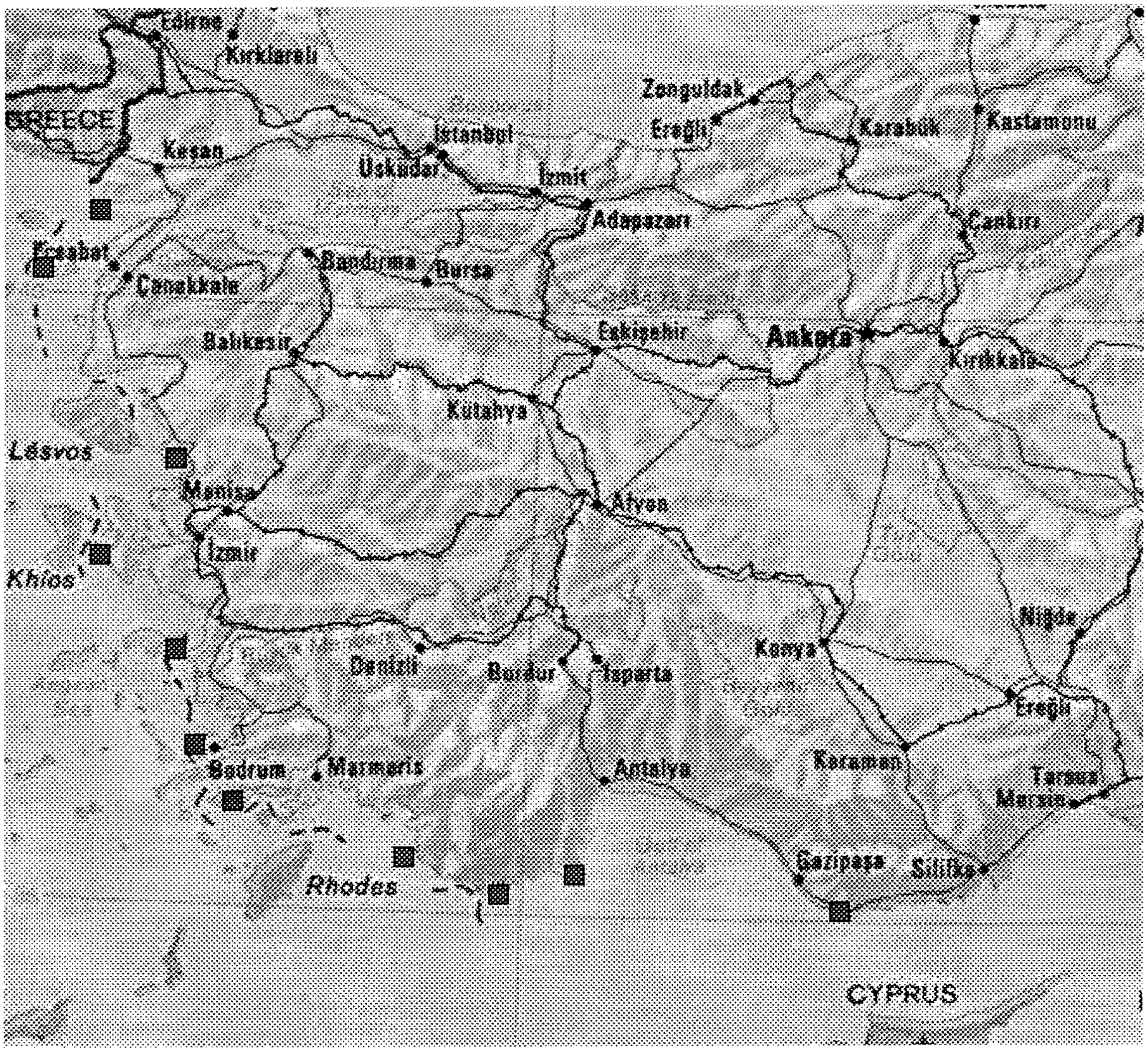


Figure 14: Demonstration of the Combined Solution

In Figure 14, there are 11 SAR locations, shown in the red squares, along the Aegean and Western Mediterranean coastline of Turkey.

5.4 Other Options

Although the combined solution represents a solid option, two other options are examined. One applies the results of 150-mile solution to the other scenarios. The second combines the 150 NM and 120 NM solutions and applies this solution to the 80 NM scenario. These two options are examined with binary models only to determine coverage rates.

5.4.1 Application of 150-Mile Solution

The 150-mile scenario obtains the maximum coverage (100%). There are also several alternate solutions that generate the same result for this scenario. Therefore the solution of this scenario is applied to the other cases. Selected SAR locations correspond to X6, X33, X63, X72, X117, and X149. 100% coverage is obtained using these variables in the 150-mile scenario. When applied to the 120-Mile scenario, coverage is decreased to 68%. Applied to the 80-mile scenario, the total coverage becomes 41%. Therefore, this does not look like a good option.

Similar to the combined solution, in Figure 15 the location of SAR sites is shown for this solution. This figure is only for demonstration, not for implementation. There are only six SAR sites in this case.

5.4.2 Application of 150+120-Mile Solution

In this case, the coverage rates for 150 and 120-mile solutions, which are obtained by using the same basis and equal number of SAR stations, are 99% and 76%, respectively. Applied to the 80-mile scenario, the selected candidate points, X6, X33, X34, X48, X72, X73, X118, and X142, provide coverage of 47%. In this case, the number of missing demand points for each scenario are:1 (1%), 1 (1%) and 5 (5%). There is a marginal decrease for all scenarios. On the other hand, this solution is cost effective because it uses only 8 SAR stations. Figure 16 shows this solution on a map.

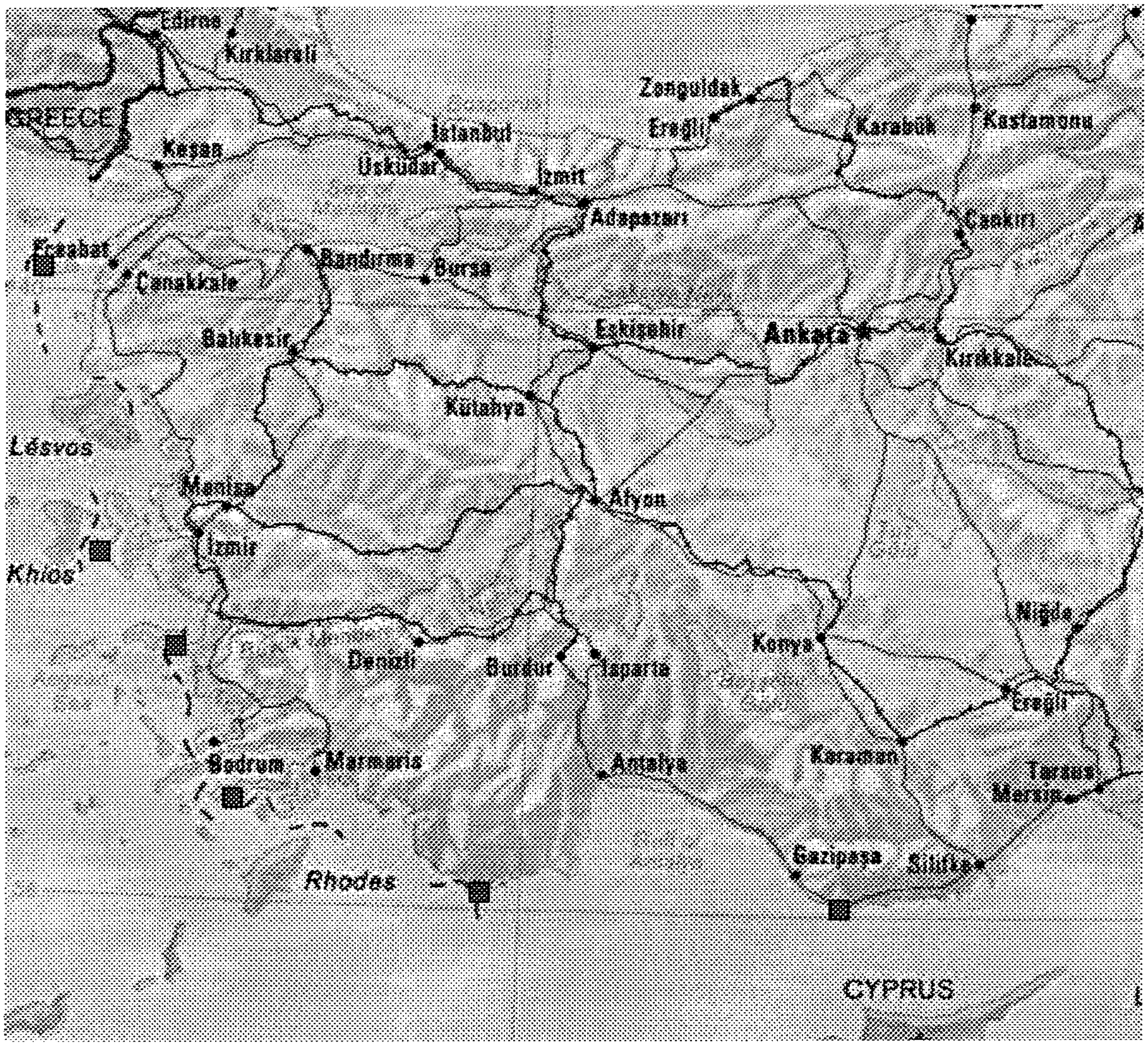


Figure 15: Demonstration of 150-Mile Solution

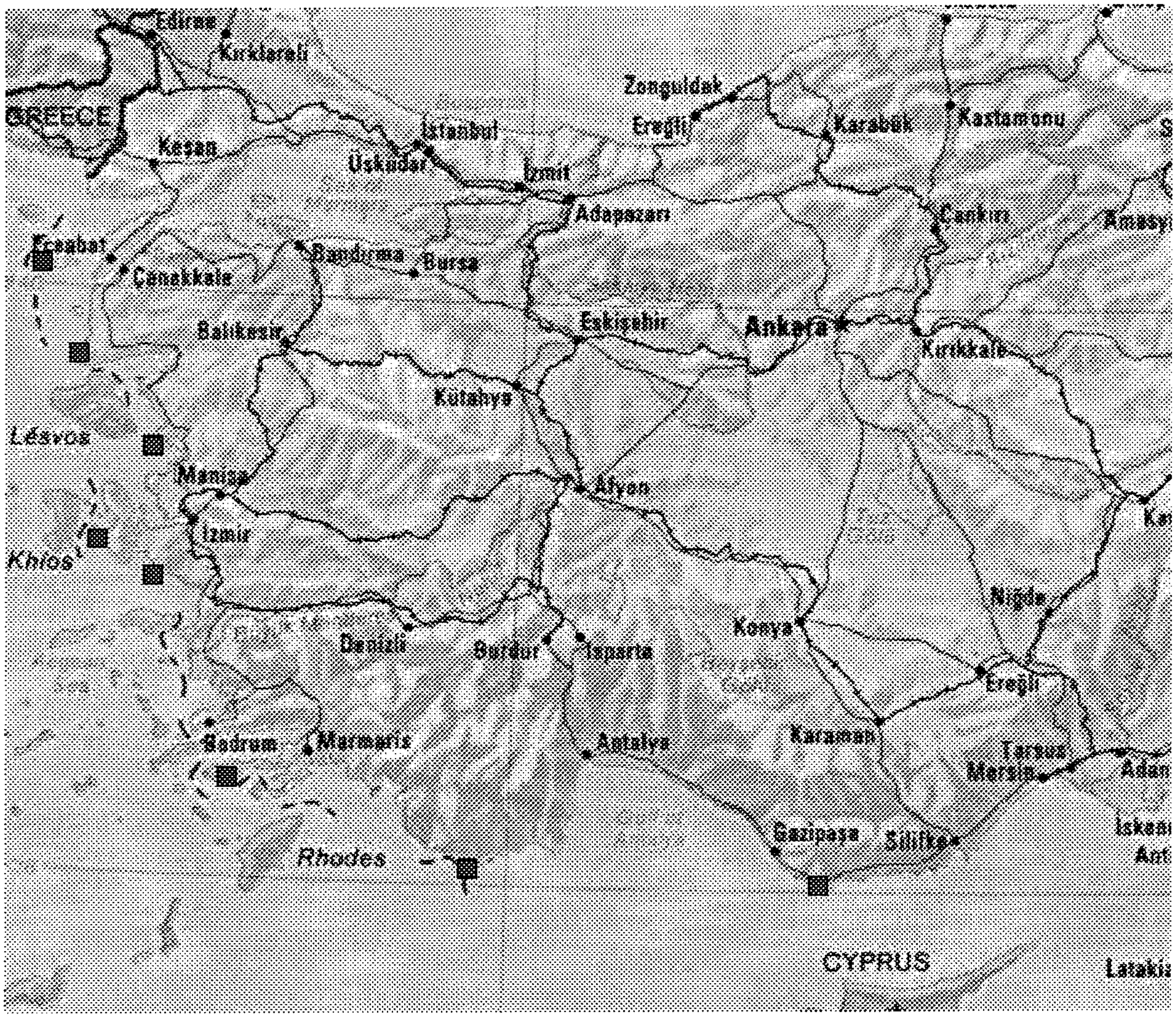


Figure 16: Demonstration of 120+150-Mile Solution

5.4.3. Conclusion

Three options were examined. The combined solution offers the best coverage rate using 11 SAR stations. The second option satisfies the maximum coverage for the 150-mile scenario, but its coverage rate is very low for the other cases. Because it uses the lowest number of SAR stations. The third option uses only 8 SAR stations, it produces near maximum coverage rates for the 150 and 120-mile scenarios, and its 80-mile scenario coverage is close to the maximum rate.

Overall, the best solution appears to be the combined solution. If there are cost considerations involved, the 150+120-mile solution should be considered. Lastly, application of 150-mile solution may be used when the other solutions are not considered.

5.5 Sensitivity Analysis

In the sensitivity analysis, we examine how constraint changes affect solution results. We change three basic constraints. The first one is the maximum number of SAR stations. The second constraint includes weather, logistics and geography requirements. The third one is to force some of the candidate points to become zero. For all cases the binary models are used.

5.5.1 Changing the Number of SAR Stations

The figures in section 5.2 show the results of changing the number of SAR stations. The right hand side (RHS) of the related constraint is changed to 7 and examined for all scenarios. The outcome and the comparison to the combined solution is shown in Figure 17. For this case, the selected SAR stations are X6, X33, X63, X68, X72, X118, and X142.

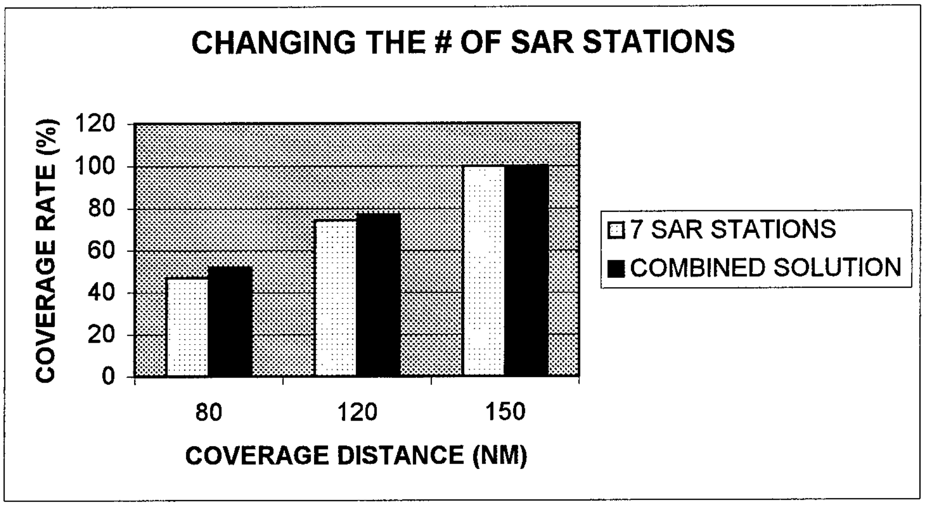


Figure 17: 7 Stations vs. the Combined Solution

According to these results, the coverage rates for 150, 120, and 80-mile scenarios are as follows: 100%, 74%, 47%. Overall, this modification does not give the best coverage rates, but shows that by using appropriate variables, we can still obtain fairly good coverage.

5.5.2 Changing the Additional Constraints

The additional constraints, weather, geography and logistics, indicate the standard of the selected SAR stations. In the model solutions, this standard was 7 out of 10. This time we tested the related constraints to see how high the model can still produce feasible solutions. At first the combined solution is used, then the separate 150-mile solution is used. The results for the combined solution are shown in Table 11.

Table 11 clearly shows that the maximum standard level that can be obtained is 8. Besides, feasible solution cannot be obtained when we apply this standard to the logistics constraint. We also note that the maximum coverage rate is 94% for the feasible solutions. Therefore, these constraints are very important and do affect the solution.

Table 11: Changes in the Additional Constraints

Changed Constraint	New Standard	New Coverage Rate (%)
Geography	8	94
Weather	8	94
Logistics	8	Infeasible
Weather & Geography	8	94
All Additional Constraints	>8	Infeasible

The 150-mile separate solution is also tested. Surprisingly, an optimal solution is found for all higher standards. Although, the coverage rate decreases as we increase the standards for all additional constraints. The results are shown in figure 18.

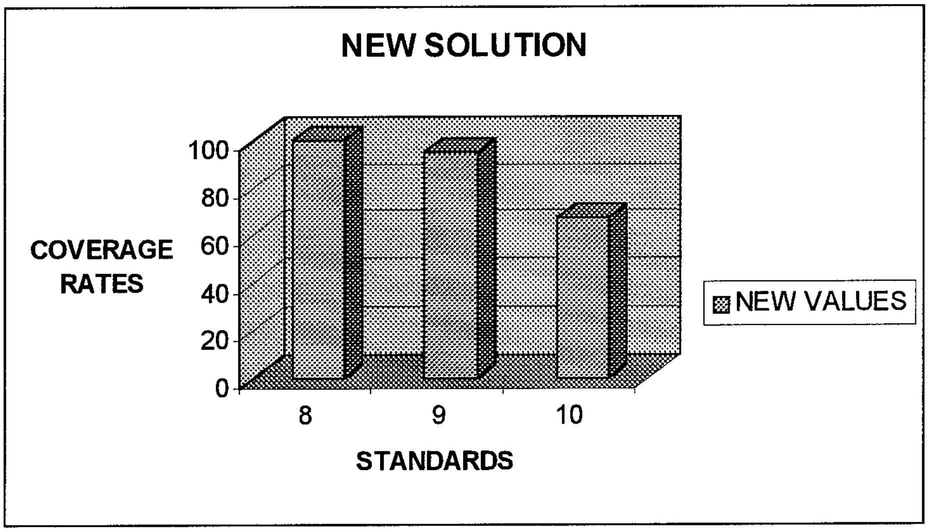


Figure 18: Coverage Rates for the Separate 150-Mile Solution

The model can still obtain 100% coverage when the standard is raised to 8. As for 9, it is 95%, and for 10, which is the maximum level, it is 67%.

5.5.3 Excluding Selected Sites From Consideration

In the combined solution, candidate points are removed one at a time. Two candidate points, X6 and X72, are important. When one of them is removed, the coverage rate decreases. If the number of candidate SAR locations also decreases, then the decline in the coverage rate becomes more obvious.

Table 12 summarizes this analysis. Both X6 and X72 are important, reducing coverage by 9%. Removing all 11 SAR stations in the combined solution only drops coverage by another 4%.

Table 12: Forcing the Basic Variables to Become 0

0 Variables	# of SAR Stations	New Coverage Rate (%)
X6	11	96
X72	11	95
X6 & X72	11	91
X6 & X72	9	90
All in the Basis	11	87

5.6 Conclusion

In the solution process, separate solutions are found and analyzed for each scenario. These solutions are combined and the best solution group is found. There are some other alternatives such as the application of 150-mile scenario, and combined application of 150 and 120-mile scenarios. These alternatives could be considered as the other options; however, the combined solution is preferred.

Sensitivity analysis was conducted. Constraints, like geography, logistics and weather, are important and can produce infeasible solutions if they become too strict.

In conclusion, several options and scenarios are presented in this chapter. Details can be found in the appendices. There are also many alternate solutions and approaches to solve this problem.

CHAPTER 6

VI. RECOMMENDATIONS AND CONCLUSION

6.1 Summary

The problem of locating SAR sites was examined using MCLP. MCLP was formulated with additional constraints to create the current model. The model was solved using LINGO 5. The problem was handled in three scenarios that use the same model with minor changes. Once the basic solutions were obtained for several scenarios, the parameters concerning these solutions were changed and new solutions were produced. While one major solution was achieved, the problem was also analyzed using the output based on these changed parameters.

Sensitivity analysis was conducted on selected SAR sites. Two sites were found particularly important. Geographic, logistic, and weather constraints were also important.

There are alternate solutions for each scenario. So for this reason, one major solution that combines these scenarios is developed and presented as the solution to be presented to decision-maker. The relationship among these solutions is also examined. The model and LINGO 5 code are very useful and can be used for similar types of problems.

Overall, the research is successful. The model successfully found the optimum sites where the SAR facilities can be located in the Aegean and the Western Mediterranean regions of Turkey. The minimum number of SAR sites that satisfy the maximum coverage in the region is found. Solution times are low, and the model is very easy and flexible to use. New constraints may be added whenever needed or present constraints can be modified for different type of scenarios.

6.2 Implementation Areas

I would like to emphasize that generally, this problem is a location problem. Although it solves the optimum location of SAR units, it can be easily applied to other areas. Radar coverage, warehouse location, facility location with a given coverage and other similar kinds of MCLP models can be solved with a similar approach.

As we explained in Chapter 3, MCLP models are very common for location problems and have wide implementation areas. For this reason, with simple modifications the model proposed in this research could be used for civilian and military cases.

6.3 Further Research

There are several open areas that can be studied for further research. First, the same model can be solved with an advanced heuristic approach such as tabu search with additional constraints and variables. On the other hand the constraints may be redefined and the number of demand and candidate points may be modified, or basing issues may be included in the model.

Tabu search is one of the new promising heuristic approaches in operations research. Object-oriented programming may be used and a bigger model, which includes more variables and constraints, can be solved by means of this approach.

Problem modification can also be done by changing the number of demand points and including multiple coverage issues as a constraint. Some other considerations can also be added to the model such as no-fly zones, SAM threats from the enemy, and loss of SAR units. Furthermore, the constraints can achieve a continuous coverage for strategic targets, which are also the demand points. This might be accomplished even without changing the concept of MCLP. On the other hand the problem can be handled as MECLP problem. In this case, coverage probabilities must be defined, and demand coverage must be redefined.

The model in this research does not thoroughly cover the basing issues, such as construction and cost constraints, personnel training, utilities, and other issues that are considered for on-base operations. One could include these considerations in the model. Similarly, different SAR concepts such as signaling, and intelligence operations, may be added to the model.

A similar model may be used for radar coverage or warehouse location problems. Generally, it can be used to find the optimum location of the facilities with the maximum coverage.

In conclusion, there are several promising further research areas in this research. Especially for larger problems, heuristic approaches are recommended, and with current variables, they may be redefined, and new constraints may be introduced to the model.

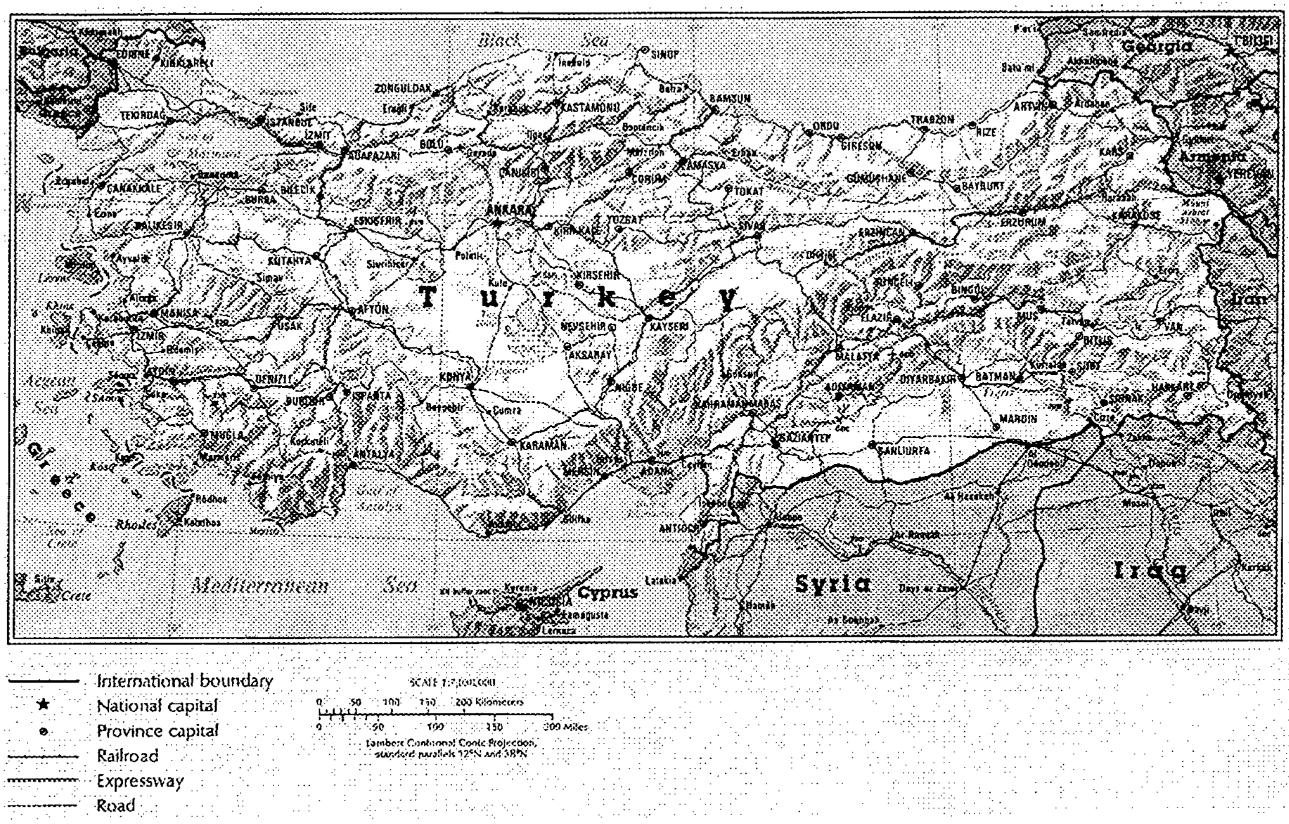
6.4 Conclusion

The model is very useful and can be readily implemented. Some improvements can be implemented in the present model. It makes a good initiative for similar problems in the Turkish Air Force. It is very flexible and with minor changes can be implemented in other location problems that the Turkish Air Force has.

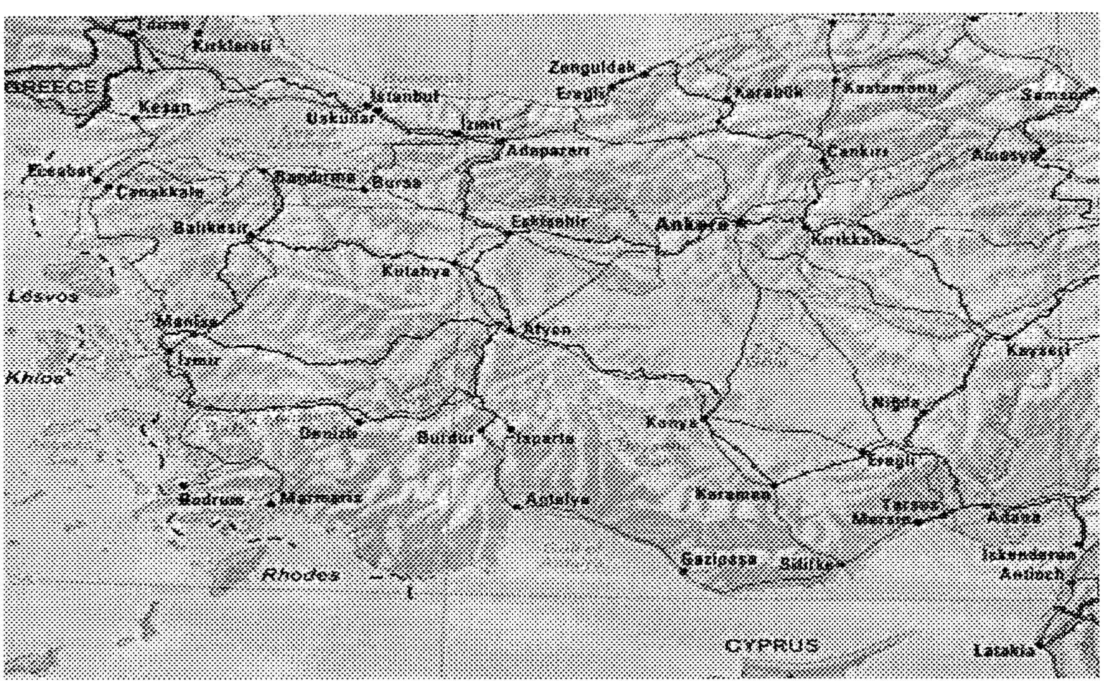
I believe there are many areas that may still be studied for the Turkish Air Force. Therefore, I strongly recommend that future officers, especially Turkish officers, do research on these problems.

APPENDIX A: Regional Maps

MAP 1: East and West Coasts of the Aegean Sea



MAP 2: Turkish Coastline



MAP 3: Turkish Coastline in the Aegean and Mediterranean.

APPENDIX B: Bonus Values & Geography, Logistics and Weather Coefficients

I. Geography, Logistics and Weather Coefficients for Every Candidate Point

Candidate points	Geography	Logistics	Weather
X1	10	7	7
X2	8	10	7
X3	10	8	8
X4	9	8	8
X5	10	10	7
X6	10	9	7
X7	9	7	8
X8	10	8	7
X9	9	8	8
X10	8	8	8
X11	9	10	9
X12	8	8	8
X13	7	8	8
X14	9	8	9
X15	10	7	10
X16	8	8	8
X17	7	8	9
X18	7	8	9
X19	6	9	10
X20	9	9	9
X21	7	8	9
X22	10	7	10
X23	10	10	10
X24	7	7	7
X25	10	8	9
X26	8	8	9
X27	7	8	8
X28	7	8	8
X29	7	8	8
X30	8	8	8
X31	7	7	7
X32	8	8	7
X33	7	7	7
X34	8	8	8
X35	7	8	7
X36	7	7	7
X37	7	8	7

X38	7	9	7
X39	8	8	8
X40	7	7	7
X41	7	7	7
X42	7	8	7
X43	7	7	7
X44	8	7	7
X45	8	8	8
X46	8	7	7
X47	10	7	7
X48	10	9	9
X49	9	8	8
X50	8	8	8
X51	7	8	8
X52	9	9	9
X53	9	9	9
X54	8	8	8
X55	8	8	8
X56	9	8	8
X57	9	9	9
X58	7	8	8
X59	9	9	10
X60	9	9	10
X61	10	7	10
X62	10	7	10
X63	10	10	10
X64	10	5	10
X65	10	6	10
X66	8	9	10
X67	9	9	10
X68	9	6	10
X69	10	9	10
X70	10	7	10
X71	10	8	10
X72	9	6	10
X73	8	7	10
X74	8	6	10
X75	7	7	8
X76	7	8	7
X77	7	7	8
X78	6	9	8
X79	6	7	7
X80	6	7	7
X81	7	9	9
X82	6	9	7
X83			

X84	7	7	7
X85	8	9	9
X86	8	9	9
X87	7	9	6
X88	10	10	10
X89	7	7	7
X90	8	8	7
X91	7	9	9
X92	7	8	8
X93	6	8	7
X94	7	8	8
X95	7	8	8
X96	7	8	8
X97	8	8	8
X98	8	8	8
X99	8	8	8
X100	7	8	8
X101	7	8	7
X102	7	7	7
X103	6	7	9
X104	7	8	8
X105	7	6	8
X106	9	8	8
X107	6	7	8
X108	8	8	7
X109	9	9	7
X110	8	9	7
X111	8	9	7
X112	10	10	10
X113	10	6	10
X115	9	7	10
X116	9	8	10
X117	10	6	10
X118	10	6	10
X119	8	8	10
X120	8	8	9
X121	7	8	7
X122	7	8	7
X123	9	6	10
X124	9	9	9
X125	10	8	9
X126	10	6	10
X127	8	10	10
X128	9	8	8
X129	8	8	8
X130	8	8	7

X131	7	7	7
X132	8	7	8
X133	8	6	9
X134	9	7	10
X135	7	8	9
X136	7	8	9
X137	9	6	10
X138	8	8	8
X139	7	9	8
X140	8	8	8
X141	9	9	10
X142	10	8	10
X143	8	8	9
X144	8	8	9
X145	8	8	10
X146	10	10	10
X147	10	10	10
X148	8	8	8
X149	8	8	8
X150	8	9	10
X151	10	10	10
X152	10	10	10

II. Bonus Values for the Demand Points

Demand Points	Bonus Values
Y(1)	8.000000
Y(2)	9.000000
Y(3)	7.000000
Y(4)	10.00000
Y(5)	6.000000
Y(6)	7.000000
Y(7)	4.000000
Y(8)	5.000000
Y(9)	5.000000
Y(10)	5.000000
Y(11)	4.000000
Y(12)	5.000000
Y(13)	6.000000
Y(14)	6.000000
Y(15)	6.000000
Y(16)	6.000000
Y(17)	6.000000
Y(18)	6.000000
Y(19)	6.000000
Y(20)	7.000000

Y(21)	7.000000
Y(22)	8.000000
Y(23)	8.000000
Y(24)	8.000000
Y(25)	7.000000
Y(26)	7.000000
Y(27)	6.000000
Y(28)	6.000000
Y(29)	6.000000
Y(30)	6.000000
Y(31)	8.000000
Y(32)	8.000000
Y(33)	9.000000
Y(34)	9.000000
Y(35)	9.000000
Y(36)	10.00000
Y(37)	10.00000
Y(38)	9.000000
Y(39)	10.00000
Y(40)	10.00000
Y(41)	10.00000
Y(42)	10.00000
Y(43)	9.000000
Y(44)	9.000000
Y(45)	8.000000
Y(46)	8.000000
Y(47)	8.000000
Y(48)	7.000000
Y(49)	10.00000
Y(50)	10.00000
Y(51)	9.000000
Y(52)	9.000000
Y(53)	7.000000
Y(54)	7.000000
Y(55)	5.000000
Y(56)	4.000000
Y(57)	4.000000
Y(58)	5.000000
Y(59)	4.000000
Y(60)	10.00000
Y(61)	6.000000
Y(62)	5.000000
Y(63)	10.00000
Y(64)	4.000000
Y(65)	4.000000
Y(66)	9.000000

Y(67)	8.000000
Y(68)	8.000000
Y(69)	9.000000
Y(70)	6.000000
Y(71)	4.000000
Y(72)	7.000000
Y(73)	4.000000
Y(74)	8.000000
Y(75)	6.000000
Y(76)	8.000000
Y(77)	8.000000
Y(78)	7.000000
Y(79)	7.000000
Y(80)	8.000000
Y(81)	9.000000
Y(82)	10.00000
Y(83)	9.000000
Y(84)	6.000000
Y(85)	6.000000
Y(86)	8.000000
Y(87)	10.00000
Y(88)	7.000000
Y(89)	10.00000
Y(90)	7.000000
Y(91)	7.000000
Y(92)	10.00000
Y(93)	10.00000
Y(94)	9.000000
Y(95)	8.000000
Y(96)	7.000000
Y(97)	7.000000
Y(98)	7.000000
Y(99)	9.000000
Y(100)	7.000000

APPENDIX C: COMPLETE MATHEMATICAL MODELS

I. Models for Separate Solutions

a. 80-Mile Formulation

```
MAX      Y( 1) + Y( 2) + Y( 3) + Y( 4) + Y( 5) + Y( 6) + Y( 7) + Y( 8)
      + Y( 9) + Y( 10) + Y( 11) + Y( 12) + Y( 13) + Y( 14) + Y( 15)
      + Y( 16) + Y( 17) + Y( 18) + Y( 19) + Y( 20) + Y( 21) + Y( 22)
      + Y( 23) + Y( 24) + Y( 25) + Y( 26) + Y( 27) + Y( 28) + Y( 29)
      + Y( 30) + Y( 31) + Y( 32) + Y( 33) + Y( 34) + Y( 35) + Y( 36)
      + Y( 37) + Y( 38) + Y( 39) + Y( 40) + Y( 41) + Y( 42) + Y( 43)
      + Y( 44) + Y( 45) + Y( 46) + Y( 47) + Y( 48) + Y( 49) + Y( 50)
      + Y( 51) + Y( 52) + Y( 53) + Y( 54) + Y( 55) + Y( 56) + Y( 57)
      + Y( 58) + Y( 59) + Y( 60) + Y( 61) + Y( 62) + Y( 63) + Y( 64)
      + Y( 65) + Y( 66) + Y( 67) + Y( 68) + Y( 69) + Y( 70) + Y( 71)
      + Y( 72) + Y( 73) + Y( 74) + Y( 75) + Y( 76) + Y( 77) + Y( 78)
      + Y( 79) + Y( 80) + Y( 81) + Y( 82) + Y( 83) + Y( 84) + Y( 85)
      + Y( 86) + Y( 87) + Y( 88) + Y( 89) + Y( 90) + Y( 91) + Y( 92)
      + Y( 93) + Y( 94) + Y( 95) + Y( 96) + Y( 97) + Y( 98) + Y( 99)
      + Y( 100)
 SUBJECT TO
 2]- X( 1) - X( 2) - X( 3) - X( 4) - X( 5) - X( 6) - X( 7) - X( 8)
      - X( 9) - X( 10) - X( 11) - X( 12) - X( 13) - X( 14) - X( 15)
      - X( 16) - X( 17) - X( 18) - X( 19) - X( 20) - X( 21) - X( 22)
      - X( 23) - X( 24) - X( 25) - X( 26) - X( 27) - X( 28) - X( 29)
      - X( 30) - X( 31) - X( 32) - X( 33) - X( 34) - X( 35) - X( 36)
      - X( 37) - X( 38) - X( 39) - X( 40) - X( 41) - X( 42) - X( 43)
      - X( 44) - X( 45) - X( 46) - X( 47) - X( 48) - X( 49) - X( 50)
      - X( 51) - X( 52) - X( 53) - X( 54) - X( 55) - X( 56) - X( 57)
      - X( 58) - X( 59) - X( 60) - X( 61) - X( 62) - X( 63) - X( 64)
      - X( 65) - X( 66) - X( 67) - X( 68) - X( 69) - X( 70) - X( 71)
      - X( 72) - X( 73) - X( 74) - X( 75) - X( 76) - X( 77) - X( 78)
      - X( 79) - X( 80) - X( 81) - X( 82) - X( 83) - X( 84) - X( 85)
      - X( 86) - X( 87) - X( 88) - X( 89) - X( 90) - X( 91) - X( 92)
      - X( 93) - X( 94) - X( 95) - X( 96) - X( 97) - X( 98) - X( 99)
      - X( 100) - X( 101) - X( 102) - X( 103) - X( 104) - X( 105)
      - X( 106) - X( 107) - X( 108) - X( 109) - X( 110) - X( 111)
      - X( 112) - X( 113) - X( 114) - X( 115) - X( 116) - X( 117)
      - X( 118) - X( 119) - X( 120) - X( 121) - X( 122) - X( 123)
      - X( 124) - X( 125) - X( 126) - X( 127) - X( 128) - X( 129)
      - X( 130) - X( 131) - X( 132) - X( 133) - X( 134) - X( 135)
      - X( 136) - X( 137) - X( 138) - X( 139) - X( 140) - X( 141)
      - X( 142) - X( 143) - X( 144) - X( 145) - X( 146) - X( 147)
      - X( 148) - X( 149) - X( 150) - X( 151) - X( 152) + A =    0
 3]  A <=    30
 4]- Y( 1) + X( 1) + X( 6) + X( 8) >=    0
 5]- Y( 2) + X( 1) + X( 2) + X( 3) + X( 4) + X( 5) + X( 6) + X( 7)
      + X( 8) + X( 9) + X( 10) + X( 11) + X( 12) + X( 13) + X( 16)
      + X( 17) + X( 18) + X( 19) + X( 21) + X( 90) + X( 91) + X( 92)
      + X( 97) + X( 106) + X( 109) + X( 110) + X( 111) >=    0
 6]- Y( 3) + X( 6) + X( 7) >=    0
```

```
7]- Y( 4) + X( 1) + X( 4) + X( 5) + X( 7) + X( 8) + X( 9) + X( 10)
     + X( 12) + X( 13) + X( 15) + X( 16) + X( 90) + X( 98) + X( 106)
     + X( 108) >=   0
8]- Y( 5) =   0
9]- Y( 6) =   0
10]- Y( 7) =   0
11]- Y( 8) =   0
12]- Y( 9) =   0
13]- Y( 10)=   0
14]- Y( 11) =   0
15]- Y( 12) =   0
16]- Y( 13) =   0
17]- Y( 14) =   0
18]- Y( 15) =   0
19]- Y( 16) =   0
20]- Y( 17) =   0
21]- Y( 18) =   0
22]- Y( 19) =   0
23]- Y( 20) =   0
24]- Y( 21) =   0
25]- Y( 22) =   0
26]- Y( 23) =   0
27]- Y( 24) =   0
28]- Y( 25) =   0
29]- Y( 26) + X( 6) >=   0
30]- Y( 27) =   0
31]- Y( 28) =   0
32]- Y( 29) =   0
33]- Y( 30) =   0
34]- Y( 31) =   0
35]- Y( 32) + X( 70) + X( 71) + X( 72) >=   0
36]- Y( 33) + X( 61) + X( 62) + X( 63) + X( 68) + X( 69) + X( 70)
     + X( 71) + X( 72) + X( 112) >=   0
37]- Y( 34) + X( 63) + X( 69) + X( 70) + X( 71) + X( 72) >=   0
38]- Y( 35) >=   0
39]- Y( 36) + X( 52) + X( 53) + X( 55) + X( 56) + X( 59) + X( 60)
     + X( 61) + X( 62) + X( 64) + X( 69) + X( 70) + X( 71) + X( 72)
     >=   0
40]- Y( 37) =   0
41]- Y( 38) + X( 62) + X( 63) + X( 72) >=   0
42]- Y( 39) + X( 60) + X( 61) + X( 62) + X( 63) + X( 64) + X( 65)
     + X( 68) + X( 69) + X( 70) + X( 71) + X( 72) + X( 73) + X( 74)
     + X( 112) + X( 114) + X( 115) + X( 116) + X( 117) + X( 118)
     >=   0
43]- Y( 40) + X( 52) + X( 53) + X( 54) + X( 55) + X( 56) + X( 57)
     + X( 58) + X( 59) + X( 60) + X( 61) + X( 62) + X( 63) + X( 64)
     + X( 65) + X( 68) + X( 69) + X( 70) + X( 71) + X( 72) + X( 73)
     + X( 74) + X( 112) + X( 114) + X( 115) + X( 116) + X( 117)
     + X( 118) >=   0
44]- Y( 41) + X( 46) + X( 47) + X( 49) + X( 51) + X( 53) + X( 54)
     + X( 55) + X( 57) + X( 58) + X( 59) + X( 60) + X( 61) + X( 62)
     + X( 63) + X( 64) + X( 65) + X( 66) + X( 67) + X( 68) + X( 69)
     + X( 70) + X( 71) + X( 72) + X( 73) + X( 74) + X( 112) + X( 114)
     + X( 115) >=   0
45]- Y( 42) + X( 43) + X( 46) + X( 47) + X( 49) + X( 52) + X( 53)
     + X( 54) + X( 57) + X( 58) + X( 60) + X( 61) + X( 62) + X( 64)
     + X( 65) + X( 68) + X( 69) + X( 70) + X( 71) + X( 72) + X( 112)
```

```
     + X( 114) >=   0
46]- Y( 43) + X( 53) + X( 56) + X( 61) + X( 62) + X( 63) + X( 72)
     >=   0
47]- Y( 44) + X( 56) + X( 62) + X( 63) >=   0
48]- Y( 45) =   0
49]- Y( 46) + X( 33) + X( 34) >=   0
50]- Y( 47) + X( 33) + X( 34) >=   0
51]- Y( 48) + X( 33) >=   0
52]- Y( 49) + X( 25) + X( 29) + X( 31) + X( 32) + X( 33) + X( 34)
     + X( 35) + X( 37) + X( 38) + X( 39) + X( 45) + X( 46) + X( 47)
     + X( 52) + X( 53) + X( 55) + X( 56) + X( 61) + X( 62) + X( 63)
     + X( 72) + X( 152) >=   0
53]- Y( 50) + X( 25) + X( 27) + X( 29) + X( 30) + X( 31) + X( 32)
     + X( 33) + X( 34) + X( 35) + X( 36) + X( 37) + X( 38) + X( 39)
     + X( 40) + X( 41) + X( 42) + X( 45) + X( 46) + X( 47) + X( 49)
     + X( 50) + X( 51) + X( 52) + X( 53) + X( 54) + X( 55) + X( 56)
     + X( 57) + X( 59) + X( 60) + X( 61) + X( 62) + X( 63) + X( 64)
     + X( 71) + X( 72) + X( 81) + X( 152) >=   0
54]- Y( 51) + X( 9) + X( 12) + X( 13) + X( 15) + X( 23) + X( 25)
     + X( 31) + X( 32) + X( 33) + X( 34) + X( 35) + X( 36) + X( 37)
     + X( 38) + X( 152) >=   0
55]- Y( 52) + X( 5) + X( 6) + X( 7) + X( 8) + X( 9) + X( 10) + X( 12)
     + X( 13) + X( 90) + X( 106) >=   0
56]- Y( 53) >=   0
57]- Y( 54) + X( 1) + X( 6) >=   0
58]- Y( 55) =   0
59]- Y( 56) =   0
60]- Y( 57) =   0
61]- Y( 58) =   0
62]- Y( 59) =   0
63]- Y( 60) + X( 5) + X( 6) + X( 7) + X( 8) + X( 9) + X( 10) + X( 11)
     + X( 12) + X( 13) + X( 14) + X( 15) + X( 20) + X( 21) + X( 22)
     + X( 23) + X( 24) + X( 25) + X( 30) + X( 31) + X( 32) + X( 33)
     + X( 34) + X( 35) + X( 38) + X( 83) + X( 86) + X( 89) + X( 90)
     + X( 92) + X( 96) + X( 98) + X( 152) >=   0
64]- Y( 61) + X( 142) + X( 144) + X( 145) + X( 146) + X( 147)
     >=   0
65]- Y( 62) =   0
66]- Y( 63) + X( 15) + X( 22) + X( 23) + X( 24) + X( 25) + X( 26)
     + X( 27) + X( 28) + X( 29) + X( 30) + X( 31) + X( 32) + X( 35)
     + X( 36) + X( 37) + X( 38) + X( 39) + X( 40) + X( 44) + X( 45)
     + X( 46) + X( 47) + X( 52) + X( 53) + X( 56) + X( 81) + X( 83)
     + X( 152) >=   0
67]- Y( 64) =   0
68]- Y( 65) =   0
69]- Y( 66) + X( 6) + X( 7) + X( 8) + X( 9) + X( 12) + X( 13) + X( 15)
     + X( 90) + X( 106) >=   0
70]- Y( 67) + X( 34) >=   0
71]- Y( 68) =   0
72]- Y( 69) + X( 25) + X( 31) + X( 32) + X( 33) + X( 34) + X( 35)
     + X( 37) + X( 38) + X( 52) + X( 53) + X( 152) >=   0
73]- Y( 70) =   0
74]- Y( 71) =   0
75]- Y( 72) + X( 1) + X( 5) + X( 6) + X( 7) + X( 8) + X( 9) + X( 10)
     + X( 13) >=   0
76]- Y( 73) =   0
77]- Y( 74) + X( 57) + X( 58) + X( 60) + X( 61) + X( 62) + X( 63)
```

```
     + X( 64) + X( 65) + X( 66) + X( 67) + X( 68) + X( 69) + X( 70)
     + X( 71) + X( 72) + X( 73) + X( 74) + X( 112) + X( 114) + X( 115)
     + X( 116) + X( 117) + X( 118) + X( 119) + X( 120) + X( 121)
     + X( 122) + X( 123) + X( 124) + X( 125) + X( 131) >=   0
78]- Y( 75) =   0
79]- Y( 76) + X( 73) + X( 74) + X( 112) + X( 116) + X( 117) + X( 118)
     + X( 119) + X( 120) + X( 121) + X( 122) + X( 123) + X( 124)
     + X( 125) + X( 126) + X( 127) + X( 131) >=   0
80]- Y( 77) + X( 112) + X( 113) + X( 114) + X( 115) + X( 116)
     + X( 117) + X( 118) + X( 119) + X( 120) + X( 122) + X( 123)
     + X( 124) + X( 125) + X( 126) + X( 127) + X( 128) + X( 131)
     >=   0
81]- Y( 78) + X( 117) + X( 118) + X( 119) + X( 120) + X( 123)
     + X( 124) + X( 126) >=   0
82]- Y( 79) + X( 120) + X( 123) + X( 124) + X( 126) >=   0
83]- Y( 80) + X( 133) + X( 134) + X( 136) + X( 137) + X( 138)
     + X( 140) + X( 141) + X( 142) + X( 143) + X( 144) + X( 145)
     >=   0
84]- Y( 81) + X( 137) + X( 139) + X( 140) + X( 141) + X( 142)
     + X( 143) + X( 144) + X( 145) + X( 146) + X( 147) + X( 148)
     + X( 149) + X( 150) >=   0
85]- Y( 82) + X( 142) + X( 143) + X( 144) + X( 145) + X( 146)
     + X( 147) + X( 148) + X( 149) + X( 150) >=   0
86]- Y( 83) + X( 113) + X( 118) + X( 119) + X( 120) + X( 121)
     + X( 123) + X( 124) + X( 125) + X( 126) + X( 127) + X( 130)
     + X( 132) + X( 133) + X( 134) + X( 135) + X( 136) + X( 137)
     + X( 138) + X( 140) + X( 141) + X( 142) >=   0
87]- Y( 84) =   0
88]- Y( 85) + X( 117) + X( 118) + X( 123) >=   0
89]- Y( 86) + X( 69) + X( 70) + X( 71) + X( 72) + X( 73) + X( 74)
     >=   0
90]- Y( 87) + X( 68) + X( 69) + X( 70) + X( 71) + X( 72) + X( 73)
     + X( 74) + X( 112) + X( 115) + X( 116) + X( 117) + X( 118)
     + X( 119) + X( 120) + X( 123) + X( 124) + X( 131) >=   0
91]- Y( 88) =   0
92]- Y( 89) + X( 112) + X( 113) + X( 114) + X( 115) + X( 116)
     + X( 117) + X( 118) + X( 119) + X( 120) + X( 121) + X( 122)
     + X( 123) + X( 124) + X( 125) + X( 126) + X( 127) + X( 128)
     + X( 130) + X( 131) + X( 132) + X( 133) + X( 134) + X( 135)
     + X( 136) + X( 137) + X( 140) + X( 141) >=   0
93]- Y( 90) =   0
94]- Y( 91) =   0
95]- Y( 92) + X( 134) + X( 136) + X( 137) + X( 138) + X( 139)
     + X( 140) + X( 141) + X( 142) + X( 143) + X( 145) + X( 146)
     + X( 147) + X( 148) + X( 149) + X( 150) >=   0
96]- Y( 93) + X( 113) + X( 120) + X( 124) + X( 125) + X( 126)
     + X( 127) + X( 128) + X( 130) + X( 132) + X( 133) + X( 134)
     + X( 135) + X( 136) + X( 137) + X( 138) + X( 139) + X( 140)
     + X( 141) + X( 142) + X( 143) + X( 144) + X( 145) + X( 146)
     + X( 148) + X( 149) >=   0
97]- Y( 94) + X( 113) + X( 114) + X( 116) + X( 117) + X( 118)
     + X( 119) + X( 120) + X( 121) + X( 122) + X( 123) + X( 124)
     + X( 125) + X( 126) + X( 127) + X( 128) + X( 130) + X( 131)
     + X( 133) + X( 134) + X( 137) >=   0
98]- Y( 95) + X( 140) + X( 141) + X( 142) + X( 143) + X( 144)
     + X( 145) >=   0
99]- Y( 96) + X( 142) >=   0
```

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100]- Y( 97) + X( 123) >=   0
101]- Y( 98) + X( 118) >=   0
102]- Y( 99) + X( 68) + X( 69) + X( 70) + X( 71) + X( 73) + X( 74)
     + X( 112) + X( 114) + X( 115) + X( 116) + X( 117) + X( 118)
     + X( 119) + X( 120) + X( 123) + X( 124) >=   0
103]- Y( 100) =   0
104]- 10 X( 1) - 8 X( 2) - 10 X( 3) - 9 X( 4) - 10 X( 5) - 10 X( 6)
     - 9 X( 7) - 10 X( 8) - 9 X( 9) - 8 X( 10) - 9 X( 11) - 8 X( 12)
     - 7 X( 13) - 9 X( 14) - 10 X( 15) - 8 X( 16) - 7 X( 17)
     - 7 X( 18) - 6 X( 19) - 9 X( 20) - 7 X( 21) - 10 X( 22)
     - 10 X( 23) - 7 X( 24) - 10 X( 25) - 8 X( 26) - 7 X( 27)
     - 7 X( 28) - 8 X( 29) - 7 X( 30) - 7 X( 31) - 8 X( 32) - 7 X( 33)
     - 8 X( 34) - 7 X( 35) - 7 X( 36) - 7 X( 37) - 7 X( 38) - 8 X( 39)
     - 7 X( 40) - 7 X( 41) - 7 X( 42) - 7 X( 43) - 8 X( 44) - 8 X( 45)
     - 8 X( 46) - 10 X( 47) - 10 X( 48) - 9 X( 49) - 8 X( 50)
     - 7 X( 51) - 9 X( 52) - 9 X( 53) - 8 X( 54) - 8 X( 55) - 9 X( 56)
     - 9 X( 57) - 7 X( 58) - 9 X( 59) - 9 X( 60) - 10 X( 61)
     - 10 X( 62) - 10 X( 63) - 10 X( 64) - 10 X( 65) - 8 X( 66)
     - 9 X( 67) - 9 X( 68) - 10 X( 69) - 10 X( 70) - 10 X( 71)
     - 9 X( 72) - 8 X( 73) - 8 X( 74) - 7 X( 75) - 7 X( 76) - 7 X( 77)
     - 6 X( 78) - 6 X( 79) - 6 X( 80) - 7 X( 81) - 6 X( 82) - 7 X( 83)
     - 7 X( 84) - 8 X( 85) - 8 X( 86) - 7 X( 87) - 10 X( 88)
     - 7 X( 89) - 8 X( 90) - 7 X( 91) - 7 X( 92) - 6 X( 93) - 7 X( 94)
     - 7 X( 95) - 7 X( 96) - 8 X( 97) - 8 X( 98) - 8 X( 99)
     - 7 X( 100) - 7 X( 101) - 7 X( 102) - 6 X( 103) - 7 X( 104)
     - 7 X( 105) - 9 X( 106) - 6 X( 107) - 8 X( 108) - 9 X( 109)
     - 8 X( 110) - 8 X( 111) - 10 X( 112) - 10 X( 113) - 5 X( 114)
     - 9 X( 115) - 9 X( 116) - 10 X( 117) - 10 X( 118) - 8 X( 119)
     - 9 X( 120) - 8 X( 121) - 7 X( 122) - 9 X( 123) - 9 X( 124)
     - 10 X( 125) - 10 X( 126) - 8 X( 127) - 9 X( 128) - 8 X( 129)
     - 8 X( 130) - 7 X( 131) - 8 X( 132) - 8 X( 133) - 8 X( 134)
     - 9 X( 135) - 7 X( 136) - 7 X( 137) - 9 X( 138) - 8 X( 139)
     - 7 X( 140) - 8 X( 141) - 9 X( 142) - 10 X( 143) - 8 X( 144)
     - 8 X( 145) - 10 X( 146) - 10 X( 147) - 8 X( 148) - 8 X( 149)
     - 8 X( 150) - 10 X( 151) - 10 X( 152) + G =   0
105]  G >=  210
106]- 7 X( 1) - 10 X( 2) - 8 X( 3) - 8 X( 4) - 10 X( 5) - 9 X( 6)
     - 7 X( 7) - 8 X( 8) - 8 X( 9) - 8 X( 10) - 10 X( 11) - 8 X( 12)
     - 8 X( 13) - 8 X( 14) - 7 X( 15) - 8 X( 16) - 8 X( 17) - 8 X( 18)
     - 9 X( 19) - 9 X( 20) - 8 X( 21) - 7 X( 22) - 10 X( 23)
     - 7 X( 24) - 8 X( 25) - 8 X( 26) - 8 X( 27) - 8 X( 28) - 8 X( 29)
     - 8 X( 30) - 7 X( 31) - 8 X( 32) - 7 X( 33) - 8 X( 34) - 8 X( 35)
     - 7 X( 36) - 8 X( 37) - 9 X( 38) - 8 X( 39) - 7 X( 40) - 7 X( 41)
     - 8 X( 42) - 7 X( 43) - 7 X( 44) - 8 X( 45) - 7 X( 46) - 7 X( 47)
     - 7 X( 48) - 9 X( 49) - 8 X( 50) - 8 X( 51) - 8 X( 52) - 9 X( 53)
     - 8 X( 54) - 8 X( 55) - 8 X( 56) - 9 X( 57) - 8 X( 58) - 8 X( 59)
     - 9 X( 60) - 9 X( 61) - 7 X( 62) - 10 X( 63) - 5 X( 64)
     - 6 X( 65) - 9 X( 66) - 10 X( 67) - 6 X( 68) - 9 X( 69)
     - 7 X( 70) - 8 X( 71) - 6 X( 72) - 7 X( 73) - 6 X( 74) - 7 X( 75)
     - 8 X( 76) - 7 X( 77) - 9 X( 78) - 7 X( 79) - 7 X( 80) - 9 X( 81)
     - 9 X( 82) - 7 X( 83) - 9 X( 84) - 9 X( 85) - 9 X( 86) - 9 X( 87)
     - 10 X( 88) - 7 X( 89) - 8 X( 90) - 9 X( 91) - 8 X( 92)
     - 8 X( 93) - 8 X( 94) - 8 X( 95) - 8 X( 96) - 8 X( 97) - 8 X( 98)
     - 8 X( 99) - 8 X( 100) - 8 X( 101) - 7 X( 102) - 7 X( 103)
     - 8 X( 104) - 6 X( 105) - 8 X( 106) - 7 X( 107) - 8 X( 108)
     - 9 X( 109) - 9 X( 110) - 9 X( 111) - 10 X( 112) - 6 X( 113)
     - 7 X( 114) - 8 X( 115) - 6 X( 116) - 6 X( 117) - 8 X( 118)
```

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     - 8 X( 119) - 8 X( 120) - 8 X( 121) - 6 X( 122) - 6 X( 123)
     - 9 X( 124) - 8 X( 125) - 6 X( 126) - 10 X( 127) - 8 X( 128)
     - 8 X( 129) - 8 X( 130) - 7 X( 131) - 7 X( 132) - 6 X( 133)
     - 7 X( 134) - 8 X( 135) - 8 X( 136) - 8 X( 137) - 6 X( 138)
     - 8 X( 139) - 9 X( 140) - 8 X( 141) - 9 X( 142) - 8 X( 143)
     - 8 X( 144) - 8 X( 145) - 10 X( 146) - 10 X( 147) - 8 X( 148)
     - 9 X( 149) - 9 X( 150) - 10 X( 151) - 10 X( 152) + L =    0
 107]  L >=   210
 108]- 7 X( 1) - 7 X( 2) - 8 X( 3) - 8 X( 4) - 7 X( 5) - 8 X( 6)
     - 7 X( 7) - 8 X( 8) - 8 X( 9) - 8 X( 10) - 9 X( 11) - 8 X( 12)
     - 9 X( 13) - 9 X( 14) - 10 X( 15) - 8 X( 16) - 9 X( 17)
     - 9 X( 18) - 10 X( 19) - 9 X( 20) - 9 X( 21) - 10 X( 22)
     - 10 X( 23) - 7 X( 24) - 9 X( 25) - 9 X( 26) - 8 X( 27)
     - 8 X( 28) - 8 X( 29) - 8 X( 30) - 7 X( 31) - 7 X( 32) - 7 X( 33)
     - 8 X( 34) - 7 X( 35) - 7 X( 36) - 7 X( 37) - 7 X( 38) - 8 X( 39)
     - 7 X( 40) - 7 X( 41) - 7 X( 42) - 7 X( 43) - 7 X( 44) - 8 X( 45)
     - 7 X( 46) - 7 X( 47) - 9 X( 48) - 8 X( 49) - 8 X( 50) - 8 X( 51)
     - 9 X( 52) - 9 X( 53) - 8 X( 54) - 8 X( 55) - 8 X( 56) - 9 X( 57)
     - 8 X( 58) - 10 X( 59) - 10 X( 60) - 10 X( 61) - 10 X( 62)
     - 10 X( 63) - 10 X( 64) - 10 X( 65) - 10 X( 66) - 10 X( 67)
     - 10 X( 68) - 10 X( 69) - 10 X( 70) - 10 X( 71) - 10 X( 72)
     - 10 X( 73) - 10 X( 74) - 8 X( 75) - 7 X( 76) - 8 X( 77)
     - 8 X( 78) - 7 X( 79) - 7 X( 80) - 9 X( 81) - 7 X( 82) - 7 X( 83)
     - 8 X( 84) - 9 X( 85) - 9 X( 86) - 6 X( 87) - 10 X( 88)
     - 7 X( 89) - 7 X( 90) - 9 X( 91) - 8 X( 92) - 7 X( 93) - 8 X( 94)
     - 8 X( 95) - 8 X( 96) - 8 X( 97) - 8 X( 98) - 8 X( 99)
     - 8 X( 100) - 8 X( 101) - 7 X( 102) - 9 X( 103) - 7 X( 104)
     - 8 X( 105) - 8 X( 106) - 8 X( 107) - 7 X( 108) - 7 X( 109)
     - 7 X( 110) - 7 X( 111) - 10 X( 112) - 10 X( 113) - 10 X( 114)
     - 10 X( 115) - 10 X( 116) - 10 X( 117) - 10 X( 118) - 10 X( 119)
     - 9 X( 120) - 7 X( 121) - 10 X( 122) - 10 X( 123) - 9 X( 124)
     - 9 X( 125) - 10 X( 126) - 10 X( 127) - 8 X( 128) - 8 X( 129)
     - 7 X( 130) - 7 X( 131) - 8 X( 132) - 9 X( 133) - 10 X( 134)
     - 9 X( 135) - 9 X( 136) - 9 X( 137) - 10 X( 138) - 8 X( 139)
     - 8 X( 140) - 10 X( 141) - 10 X( 142) - 9 X( 143) - 8 X( 144)
     - 10 X( 145) - 10 X( 146) - 10 X( 147) - 8 X( 148) - 10 X( 149)
     - 10 X( 150) - 10 X( 151) - 10 X( 152) + W =    0
 109]  W >=   210
 END

ALL VARIABLES ARE BINARY
```

b. 120-Mile Formulation

```
MAX      Y( 1) + Y( 2) + Y( 3) + Y( 4) + Y( 5) + Y( 6) + Y( 7) + Y( 8)
     + Y( 9) + Y( 10) + Y( 11) + Y( 12) + Y( 13) + Y( 14) + Y( 15)
     + Y( 16) + Y( 17) + Y( 18) + Y( 19) + Y( 20) + Y( 21) + Y( 22)
     + Y( 23) + Y( 24) + Y( 25) + Y( 26) + Y( 27) + Y( 28) + Y( 29)
     + Y( 30) + Y( 31) + Y( 32) + Y( 33) + Y( 34) + Y( 35) + Y( 36)
     + Y( 37) + Y( 38) + Y( 39) + Y( 40) + Y( 41) + Y( 42) + Y( 43)
     + Y( 44) + Y( 45) + Y( 46) + Y( 47) + Y( 48) + Y( 49) + Y( 50)
     + Y( 51) + Y( 52) + Y( 53) + Y( 54) + Y( 55) + Y( 56) + Y( 57)
     + Y( 58) + Y( 59) + Y( 60) + Y( 61) + Y( 62) + Y( 63) + Y( 64)
     + Y( 65) + Y( 66) + Y( 67) + Y( 68) + Y( 69) + Y( 70) + Y( 71)
     + Y( 72) + Y( 73) + Y( 74) + Y( 75) + Y( 76) + Y( 77) + Y( 78)
     + Y( 79) + Y( 80) + Y( 81) + Y( 82) + Y( 83) + Y( 84) + Y( 85)
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```
     + Y( 86) + Y( 87) + Y( 88) + Y( 89) + Y( 90) + Y( 91) + Y( 92)
     + Y( 93) + Y( 94) + Y( 95) + Y( 96) + Y( 97) + Y( 98) + Y( 99)
     + Y( 100)
SUBJECT TO
2]- X( 1) - X( 2) - X( 3) - X( 4) - X( 5) - X( 6) - X( 7) - X( 8)
     - X( 9) - X( 10) - X( 11) - X( 12) - X( 13) - X( 14) - X( 15)
     - X( 16) - X( 17) - X( 18) - X( 19) - X( 20) - X( 21) - X( 22)
     - X( 23) - X( 24) - X( 25) - X( 26) - X( 27) - X( 28) - X( 29)
     - X( 30) - X( 31) - X( 32) - X( 33) - X( 34) - X( 35) - X( 36)
     - X( 37) - X( 38) - X( 39) - X( 40) - X( 41) - X( 42) - X( 43)
     - X( 44) - X( 45) - X( 46) - X( 47) - X( 48) - X( 49) - X( 50)
     - X( 51) - X( 52) - X( 53) - X( 54) - X( 55) - X( 56) - X( 57)
     - X( 58) - X( 59) - X( 60) - X( 61) - X( 62) - X( 63) - X( 64)
     - X( 65) - X( 66) - X( 67) - X( 68) - X( 69) - X( 70) - X( 71)
     - X( 72) - X( 73) - X( 74) - X( 75) - X( 76) - X( 77) - X( 78)
     - X( 79) - X( 80) - X( 81) - X( 82) - X( 83) - X( 84) - X( 85)
     - X( 86) - X( 87) - X( 88) - X( 89) - X( 90) - X( 91) - X( 92)
     - X( 93) - X( 94) - X( 95) - X( 96) - X( 97) - X( 98) - X( 99)
     - X( 100) - X( 101) - X( 102) - X( 103) - X( 104) - X( 105)
     - X( 106) - X( 107) - X( 108) - X( 109) - X( 110) - X( 111)
     - X( 112) - X( 113) - X( 114) - X( 115) - X( 116) - X( 117)
     - X( 118) - X( 119) - X( 120) - X( 121) - X( 122) - X( 123)
     - X( 124) - X( 125) - X( 126) - X( 127) - X( 128) - X( 129)
     - X( 130) - X( 131) - X( 132) - X( 133) - X( 134) - X( 135)
     - X( 136) - X( 137) - X( 138) - X( 139) - X( 140) - X( 141)
     - X( 142) - X( 143) - X( 144) - X( 145) - X( 146) - X( 147)
     - X( 148) - X( 149) - X( 150) - X( 151) - X( 152) + A =    0
3]  A <=   7
4]- Y( 1) + X( 1) + X( 2) + X( 3) + X( 4) + X( 5) + X( 6) + X( 7)
     + X( 8) + X( 9) + X( 10) + X( 12) + X( 13) + X( 16) + X( 108)
     + X( 109) >=   0
5]- Y( 2) + X( 1) + X( 2) + X( 3) + X( 4) + X( 5) + X( 6) + X( 7)
     + X( 8) + X( 9) + X( 10) + X( 11) + X( 12) + X( 13) + X( 14)
     + X( 16) + X( 17) + X( 18) + X( 19) + X( 20) + X( 21) + X( 23)
     + X( 86) + X( 87) + X( 89) + X( 90) + X( 91) + X( 92) + X( 94)
     + X( 97) + X( 100) + X( 104) + X( 105) + X( 106) + X( 109)
     + X( 110) + X( 111) >=   0
6]- Y( 3) + X( 1) + X( 4) + X( 5) + X( 6) + X( 7) + X( 8) + X( 9)
     + X( 10) + X( 12) + X( 13) + X( 90) + X( 106) + X( 108) >=   0
7]- Y( 4) + X( 1) + X( 2) + X( 3) + X( 4) + X( 5) + X( 7) + X( 8)
     + X( 9) + X( 10) + X( 11) + X( 12) + X( 13) + X( 15) + X( 16)
     + X( 17) + X( 18) + X( 19) + X( 21) + X( 86) + X( 89) + X( 90)
     + X( 91) + X( 92) + X( 94) + X( 97) + X( 98) + X( 99) + X( 106)
     + X( 108) + X( 109) + X( 110) + X( 111) >=   0
8]- Y( 5) + X( 6) + X( 7) + X( 8) + X( 9) + X( 12) + X( 13) + X( 15)
     + X( 90) + X( 106) >=   0
9]- Y( 6) + X( 6) + X( 7) + X( 8) + X( 9) + X( 12) + X( 13) + X( 15)
     + X( 31) + X( 33) + X( 34) + X( 38) + X( 90) + X( 106) >=   0
10]- Y( 7) >=   0
11]- Y( 8) + X( 33) >=   0
12]- Y( 9) + X( 33) >=   0
13]- Y( 10) + X( 33) >=   0
14]- Y( 11) =   0
15]- Y( 12) + X( 33) >=   0
16]- Y( 13) + X( 33) >=   0
17]- Y( 14) =   0
18]- Y( 15) =   0
```

```
19]- Y( 16) =   0
20]- Y( 17) =   0
21]- Y( 18) =   0
22]- Y( 19) =   0
23]- Y( 20) + X( 53) + X( 56) + X( 61) + X( 62) + X( 63) + X( 71)
     + X( 72) >=   0
24]- Y( 21) + X( 72) + X( 73) >=   0
25]- Y( 22) =   0
26]- Y( 23) + X( 72) >=   0
27]- Y( 24) =   0
28]- Y( 25) =   0
29]- Y( 26) + X( 6) + X( 7) + X( 8) + X( 9) + X( 13) >=   0
30]- Y( 27) =   0
31]- Y( 28) =   0
32]- Y( 29) + X( 6) + X( 8) + X( 13) >=   0
33]- Y( 30) + X( 33) + X( 34) + X( 38) >=   0
34]- Y( 31) + X( 61) + X( 62) + X( 63) + X( 69) + X( 70) + X( 71)
     + X( 72) >=   0
35]- Y( 32) + X( 61) + X( 62) + X( 63) + X( 64) + X( 68) + X( 69)
     + X( 70) + X( 71) + X( 72) + X( 74) >=   0
36]- Y( 33) + X( 52) + X( 53) + X( 54) + X( 55) + X( 57) + X( 58)
     + X( 59) + X( 60) + X( 61) + X( 62) + X( 63) + X( 64) + X( 65)
     + X( 66) + X( 67) + X( 68) + X( 69) + X( 70) + X( 71) + X( 72)
     + X( 73) + X( 74) + X( 112) + X( 114) + X( 115) + X( 116)
     + X( 117) + X( 118) >=   0
37]- Y( 34) + X( 53) + X( 56) + X( 57) + X( 59) + X( 60) + X( 61)
     + X( 62) + X( 63) + X( 64) + X( 65) + X( 68) + X( 69) + X( 70)
     + X( 71) + X( 72) + X( 74) + X( 112) >=   0
38]- Y( 35) + X( 46) + X( 47) + X( 48) + X( 49) + X( 52) + X( 53)
     + X( 54) + X( 55) + X( 56) + X( 57) + X( 59) + X( 60) + X( 64)
     + X( 65) + X( 68) + X( 74) >=   0
39]- Y( 36) + X( 45) + X( 46) + X( 49) + X( 51) + X( 52) + X( 53)
     + X( 54) + X( 55) + X( 56) + X( 57) + X( 58) + X( 59) + X( 60)
     + X( 61) + X( 62) + X( 64) + X( 65) + X( 66) + X( 67) + X( 68)
     + X( 69) + X( 70) + X( 71) + X( 72) + X( 73) + X( 74) + X( 75)
     + X( 112) >=   0
40]- Y( 37) + X( 33) + X( 35) + X( 37) + X( 38) + X( 46) + X( 49)
     + X( 51) + X( 54) + X( 57) + X( 58) + X( 59) + X( 64) + X( 65)
     + X( 68) + X( 69) + X( 70) + X( 75) >=   0
41]- Y( 38) + X( 52) + X( 53) + X( 55) + X( 59) + X( 60) + X( 61)
     + X( 62) + X( 63) + X( 64) + X( 69) + X( 70) + X( 71) + X( 72)
     >=   0
42]- Y( 39) + X( 51) + X( 52) + X( 53) + X( 54) + X( 55) + X( 56)
     + X( 57) + X( 58) + X( 59) + X( 60) + X( 61) + X( 62) + X( 63)
     + X( 64) + X( 65) + X( 66) + X( 67) + X( 68) + X( 69) + X( 70)
     + X( 71) + X( 72) + X( 73) + X( 74) + X( 75) + X( 76) + X( 112)
     + X( 114) + X( 115) + X( 116) + X( 117) + X( 118) + X( 119)
     + X( 131) >=   0
43]- Y( 40) + X( 39) + X( 40) + X( 45) + X( 46) + X( 47) + X( 49)
     + X( 50) + X( 51) + X( 52) + X( 53) + X( 54) + X( 55) + X( 56)
     + X( 57) + X( 58) + X( 59) + X( 60) + X( 61) + X( 62) + X( 63)
     + X( 64) + X( 65) + X( 66) + X( 68) + X( 69) + X( 70) + X( 71)
     + X( 72) + X( 73) + X( 74) + X( 75) + X( 76) + X( 112) + X( 114)
     + X( 115) + X( 116) + X( 117) + X( 118) + X( 119) >=   0
44]- Y( 41) + X( 29) + X( 33) + X( 35) + X( 36) + X( 37) + X( 40)
     + X( 41) + X( 42) + X( 44) + X( 45) + X( 46) + X( 47) + X( 49)
     + X( 50) + X( 51) + X( 53) + X( 54) + X( 55) + X( 57) + X( 58)
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     + X( 59) + X( 60) + X( 61) + X( 62) + X( 63) + X( 64) + X( 65)
     + X( 66) + X( 67) + X( 68) + X( 69) + X( 70) + X( 71) + X( 72)
     + X( 73) + X( 74) + X( 76) + X( 77) + X( 112) + X( 114) + X( 115)
     + X( 116) + X( 117) + X( 118) + X( 152) >=   0
45]- Y( 42) + X( 29) + X( 31) + X( 32) + X( 35) + X( 36) + X( 37)
     + X( 39) + X( 40) + X( 41) + X( 42) + X( 43) + X( 44) + X( 46)
     + X( 47) + X( 49) + X( 51) + X( 52) + X( 53) + X( 54) + X( 57)
     + X( 58) + X( 60) + X( 61) + X( 62) + X( 64) + X( 65) + X( 66)
     + X( 67) + X( 68) + X( 69) + X( 70) + X( 71) + X( 72) + X( 73)
     + X( 74) + X( 75) + X( 76) + X( 77) + X( 112) + X( 114) + X( 115)
     + X( 116) + X( 152) >=   0
46]- Y( 43) + X( 31) + X( 32) + X( 33) + X( 34) + X( 35) + X( 37)
     + X( 39) + X( 45) + X( 46) + X( 52) + X( 53) + X( 55) + X( 56)
     + X( 57) + X( 60) + X( 61) + X( 62) + X( 63) + X( 64) + X( 69)
     + X( 70) + X( 71) + X( 72) + X( 152) >=   0
47]- Y( 44) + X( 31) + X( 32) + X( 33) + X( 34) + X( 35) + X( 39)
     + X( 45) + X( 46) + X( 52) + X( 53) + X( 55) + X( 56) + X( 59)
     + X( 60) + X( 61) + X( 62) + X( 63) + X( 70) + X( 71) + X( 152)
     >=   0
48]- Y( 45) + X( 47) + X( 52) + X( 53) + X( 56) + X( 61) + X( 63)
     + X( 72) >=   0
49]- Y( 46) + X( 25) + X( 31) + X( 32) + X( 33) + X( 34) + X( 35)
     + X( 37) + X( 39) + X( 45) + X( 46) + X( 47) + X( 52) + X( 53)
     + X( 55) + X( 56) + X( 61) + X( 62) + X( 63) + X( 72) + X( 152)
     >=   0
50]- Y( 47) + X( 25) + X( 31) + X( 32) + X( 33) + X( 34) + X( 35)
     + X( 37) + X( 38) + X( 39) + X( 45) + X( 47) + X( 52) + X( 53)
     + X( 56) + X( 61) + X( 62) + X( 63) + X( 152) >=   0
51]- Y( 48) + X( 25) + X( 31) + X( 32) + X( 34) + X( 35) + X( 37)
     + X( 38) + X( 152) >=   0
52]- Y( 49) + X( 23) + X( 24) + X( 25) + X( 26) + X( 27) + X( 28)
     + X( 29) + X( 31) + X( 32) + X( 33) + X( 34) + X( 35) + X( 36)
     + X( 37) + X( 38) + X( 39) + X( 40) + X( 41) + X( 42) + X( 44)
     + X( 45) + X( 46) + X( 47) + X( 49) + X( 51) + X( 52) + X( 53)
     + X( 55) + X( 56) + X( 57) + X( 60) + X( 61) + X( 62) + X( 63)
     + X( 64) + X( 69) + X( 70) + X( 72) + X( 75) + X( 81) + X( 83)
     + X( 152) >=   0
53]- Y( 50) + X( 12) + X( 13) + X( 14) + X( 15) + X( 20) + X( 22)
     + X( 25) + X( 26) + X( 27) + X( 29) + X( 30) + X( 31) + X( 32)
     + X( 33) + X( 34) + X( 35) + X( 36) + X( 37) + X( 38) + X( 39)
     + X( 40) + X( 41) + X( 42) + X( 43) + X( 45) + X( 46) + X( 47)
     + X( 49) + X( 50) + X( 51) + X( 52) + X( 53) + X( 54) + X( 55)
     + X( 56) + X( 57) + X( 58) + X( 59) + X( 60) + X( 61) + X( 62)
     + X( 63) + X( 64) + X( 65) + X( 66) + X( 67) + X( 68) + X( 69)
     + X( 70) + X( 71) + X( 72) + X( 75) + X( 76) + X( 77) + X( 78)
     + X( 79) + X( 80) + X( 81) + X( 82) + X( 83) + X( 84) + X( 86)
     + X( 152) >=   0
54]- Y( 51) + X( 5) + X( 6) + X( 7) + X( 9) + X( 10) + X( 11) + X( 12)
     + X( 13) + X( 14) + X( 15) + X( 22) + X( 23) + X( 24) + X( 25)
     + X( 26) + X( 27) + X( 28) + X( 29) + X( 30) + X( 31) + X( 32)
     + X( 33) + X( 34) + X( 35) + X( 36) + X( 37) + X( 38) + X( 40)
     + X( 44) + X( 45) + X( 46) + X( 52) + X( 53) + X( 56) + X( 81)
     + X( 83) + X( 86) + X( 89) + X( 90) + X( 91) + X( 92) + X( 152)
     >=   0
55]- Y( 52) + X( 4) + X( 5) + X( 6) + X( 7) + X( 8) + X( 9) + X( 10)
     + X( 11) + X( 12) + X( 13) + X( 14) + X( 15) + X( 16) + X( 20)
     + X( 21) + X( 22) + X( 23) + X( 24) + X( 25) + X( 31) + X( 32)
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     + X( 33) + X( 34) + X( 38) + X( 86) + X( 90) + X( 91) + X( 92)
     + X( 98) + X( 99) + X( 106) + X( 108) >=   0
56]- Y( 53) + X( 1) + X( 6) + X( 8) >=   0
57]- Y( 54) + X( 1) + X( 2) + X( 4) + X( 5) + X( 6) + X( 7) + X( 8)
     + X( 106) + X( 108) + X( 109) >=   0
58]- Y( 55) =   0
59]- Y( 56) =   0
60]- Y( 57) =   0
61]- Y( 58) =   0
62]- Y( 59) =   0
63]- Y( 60) + X( 1) + X( 2) + X( 3) + X( 4) + X( 5) + X( 6) + X( 7)
     + X( 8) + X( 9) + X( 10) + X( 11) + X( 12) + X( 13) + X( 14)
     + X( 15) + X( 16) + X( 17) + X( 19) + X( 20) + X( 21) + X( 22)
     + X( 23) + X( 24) + X( 25) + X( 28) + X( 29) + X( 30) + X( 31)
     + X( 32) + X( 33) + X( 34) + X( 35) + X( 36) + X( 38) + X( 39)
     + X( 40) + X( 44) + X( 45) + X( 47) + X( 80) + X( 81) + X( 82)
     + X( 83) + X( 84) + X( 85) + X( 86) + X( 87) + X( 88) + X( 89)
     + X( 90) + X( 92) + X( 93) + X( 94) + X( 95) + X( 96) + X( 97)
     + X( 98) + X( 100) + X( 101) + X( 102) + X( 103) + X( 108)
     + X( 109) + X( 152) >=   0
64]- Y( 61) + X( 141) + X( 142) + X( 143) + X( 144) + X( 145)
     + X( 146) + X( 147) + X( 148) + X( 149) + X( 150) >=   0
65]- Y( 62) + X( 142) + X( 144) >=   0
66]- Y( 63) + X( 8) + X( 9) + X( 10) + X( 12) + X( 13) + X( 15)
     + X( 22) + X( 23) + X( 24) + X( 25) + X( 26) + X( 27) + X( 28)
     + X( 29) + X( 30) + X( 31) + X( 32) + X( 35) + X( 36) + X( 37)
     + X( 38) + X( 39) + X( 40) + X( 44) + X( 45) + X( 46) + X( 47)
     + X( 49) + X( 50) + X( 52) + X( 53) + X( 54) + X( 55) + X( 56)
     + X( 57) + X( 59) + X( 60) + X( 61) + X( 62) + X( 63) + X( 64)
     + X( 71) + X( 72) + X( 80) + X( 81) + X( 82) + X( 83) + X( 84)
     + X( 85) + X( 87) + X( 89) + X( 90) + X( 91) + X( 152) >=   0
67]- Y( 64) =   0
68]- Y( 65) =   0
69]- Y( 66) + X( 1) + X( 4) + X( 5) + X( 6) + X( 7) + X( 8) + X( 9)
     + X( 10) + X( 11) + X( 12) + X( 13) + X( 14) + X( 15) + X( 20)
     + X( 22) + X( 24) + X( 25) + X( 30) + X( 31) + X( 32) + X( 33)
     + X( 34) + X( 35) + X( 37) + X( 38) + X( 86) + X( 89) + X( 90)
     + X( 91) + X( 92) + X( 99) + X( 106) + X( 121) + X( 152)
     >=   0
70]- Y( 67) + X( 8) + X( 9) + X( 12) + X( 13) + X( 15) + X( 23)
     + X( 25) + X( 31) + X( 32) + X( 33) + X( 34) + X( 35) + X( 37)
     + X( 38) + X( 152) >=   0
71]- Y( 68) + X( 62) + X( 73) >=   0
72]- Y( 69) + X( 13) + X( 15) + X( 23) + X( 24) + X( 25) + X( 29)
     + X( 30) + X( 31) + X( 32) + X( 33) + X( 34) + X( 35) + X( 36)
     + X( 37) + X( 38) + X( 39) + X( 40) + X( 45) + X( 46) + X( 52)
     + X( 53) + X( 55) + X( 56) + X( 61) + X( 62) + X( 63) + X( 72)
     + X( 152) >=   0
73]- Y( 70) + X( 6) + X( 8) + X( 13) >=   0
74]- Y( 71) =   0
75]- Y( 72) + X( 1) + X( 2) + X( 3) + X( 4) + X( 5) + X( 6) + X( 7)
     + X( 8) + X( 9) + X( 10) + X( 11) + X( 13) + X( 14) + X( 15)
     + X( 16) + X( 21) + X( 86) + X( 91) + X( 92) + X( 97) + X( 98)
     + X( 99) + X( 108) + X( 109) >=   0
76]- Y( 73) =   0
77]- Y( 74) + X( 49) + X( 50) + X( 51) + X( 52) + X( 53) + X( 54)
     + X( 55) + X( 57) + X( 58) + X( 59) + X( 60) + X( 61) + X( 62)
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     + X( 63) + X( 64) + X( 65) + X( 66) + X( 67) + X( 68) + X( 69)
     + X( 70) + X( 71) + X( 72) + X( 73) + X( 74) + X( 75) + X( 76)
     + X( 77) + X( 112) + X( 114) + X( 115) + X( 116) + X( 117)
     + X( 118) + X( 119) + X( 120) + X( 121) + X( 122) + X( 123)
     + X( 124) + X( 125) + X( 126) + X( 127) + X( 131) >=   0
78]- Y( 75) =   0
79]- Y( 76) + X( 68) + X( 69) + X( 70) + X( 73) + X( 74) + X( 112)
     + X( 116) + X( 117) + X( 118) + X( 119) + X( 120) + X( 121)
     + X( 122) + X( 123) + X( 124) + X( 125) + X( 126) + X( 127)
     + X( 128) + X( 130) + X( 131) >=   0
80]- Y( 77) + X( 73) + X( 74) + X( 112) + X( 113) + X( 114) + X( 115)
     + X( 116) + X( 117) + X( 118) + X( 119) + X( 120) + X( 122)
     + X( 123) + X( 124) + X( 125) + X( 126) + X( 127) + X( 128)
     + X( 130) + X( 131) + X( 132) + X( 133) + X( 137) >=   0
81]- Y( 78) + X( 116) + X( 117) + X( 118) + X( 119) + X( 120)
     + X( 121) + X( 123) + X( 124) + X( 125) + X( 126) + X( 127)
     >=   0
82]- Y( 79) + X( 112) + X( 114) + X( 115) + X( 116) + X( 117)
     + X( 118) + X( 119) + X( 120) + X( 121) + X( 123) + X( 124)
     + X( 125) + X( 126) + X( 127) + X( 128) >=   0
83]- Y( 80) + X( 113) + X( 120) + X( 123) + X( 124) + X( 125)
     + X( 126) + X( 127) + X( 128) + X( 130) + X( 132) + X( 133)
     + X( 134) + X( 135) + X( 136) + X( 137) + X( 138) + X( 139)
     + X( 140) + X( 141) + X( 142) + X( 143) + X( 144) + X( 145)
     + X( 146) + X( 148) + X( 149) >=   0
84]- Y( 81) + X( 134) + X( 136) + X( 137) + X( 138) + X( 139)
     + X( 140) + X( 141) + X( 142) + X( 143) + X( 144) + X( 145)
     + X( 146) + X( 147) + X( 148) + X( 149) + X( 150) >=   0
85]- Y( 82) + X( 139) + X( 140) + X( 141) + X( 142) + X( 143)
     + X( 144) + X( 145) + X( 146) + X( 147) + X( 148) + X( 149)
     + X( 150) >=   0
86]- Y( 83) + X( 113) + X( 116) + X( 117) + X( 118) + X( 119)
     + X( 120) + X( 121) + X( 122) + X( 123) + X( 124) + X( 125)
     + X( 126) + X( 127) + X( 130) + X( 131) + X( 132) + X( 133)
     + X( 134) + X( 135) + X( 136) + X( 137) + X( 138) + X( 139)
     + X( 140) + X( 141) + X( 142) + X( 143) + X( 144) >=   0
87]- Y( 84) + X( 70) + X( 112) + X( 114) + X( 116) + X( 117) + X( 118)
     >=   0
88]- Y( 85) + X( 114) + X( 116) + X( 117) + X( 118) + X( 119)
     + X( 120) + X( 123) + X( 124) >=   0
89]- Y( 86) + X( 61) + X( 63) + X( 68) + X( 69) + X( 70) + X( 71)
     + X( 72) + X( 73) + X( 74) + X( 112) + X( 114) + X( 116)
     + X( 117) + X( 118) >=   0
90]- Y( 87) + X( 58) + X( 59) + X( 60) + X( 61) + X( 62) + X( 63)
     + X( 64) + X( 65) + X( 66) + X( 67) + X( 68) + X( 69) + X( 70)
     + X( 71) + X( 72) + X( 73) + X( 74) + X( 112) + X( 115) + X( 116)
     + X( 117) + X( 118) + X( 119) + X( 120) + X( 121) + X( 122)
     + X( 123) + X( 124) + X( 125) + X( 126) + X( 131) >=   0
91]- Y( 88) + X( 142) + X( 144) + X( 145) + X( 146) + X( 147)
     >=   0
92]- Y( 89) + X( 68) + X( 73) + X( 74) + X( 112) + X( 113) + X( 114)
     + X( 115) + X( 116) + X( 117) + X( 118) + X( 119) + X( 120)
     + X( 121) + X( 122) + X( 123) + X( 124) + X( 125) + X( 126)
     + X( 127) + X( 128) + X( 130) + X( 131) + X( 132) + X( 133)
     + X( 134) + X( 135) + X( 136) + X( 137) + X( 138) + X( 140)
     + X( 141) + X( 142) >=   0
93]- Y( 90) + X( 69) + X( 70) + X( 71) + X( 72) >=   0
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94]- Y( 91) + X( 118) + X( 120) + X( 123) + X( 124) + X( 126)
     + X( 140) + X( 141) + X( 142) >=   0
95]- Y( 92) + X( 130) + X( 133) + X( 134) + X( 135) + X( 136)
     + X( 137) + X( 138) + X( 139) + X( 140) + X( 141) + X( 142)
     + X( 143) + X( 145) + X( 146) + X( 147) + X( 148) + X( 149)
     + X( 150) >=   0
96]- Y( 93) + X( 113) + X( 118) + X( 119) + X( 120) + X( 121)
     + X( 122) + X( 123) + X( 124) + X( 125) + X( 126) + X( 127)
     + X( 128) + X( 130) + X( 132) + X( 133) + X( 134) + X( 135)
     + X( 136) + X( 137) + X( 138) + X( 139) + X( 140) + X( 141)
     + X( 142) + X( 143) + X( 144) + X( 145) + X( 146) + X( 147)
     + X( 148) + X( 149) + X( 150) >=   0
97]- Y( 94) + X( 112) + X( 113) + X( 114) + X( 115) + X( 116)
     + X( 117) + X( 118) + X( 119) + X( 120) + X( 121) + X( 122)
     + X( 123) + X( 124) + X( 125) + X( 126) + X( 127) + X( 128)
     + X( 130) + X( 131) + X( 132) + X( 133) + X( 134) + X( 135)
     + X( 136) + X( 137) + X( 140) + X( 141) + X( 142) >=   0
98]- Y( 95) + X( 123) + X( 124) + X( 125) + X( 126) + X( 130)
     + X( 133) + X( 134) + X( 135) + X( 136) + X( 137) + X( 138)
     + X( 139) + X( 140) + X( 141) + X( 142) + X( 143) + X( 144)
     + X( 145) + X( 146) + X( 148) + X( 149) >=   0
99]- Y( 96) + X( 141) + X( 142) + X( 144) + X( 145) >=   0
100]- Y( 97) + X( 118) + X( 120) + X( 123) + X( 124) >=   0
101]- Y( 98) + X( 114) + X( 116) + X( 117) + X( 118) + X( 119)
     + X( 120) + X( 123) >=   0
102]- Y( 99) + X( 64) + X( 65) + X( 67) + X( 68) + X( 69) + X( 70)
     + X( 71) + X( 72) + X( 73) + X( 74) + X( 112) + X( 114) + X( 115)
     + X( 116) + X( 117) + X( 118) + X( 119) + X( 120) + X( 121)
     + X( 122) + X( 123) + X( 124) + X( 125) + X( 126) + X( 131)
     >=   0
103]- Y( 100) + X( 68) + X( 69) + X( 70) + X( 71) + X( 72) + X( 73)
     + X( 74) + X( 112) + X( 114) + X( 116) + X( 117) + X( 118)
     + X( 119) >=   0
104]- 10 X( 1) - 8 X( 2) - 10 X( 3) - 9 X( 4) - 10 X( 5) - 10 X( 6)
     - 9 X( 7) - 10 X( 8) - 9 X( 9) - 8 X( 10) - 9 X( 11) - 8 X( 12)
     - 7 X( 13) - 9 X( 14) - 10 X( 15) - 8 X( 16) - 7 X( 17)
     - 7 X( 18) - 6 X( 19) - 9 X( 20) - 7 X( 21) - 10 X( 22)
     - 10 X( 23) - 7 X( 24) - 10 X( 25) - 8 X( 26) - 7 X( 27)
     - 7 X( 28) - 8 X( 29) - 7 X( 30) - 7 X( 31) - 8 X( 32) - 7 X( 33)
     - 8 X( 34) - 7 X( 35) - 7 X( 36) - 7 X( 37) - 7 X( 38) - 8 X( 39)
     - 7 X( 40) - 7 X( 41) - 7 X( 42) - 7 X( 43) - 8 X( 44) - 8 X( 45)
     - 8 X( 46) - 10 X( 47) - 10 X( 48) - 9 X( 49) - 8 X( 50)
     - 7 X( 51) - 9 X( 52) - 9 X( 53) - 8 X( 54) - 8 X( 55) - 9 X( 56)
     - 9 X( 57) - 7 X( 58) - 9 X( 59) - 9 X( 60) - 10 X( 61)
     - 10 X( 62) - 10 X( 63) - 10 X( 64) - 10 X( 65) - 8 X( 66)
     - 9 X( 67) - 9 X( 68) - 10 X( 69) - 10 X( 70) - 10 X( 71)
     - 9 X( 72) - 8 X( 73) - 8 X( 74) - 7 X( 75) - 7 X( 76) - 7 X( 77)
     - 6 X( 78) - 6 X( 79) - 6 X( 80) - 7 X( 81) - 6 X( 82) - 7 X( 83)
     - 7 X( 84) - 8 X( 85) - 8 X( 86) - 7 X( 87) - 10 X( 88)
     - 7 X( 89) - 8 X( 90) - 7 X( 91) - 7 X( 92) - 6 X( 93) - 7 X( 94)
     - 7 X( 95) - 7 X( 96) - 8 X( 97) - 8 X( 98) - 8 X( 99)
     - 7 X( 100) - 7 X( 101) - 7 X( 102) - 6 X( 103) - 7 X( 104)
     - 7 X( 105) - 9 X( 106) - 6 X( 107) - 8 X( 108) - 9 X( 109)
     - 8 X( 110) - 8 X( 111) - 10 X( 112) - 10 X( 113) - 5 X( 114)
     - 9 X( 115) - 9 X( 116) - 10 X( 117) - 10 X( 118) - 8 X( 119)
     - 9 X( 120) - 8 X( 121) - 7 X( 122) - 9 X( 123) - 9 X( 124)
     - 10 X( 125) - 10 X( 126) - 8 X( 127) - 9 X( 128) - 8 X( 129)
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```
     - 8 X( 130) - 7 X( 131) - 8 X( 132) - 8 X( 133) - 8 X( 134)
     - 9 X( 135) - 7 X( 136) - 7 X( 137) - 9 X( 138) - 8 X( 139)
     - 7 X( 140) - 8 X( 141) - 9 X( 142) - 10 X( 143) - 8 X( 144)
     - 8 X( 145) - 10 X( 146) - 10 X( 147) - 8 X( 148) - 8 X( 149)
     - 8 X( 150) - 10 X( 151) - 10 X( 152) + G =    0
105]  G >=   49
106]- 7 X( 1) - 10 X( 2) - 8 X( 3) - 8 X( 4) - 10 X( 5) - 9 X( 6)
     - 7 X( 7) - 8 X( 8) - 8 X( 9) - 8 X( 10) - 10 X( 11) - 8 X( 12)
     - 8 X( 13) - 8 X( 14) - 7 X( 15) - 8 X( 16) - 8 X( 17) - 8 X( 18)
     - 9 X( 19) - 9 X( 20) - 8 X( 21) - 7 X( 22) - 10 X( 23)
     - 7 X( 24) - 8 X( 25) - 8 X( 26) - 8 X( 27) - 8 X( 28) - 8 X( 29)
     - 8 X( 30) - 7 X( 31) - 8 X( 32) - 7 X( 33) - 8 X( 34) - 8 X( 35)
     - 7 X( 36) - 8 X( 37) - 9 X( 38) - 8 X( 39) - 7 X( 40) - 7 X( 41)
     - 8 X( 42) - 7 X( 43) - 7 X( 44) - 8 X( 45) - 7 X( 46) - 7 X( 47)
     - 7 X( 48) - 9 X( 49) - 8 X( 50) - 8 X( 51) - 8 X( 52) - 9 X( 53)
     - 8 X( 54) - 8 X( 55) - 8 X( 56) - 9 X( 57) - 8 X( 58) - 8 X( 59)
     - 9 X( 60) - 9 X( 61) - 7 X( 62) - 10 X( 63) - 5 X( 64)
     - 6 X( 65) - 9 X( 66) - 10 X( 67) - 6 X( 68) - 9 X( 69)
     - 7 X( 70) - 8 X( 71) - 6 X( 72) - 7 X( 73) - 6 X( 74) - 7 X( 75)
     - 8 X( 76) - 7 X( 77) - 9 X( 78) - 7 X( 79) - 7 X( 80) - 9 X( 81)
     - 9 X( 82) - 7 X( 83) - 9 X( 84) - 9 X( 85) - 9 X( 86) - 9 X( 87)
     - 10 X( 88) - 7 X( 89) - 8 X( 90) - 9 X( 91) - 8 X( 92)
     - 8 X( 93) - 8 X( 94) - 8 X( 95) - 8 X( 96) - 8 X( 97) - 8 X( 98)
     - 8 X( 99) - 8 X( 100) - 8 X( 101) - 7 X( 102) - 7 X( 103)
     - 8 X( 104) - 6 X( 105) - 8 X( 106) - 7 X( 107) - 8 X( 108)
     - 9 X( 109) - 9 X( 110) - 9 X( 111) - 10 X( 112) - 6 X( 113)
     - 7 X( 114) - 8 X( 115) - 6 X( 116) - 6 X( 117) - 8 X( 118)
     - 8 X( 119) - 8 X( 120) - 8 X( 121) - 6 X( 122) - 6 X( 123)
     - 9 X( 124) - 8 X( 125) - 6 X( 126) - 10 X( 127) - 8 X( 128)
     - 8 X( 129) - 8 X( 130) - 7 X( 131) - 7 X( 132) - 6 X( 133)
     - 7 X( 134) - 8 X( 135) - 8 X( 136) - 8 X( 137) - 6 X( 138)
     - 8 X( 139) - 9 X( 140) - 8 X( 141) - 9 X( 142) - 8 X( 143)
     - 8 X( 144) - 8 X( 145) - 10 X( 146) - 10 X( 147) - 8 X( 148)
     - 9 X( 149) - 9 X( 150) - 10 X( 151) - 10 X( 152) + L =    0
107]  L >=   49
108]- 7 X( 1) - 7 X( 2) - 8 X( 3) - 8 X( 4) - 7 X( 5) - 8 X( 6)
     - 7 X( 7) - 8 X( 8) - 8 X( 9) - 8 X( 10) - 9 X( 11) - 8 X( 12)
     - 9 X( 13) - 9 X( 14) - 10 X( 15) - 8 X( 16) - 9 X( 17)
     - 9 X( 18) - 10 X( 19) - 9 X( 20) - 9 X( 21) - 10 X( 22)
     - 10 X( 23) - 7 X( 24) - 9 X( 25) - 9 X( 26) - 8 X( 27)
     - 8 X( 28) - 8 X( 29) - 8 X( 30) - 7 X( 31) - 7 X( 32) - 7 X( 33)
     - 8 X( 34) - 7 X( 35) - 7 X( 36) - 7 X( 37) - 7 X( 38) - 8 X( 39)
     - 7 X( 40) - 7 X( 41) - 7 X( 42) - 7 X( 43) - 7 X( 44) - 8 X( 45)
     - 7 X( 46) - 7 X( 47) - 9 X( 48) - 8 X( 49) - 8 X( 50) - 8 X( 51)
     - 9 X( 52) - 9 X( 53) - 8 X( 54) - 8 X( 55) - 8 X( 56) - 9 X( 57)
     - 8 X( 58) - 10 X( 59) - 10 X( 60) - 10 X( 61) - 10 X( 62)
     - 10 X( 63) - 10 X( 64) - 10 X( 65) - 10 X( 66) - 10 X( 67)
     - 10 X( 68) - 10 X( 69) - 10 X( 70) - 10 X( 71) - 10 X( 72)
     - 10 X( 73) - 10 X( 74) - 8 X( 75) - 7 X( 76) - 8 X( 77)
     - 8 X( 78) - 7 X( 79) - 7 X( 80) - 9 X( 81) - 7 X( 82) - 7 X( 83)
     - 8 X( 84) - 9 X( 85) - 9 X( 86) - 6 X( 87) - 10 X( 88)
     - 7 X( 89) - 7 X( 90) - 9 X( 91) - 8 X( 92) - 7 X( 93) - 8 X( 94)
     - 8 X( 95) - 8 X( 96) - 8 X( 97) - 8 X( 98) - 8 X( 99)
     - 8 X( 100) - 8 X( 101) - 7 X( 102) - 9 X( 103) - 7 X( 104)
     - 8 X( 105) - 8 X( 106) - 8 X( 107) - 7 X( 108) - 7 X( 109)
     - 7 X( 110) - 7 X( 111) - 10 X( 112) - 10 X( 113) - 10 X( 114)
     - 10 X( 115) - 10 X( 116) - 10 X( 117) - 10 X( 118) - 10 X( 119)
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     - 9 X( 120) - 7 X( 121) - 10 X( 122) - 10 X( 123) - 9 X( 124)
     - 9 X( 125) - 10 X( 126) - 10 X( 127) - 8 X( 128) - 8 X( 129)
     - 7 X( 130) - 7 X( 131) - 8 X( 132) - 9 X( 133) - 10 X( 134)
     - 9 X( 135) - 9 X( 136) - 9 X( 137) - 10 X( 138) - 8 X( 139)
     - 8 X( 140) - 10 X( 141) - 10 X( 142) - 9 X( 143) - 8 X( 144)
     - 10 X( 145) - 10 X( 146) - 10 X( 147) - 8 X( 148) - 10 X( 149)
     - 10 X( 150) - 10 X( 151) - 10 X( 152) + W =    0
109]  W >=   49
END

ALL VARIABLES ARE BINARY
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c. 150-Mile Formulation

```
MAX      Y( 1) + Y( 2) + Y( 3) + Y( 4) + Y( 5) + Y( 6) + Y( 7) + Y( 8)
     + Y( 9) + Y( 10) + Y( 11) + Y( 12) + Y( 13) + Y( 14) + Y( 15)
     + Y( 16) + Y( 17) + Y( 18) + Y( 19) + Y( 20) + Y( 21) + Y( 22)
     + Y( 23) + Y( 24) + Y( 25) + Y( 26) + Y( 27) + Y( 28) + Y( 29)
     + Y( 30) + Y( 31) + Y( 32) + Y( 33) + Y( 34) + Y( 35) + Y( 36)
     + Y( 37) + Y( 38) + Y( 39) + Y( 40) + Y( 41) + Y( 42) + Y( 43)
     + Y( 44) + Y( 45) + Y( 46) + Y( 47) + Y( 48) + Y( 49) + Y( 50)
     + Y( 51) + Y( 52) + Y( 53) + Y( 54) + Y( 55) + Y( 56) + Y( 57)
     + Y( 58) + Y( 59) + Y( 60) + Y( 61) + Y( 62) + Y( 63) + Y( 64)
     + Y( 65) + Y( 66) + Y( 67) + Y( 68) + Y( 69) + Y( 70) + Y( 71)
     + Y( 72) + Y( 73) + Y( 74) + Y( 75) + Y( 76) + Y( 77) + Y( 78)
     + Y( 79) + Y( 80) + Y( 81) + Y( 82) + Y( 83) + Y( 84) + Y( 85)
     + Y( 86) + Y( 87) + Y( 88) + Y( 89) + Y( 90) + Y( 91) + Y( 92)
     + Y( 93) + Y( 94) + Y( 95) + Y( 96) + Y( 97) + Y( 98) + Y( 99)
     + Y( 100)
SUBJECT TO
2]- X( 1) - X( 2) - X( 3) - X( 4) - X( 5) - X( 6) - X( 7) - X( 8)
     - X( 9) - X( 10) - X( 11) - X( 12) - X( 13) - X( 14) - X( 15)
     - X( 16) - X( 17) - X( 18) - X( 19) - X( 20) - X( 21) - X( 22)
     - X( 23) - X( 24) - X( 25) - X( 26) - X( 27) - X( 28) - X( 29)
     - X( 30) - X( 31) - X( 32) - X( 33) - X( 34) - X( 35) - X( 36)
     - X( 37) - X( 38) - X( 39) - X( 40) - X( 41) - X( 42) - X( 43)
     - X( 44) - X( 45) - X( 46) - X( 47) - X( 48) - X( 49) - X( 50)
     - X( 51) - X( 52) - X( 53) - X( 54) - X( 55) - X( 56) - X( 57)
     - X( 58) - X( 59) - X( 60) - X( 61) - X( 62) - X( 63) - X( 64)
     - X( 65) - X( 66) - X( 67) - X( 68) - X( 69) - X( 70) - X( 71)
     - X( 72) - X( 73) - X( 74) - X( 75) - X( 76) - X( 77) - X( 78)
     - X( 79) - X( 80) - X( 81) - X( 82) - X( 83) - X( 84) - X( 85)
     - X( 86) - X( 87) - X( 88) - X( 89) - X( 90) - X( 91) - X( 92)
     - X( 93) - X( 94) - X( 95) - X( 96) - X( 97) - X( 98) - X( 99)
     - X( 100) - X( 101) - X( 102) - X( 103) - X( 104) - X( 105)
     - X( 106) - X( 107) - X( 108) - X( 109) - X( 110) - X( 111)
     - X( 112) - X( 113) - X( 114) - X( 115) - X( 116) - X( 117)
     - X( 118) - X( 119) - X( 120) - X( 121) - X( 122) - X( 123)
     - X( 124) - X( 125) - X( 126) - X( 127) - X( 128) - X( 129)
     - X( 130) - X( 131) - X( 132) - X( 133) - X( 134) - X( 135)
     - X( 136) - X( 137) - X( 138) - X( 139) - X( 140) - X( 141)
     - X( 142) - X( 143) - X( 144) - X( 145) - X( 146) - X( 147)
     - X( 148) - X( 149) - X( 150) - X( 151) - X( 152) + A =    0
3]  A <=   10
4]- Y( 1) + X( 1) + X( 2) + X( 3) + X( 4) + X( 5) + X( 6) + X( 7)
```

```
      + X( 8) + X( 9) + X( 10) + X( 11) + X( 12) + X( 13) + X( 14)
      + X( 15) + X( 16) + X( 17) + X( 18) + X( 19) + X( 21) + X( 90)
      + X( 91) + X( 92) + X( 99) + X( 106) + X( 108) + X( 109)
      + X( 110) + X( 111) >=   0
 5]- Y( 2) + X( 1) + X( 2) + X( 3) + X( 4) + X( 5) + X( 6) + X( 7)
      + X( 8) + X( 9) + X( 10) + X( 11) + X( 12) + X( 13) + X( 14)
      + X( 16) + X( 17) + X( 18) + X( 19) + X( 20) + X( 21) + X( 22)
      + X( 23) + X( 24) + X( 25) + X( 31) + X( 33) + X( 34) + X( 38)
      + X( 83) + X( 84) + X( 85) + X( 86) + X( 87) + X( 88) + X( 89)
      + X( 90) + X( 91) + X( 92) + X( 93) + X( 94) + X( 95) + X( 97)
      + X( 100) + X( 101) + X( 104) + X( 105) + X( 106) + X( 107)
      + X( 109) + X( 110) + X( 111) + X( 151) >=   0
 6]- Y( 3) + X( 1) + X( 2) + X( 3) + X( 4) + X( 5) + X( 6) + X( 7)
      + X( 8) + X( 9) + X( 10) + X( 11) + X( 12) + X( 13) + X( 15)
      + X( 16) + X( 21) + X( 38) + X( 86) + X( 90) + X( 92) + X( 97)
      + X( 98) + X( 99) + X( 106) + X( 108) + X( 109) >=   0
 7]- Y( 4) + X( 1) + X( 2) + X( 3) + X( 4) + X( 5) + X( 7) + X( 8)
      + X( 9) + X( 10) + X( 11) + X( 12) + X( 13) + X( 15) + X( 16)
      + X( 17) + X( 18) + X( 19) + X( 21) + X( 24) + X( 31) + X( 32)
      + X( 33) + X( 83) + X( 84) + X( 85) + X( 86) + X( 87) + X( 89)
      + X( 90) + X( 91) + X( 92) + X( 93) + X( 94) + X( 95) + X( 96)
      + X( 97) + X( 98) + X( 99) + X( 104) + X( 105) + X( 106)
      + X( 108) + X( 109) + X( 110) + X( 111) >=   0
 8]- Y( 5) + X( 1) + X( 4) + X( 6) + X( 7) + X( 8) + X( 9) + X( 10)
      + X( 11) + X( 12) + X( 13) + X( 14) + X( 15) + X( 16) + X( 20)
      + X( 21) + X( 23) + X( 25) + X( 31) + X( 33) + X( 34) + X( 38)
      + X( 86) + X( 90) + X( 92) + X( 98) + X( 106) + X( 108) >=   0
 9]- Y( 6) + X( 5) + X( 6) + X( 7) + X( 8) + X( 9) + X( 10) + X( 12)
      + X( 13) + X( 14) + X( 15) + X( 20) + X( 22) + X( 23) + X( 24)
      + X( 25) + X( 30) + X( 31) + X( 32) + X( 33) + X( 34) + X( 35)
      + X( 37) + X( 38) + X( 86) + X( 90) + X( 91) + X( 92) + X( 106)
      + X( 152) >=   0
10]- Y( 7) + X( 13) + X( 33) + X( 34) + X( 38) >=   0
11]- Y( 8) + X( 31) + X( 32) + X( 33) + X( 34) + X( 35) + X( 37)
      + X( 38) >=   0
12]- Y( 9) + X( 31) + X( 32) + X( 33) + X( 34) + X( 35) + X( 37)
      + X( 38) + X( 52) + X( 53) + X( 56) + X( 62) >=   0
13]- Y( 10) + X( 31) + X( 33) + X( 34) + X( 35) + X( 37) + X( 38)
      + X( 52) + X( 53) + X( 56) + X( 62) + X( 63) >=   0
14]- Y( 11) + X( 33) + X( 34) >=   0
15]- Y( 12) + X( 31) + X( 32) + X( 33) + X( 34) + X( 35) + X( 37)
      + X( 38) >=   0
16]- Y( 13) + X( 31) + X( 32) + X( 33) + X( 34) + X( 35) + X( 36)
      + X( 37) + X( 38) + X( 47) + X( 52) + X( 53) + X( 56) + X( 61)
      + X( 62) + X( 72) >=   0
17]- Y( 14) + X( 33) + X( 34) + X( 37) + X( 52) + X( 53) + X( 56)
      + X( 62) + X( 63) + X( 72) >=   0
18]- Y( 15) + X( 33) + X( 34) + X( 35) + X( 37) + X( 47) + X( 52)
      + X( 53) + X( 56) + X( 61) + X( 62) + X( 71) + X( 72) >=   0
19]- Y( 16) + X( 33) + X( 62) + X( 63) + X( 72) >=   0
20]- Y( 17) + X( 33) + X( 34) >=   0
21]- Y( 18) + X( 33) + X( 34) + X( 35) + X( 37) + X( 47) + X( 52)
      + X( 53) + X( 55) + X( 56) + X( 59) + X( 60) + X( 61) + X( 62)
      + X( 63) + X( 71) + X( 72) >=   0
22]- Y( 19) + X( 33) + X( 34) + X( 35) + X( 37) + X( 46) + X( 47)
      + X( 48) + X( 53) + X( 55) + X( 56) + X( 59) + X( 60) + X( 62)
      + X( 64) + X( 71) + X( 72) >=   0
```

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23]- Y( 20) + X( 33) + X( 35) + X( 37) + X( 47) + X( 48) + X( 53)
     + X( 55) + X( 56) + X( 59) + X( 60) + X( 61) + X( 62) + X( 63)
     + X( 64) + X( 69) + X( 70) + X( 71) + X( 72) >=   0
24]- Y( 21) + X( 33) + X( 52) + X( 53) + X( 55) + X( 56) + X( 60)
     + X( 61) + X( 62) + X( 70) + X( 71) + X( 72) + X( 73) >=   0
25]- Y( 22) + X( 63) + X( 72) >=   0
26]- Y( 23) + X( 61) + X( 62) + X( 63) + X( 69) + X( 70) + X( 71)
     + X( 72) >=   0
27]- Y( 24) + X( 62) + X( 63) + X( 70) + X( 71) + X( 72) >=   0
28]- Y( 25) + X( 72) >=   0
29]- Y( 26) + X( 1) + X( 2) + X( 4) + X( 5) + X( 6) + X( 7) + X( 8)
     + X( 9) + X( 12) + X( 13) + X( 15) + X( 16) + X( 38) + X( 90)
     + X( 91) + X( 99) + X( 106) + X( 108) + X( 109) >=   0
30]- Y( 27) + X( 1) + X( 5) + X( 6) + X( 7) + X( 8) + X( 9) + X( 13)
     + X( 106) >=   0
31]- Y( 28) + X( 6) + X( 7) + X( 8) + X( 9) + X( 12) + X( 13) + X( 33)
     + X( 34) + X( 38) + X( 90) + X( 106) >=   0
32]- Y( 29) + X( 5) + X( 6) + X( 7) + X( 8) + X( 9) + X( 10) + X( 12)
     + X( 13) + X( 15) + X( 31) + X( 33) + X( 34) + X( 38) + X( 90)
     >=   0
33]- Y( 30) + X( 6) + X( 7) + X( 8) + X( 9) + X( 12) + X( 13) + X( 15)
     + X( 25) + X( 31) + X( 32) + X( 33) + X( 34) + X( 35) + X( 37)
     + X( 38) + X( 90) + X( 106) >=   0
34]- Y( 31) + X( 53) + X( 54) + X( 55) + X( 56) + X( 57) + X( 59)
     + X( 60) + X( 61) + X( 62) + X( 63) + X( 68) + X( 69) + X( 70)
     + X( 71) + X( 72) + X( 73) + X( 74) + X( 112) + X( 114) + X( 116)
     + X( 117) + X( 118) >=   0
35]- Y( 32) + X( 49) + X( 52) + X( 53) + X( 54) + X( 55) + X( 56)
     + X( 57) + X( 58) + X( 59) + X( 60) + X( 61) + X( 62) + X( 63)
     + X( 64) + X( 65) + X( 66) + X( 67) + X( 68) + X( 69) + X( 70)
     + X( 71) + X( 72) + X( 73) + X( 74) + X( 112) + X( 114) + X( 115)
     + X( 116) + X( 117) + X( 118) >=   0
36]- Y( 33) + X( 39) + X( 40) + X( 41) + X( 45) + X( 47) + X( 49)
     + X( 50) + X( 51) + X( 52) + X( 53) + X( 54) + X( 55) + X( 57)
     + X( 58) + X( 59) + X( 60) + X( 61) + X( 62) + X( 63) + X( 64)
     + X( 65) + X( 66) + X( 67) + X( 68) + X( 69) + X( 70) + X( 71)
     + X( 72) + X( 73) + X( 74) + X( 75) + X( 76) + X( 112) + X( 114)
     + X( 115) + X( 116) + X( 117) + X( 118) + X( 119) + X( 131)
     >=   0
37]- Y( 34) + X( 37) + X( 41) + X( 45) + X( 47) + X( 48) + X( 49)
     + X( 51) + X( 52) + X( 53) + X( 54) + X( 55) + X( 56) + X( 57)
     + X( 58) + X( 59) + X( 60) + X( 61) + X( 62) + X( 63) + X( 64)
     + X( 65) + X( 66) + X( 67) + X( 68) + X( 69) + X( 70) + X( 71)
     + X( 72) + X( 73) + X( 74) + X( 112) + X( 114) + X( 115)
     + X( 116) + X( 117) + X( 118) >=   0
38]- Y( 35) + X( 29) + X( 32) + X( 33) + X( 34) + X( 35) + X( 36)
     + X( 37) + X( 39) + X( 41) + X( 42) + X( 45) + X( 46) + X( 47)
     + X( 48) + X( 49) + X( 50) + X( 51) + X( 52) + X( 53) + X( 54)
     + X( 55) + X( 56) + X( 57) + X( 58) + X( 59) + X( 60) + X( 64)
     + X( 65) + X( 66) + X( 67) + X( 68) + X( 74) + X( 75) + X( 76)
     + X( 152) >=   0
39]- Y( 36) + X( 27) + X( 28) + X( 29) + X( 31) + X( 32) + X( 33)
     + X( 34) + X( 35) + X( 36) + X( 40) + X( 41) + X( 42) + X( 45)
     + X( 46) + X( 49) + X( 50) + X( 51) + X( 52) + X( 53) + X( 54)
     + X( 55) + X( 56) + X( 57) + X( 58) + X( 59) + X( 60) + X( 61)
     + X( 62) + X( 64) + X( 65) + X( 66) + X( 67) + X( 68) + X( 69)
     + X( 70) + X( 71) + X( 72) + X( 73) + X( 74) + X( 75) + X( 76)
```

```
     + X( 77) + X( 112) + X( 114) + X( 115) + X( 116) + X( 117)
     + X( 118) + X( 152) >=   0
40]- Y( 37) + X( 27) + X( 28) + X( 29) + X( 30) + X( 31) + X( 32)
     + X( 33) + X( 35) + X( 36) + X( 37) + X( 38) + X( 41) + X( 42)
     + X( 43) + X( 44) + X( 46) + X( 49) + X( 51) + X( 54) + X( 57)
     + X( 58) + X( 59) + X( 64) + X( 65) + X( 66) + X( 67) + X( 68)
     + X( 69) + X( 70) + X( 75) + X( 76) + X( 77) + X( 81) + X( 112)
     + X( 114) + X( 115) + X( 152) >=   0
41]- Y( 38) + X( 29) + X( 31) + X( 32) + X( 33) + X( 35) + X( 36)
     + X( 37) + X( 39) + X( 40) + X( 45) + X( 46) + X( 47) + X( 49)
     + X( 50) + X( 51) + X( 52) + X( 53) + X( 54) + X( 55) + X( 56)
     + X( 57) + X( 58) + X( 59) + X( 60) + X( 61) + X( 62) + X( 63)
     + X( 64) + X( 65) + X( 68) + X( 69) + X( 70) + X( 71) + X( 72)
     + X( 74) + X( 75) + X( 152) >=   0
42]- Y( 39) + X( 40) + X( 41) + X( 42) + X( 45) + X( 47) + X( 50)
     + X( 51) + X( 52) + X( 53) + X( 54) + X( 55) + X( 56) + X( 57)
     + X( 58) + X( 59) + X( 60) + X( 61) + X( 62) + X( 63) + X( 64)
     + X( 65) + X( 66) + X( 67) + X( 68) + X( 69) + X( 70) + X( 71)
     + X( 72) + X( 73) + X( 74) + X( 75) + X( 76) + X( 77) + X( 112)
     + X( 114) + X( 115) + X( 116) + X( 117) + X( 118) + X( 119)
     + X( 120) + X( 121) + X( 122) + X( 123) + X( 124) + X( 125)
     + X( 131) >=   0
43]- Y( 40) + X( 28) + X( 29) + X( 32) + X( 35) + X( 36) + X( 37)
     + X( 39) + X( 40) + X( 41) + X( 42) + X( 43) + X( 45) + X( 46)
     + X( 47) + X( 49) + X( 50) + X( 51) + X( 52) + X( 53) + X( 54)
     + X( 55) + X( 56) + X( 57) + X( 58) + X( 59) + X( 60) + X( 61)
     + X( 62) + X( 63) + X( 64) + X( 65) + X( 66) + X( 68) + X( 69)
     + X( 70) + X( 71) + X( 72) + X( 73) + X( 74) + X( 75) + X( 76)
     + X( 77) + X( 78) + X( 79) + X( 112) + X( 114) + X( 115)
     + X( 116) + X( 117) + X( 118) + X( 119) + X( 120) + X( 121)
     + X( 122) + X( 123) + X( 124) + X( 125) + X( 131) + X( 152)
     >=   0
44]- Y( 41) + X( 26) + X( 27) + X( 28) + X( 29) + X( 30) + X( 31)
     + X( 32) + X( 33) + X( 35) + X( 36) + X( 37) + X( 38) + X( 40)
     + X( 41) + X( 42) + X( 43) + X( 44) + X( 45) + X( 46) + X( 47)
     + X( 49) + X( 50) + X( 51) + X( 53) + X( 54) + X( 55) + X( 57)
     + X( 58) + X( 59) + X( 60) + X( 61) + X( 62) + X( 63) + X( 64)
     + X( 65) + X( 66) + X( 67) + X( 68) + X( 69) + X( 70) + X( 71)
     + X( 72) + X( 73) + X( 74) + X( 76) + X( 77) + X( 78) + X( 79)
     + X( 80) + X( 81) + X( 112) + X( 114) + X( 115) + X( 116)
     + X( 117) + X( 118) + X( 119) + X( 120) + X( 121) + X( 152)
     >=   0
45]- Y( 42) + X( 25) + X( 26) + X( 27) + X( 28) + X( 29) + X( 30)
     + X( 31) + X( 32) + X( 34) + X( 35) + X( 36) + X( 37) + X( 38)
     + X( 39) + X( 40) + X( 41) + X( 42) + X( 43) + X( 44) + X( 46)
     + X( 47) + X( 49) + X( 51) + X( 52) + X( 53) + X( 54) + X( 57)
     + X( 58) + X( 60) + X( 61) + X( 62) + X( 64) + X( 65) + X( 66)
     + X( 67) + X( 68) + X( 69) + X( 70) + X( 71) + X( 72) + X( 73)
     + X( 74) + X( 75) + X( 76) + X( 77) + X( 78) + X( 79) + X( 80)
     + X( 81) + X( 112) + X( 114) + X( 115) + X( 116) + X( 119)
     + X( 120) + X( 121) + X( 131) + X( 152) >=   0
46]- Y( 43) + X( 25) + X( 27) + X( 28) + X( 29) + X( 30) + X( 31)
     + X( 32) + X( 33) + X( 34) + X( 35) + X( 36) + X( 37) + X( 38)
     + X( 39) + X( 40) + X( 41) + X( 42) + X( 45) + X( 46) + X( 49)
     + X( 50) + X( 51) + X( 52) + X( 53) + X( 54) + X( 55) + X( 56)
     + X( 57) + X( 58) + X( 59) + X( 60) + X( 61) + X( 62) + X( 63)
     + X( 64) + X( 65) + X( 66) + X( 67) + X( 68) + X( 69) + X( 70)
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     + X( 71) + X( 72) + X( 74) + X( 75) + X( 76) + X( 152) >=   0
47]- Y( 44) + X( 27) + X( 28) + X( 29) + X( 30) + X( 31) + X( 32)
     + X( 33) + X( 34) + X( 35) + X( 36) + X( 38) + X( 39) + X( 40)
     + X( 41) + X( 42) + X( 44) + X( 45) + X( 46) + X( 49) + X( 50)
     + X( 51) + X( 52) + X( 53) + X( 54) + X( 55) + X( 56) + X( 57)
     + X( 58) + X( 59) + X( 60) + X( 61) + X( 62) + X( 63) + X( 68)
     + X( 69) + X( 70) + X( 71) + X( 75) + X( 81) + X( 152) >=   0
48]- Y( 45) + X( 29) + X( 30) + X( 31) + X( 33) + X( 34) + X( 36)
     + X( 38) + X( 39) + X( 40) + X( 41) + X( 45) + X( 47) + X( 52)
     + X( 53) + X( 54) + X( 55) + X( 56) + X( 59) + X( 60) + X( 61)
     + X( 63) + X( 64) + X( 71) + X( 72) + X( 152) >=   0
49]- Y( 46) + X( 15) + X( 23) + X( 24) + X( 25) + X( 26) + X( 27)
     + X( 28) + X( 29) + X( 30) + X( 31) + X( 32) + X( 33) + X( 34)
     + X( 35) + X( 36) + X( 37) + X( 39) + X( 40) + X( 41) + X( 44)
     + X( 45) + X( 46) + X( 47) + X( 49) + X( 50) + X( 51) + X( 52)
     + X( 53) + X( 54) + X( 55) + X( 56) + X( 57) + X( 59) + X( 60)
     + X( 61) + X( 62) + X( 63) + X( 64) + X( 69) + X( 70) + X( 71)
     + X( 72) + X( 83) + X( 152) >=   0
50]- Y( 47) + X( 15) + X( 23) + X( 24) + X( 25) + X( 27) + X( 29)
     + X( 30) + X( 31) + X( 32) + X( 33) + X( 34) + X( 35) + X( 37)
     + X( 38) + X( 39) + X( 40) + X( 41) + X( 44) + X( 45) + X( 46)
     + X( 47) + X( 49) + X( 50) + X( 52) + X( 53) + X( 54) + X( 55)
     + X( 56) + X( 59) + X( 61) + X( 62) + X( 63) + X( 64) + X( 71)
     + X( 81) + X( 83) + X( 152) >=   0
51]- Y( 48) + X( 8) + X( 9) + X( 12) + X( 13) + X( 15) + X( 23)
     + X( 24) + X( 25) + X( 29) + X( 30) + X( 31) + X( 32) + X( 34)
     + X( 35) + X( 36) + X( 37) + X( 38) + X( 39) + X( 45) + X( 46)
     + X( 47) + X( 52) + X( 53) + X( 56) + X( 62) + X( 63) + X( 81)
     + X( 90) + X( 106) + X( 152) >=   0
52]- Y( 49) + X( 8) + X( 9) + X( 12) + X( 13) + X( 14) + X( 15)
     + X( 20) + X( 22) + X( 23) + X( 24) + X( 25) + X( 26) + X( 27)
     + X( 28) + X( 29) + X( 31) + X( 32) + X( 33) + X( 34) + X( 35)
     + X( 36) + X( 37) + X( 38) + X( 39) + X( 40) + X( 41) + X( 42)
     + X( 43) + X( 44) + X( 45) + X( 46) + X( 47) + X( 49) + X( 51)
     + X( 52) + X( 53) + X( 54) + X( 55) + X( 56) + X( 57) + X( 58)
     + X( 59) + X( 60) + X( 61) + X( 62) + X( 63) + X( 64) + X( 65)
     + X( 66) + X( 67) + X( 68) + X( 69) + X( 70) + X( 72) + X( 75)
     + X( 76) + X( 77) + X( 78) + X( 79) + X( 80) + X( 81) + X( 82)
     + X( 83) + X( 86) + X( 90) + X( 152) >=   0
53]- Y( 50) + X( 7) + X( 8) + X( 9) + X( 10) + X( 11) + X( 12)
     + X( 13) + X( 14) + X( 15) + X( 20) + X( 21) + X( 22) + X( 25)
     + X( 26) + X( 27) + X( 29) + X( 30) + X( 31) + X( 32) + X( 33)
     + X( 34) + X( 35) + X( 36) + X( 37) + X( 38) + X( 39) + X( 40)
     + X( 41) + X( 42) + X( 43) + X( 45) + X( 46) + X( 47) + X( 49)
     + X( 50) + X( 51) + X( 52) + X( 53) + X( 54) + X( 55) + X( 56)
     + X( 57) + X( 58) + X( 59) + X( 60) + X( 61) + X( 62) + X( 63)
     + X( 64) + X( 65) + X( 66) + X( 67) + X( 68) + X( 69) + X( 70)
     + X( 71) + X( 72) + X( 73) + X( 74) + X( 75) + X( 76) + X( 77)
     + X( 78) + X( 79) + X( 80) + X( 81) + X( 82) + X( 83) + X( 84)
     + X( 85) + X( 86) + X( 87) + X( 88) + X( 89) + X( 90) + X( 91)
     + X( 92) + X( 93) + X( 94) + X( 101) + X( 102) + X( 103)
     + X( 106) + X( 112) + X( 114) + X( 115) + X( 152) >=   0
54]- Y( 51) + X( 1) + X( 4) + X( 5) + X( 6) + X( 7) + X( 9) + X( 10)
     + X( 11) + X( 12) + X( 13) + X( 14) + X( 15) + X( 17) + X( 21)
     + X( 22) + X( 23) + X( 24) + X( 25) + X( 26) + X( 27) + X( 28)
     + X( 29) + X( 30) + X( 31) + X( 32) + X( 33) + X( 34) + X( 35)
     + X( 36) + X( 37) + X( 38) + X( 40) + X( 41) + X( 42) + X( 43)
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     + X( 44) + X( 45) + X( 46) + X( 49) + X( 50) + X( 51) + X( 52)
     + X( 53) + X( 56) + X( 59) + X( 60) + X( 61) + X( 62) + X( 63)
     + X( 72) + X( 79) + X( 80) + X( 81) + X( 82) + X( 83) + X( 84)
     + X( 85) + X( 86) + X( 87) + X( 88) + X( 89) + X( 90) + X( 91)
     + X( 92) + X( 93) + X( 94) + X( 97) + X( 98) + X( 99) + X( 101)
     + X( 102) + X( 103) + X( 152) >=   0
55]- Y( 52) + X( 1) + X( 4) + X( 5) + X( 6) + X( 7) + X( 8) + X( 9)
     + X( 10) + X( 11) + X( 12) + X( 13) + X( 14) + X( 15) + X( 16)
     + X( 17) + X( 20) + X( 21) + X( 22) + X( 23) + X( 24) + X( 25)
     + X( 27) + X( 28) + X( 29) + X( 30) + X( 31) + X( 32) + X( 33)
     + X( 34) + X( 38) + X( 39) + X( 40) + X( 41) + X( 42) + X( 43)
     + X( 44) + X( 45) + X( 46) + X( 49) + X( 50) + X( 51) + X( 52)
     + X( 53) + X( 54) + X( 55) + X( 56) + X( 59) + X( 60) + X( 61)
     + X( 62) + X( 63) + X( 80) + X( 82) + X( 84) + X( 85) + X( 86)
     + X( 87) + X( 89) + X( 90) + X( 91) + X( 92) + X( 93) + X( 94)
     + X( 97) + X( 98) + X( 99) + X( 102) + X( 103) + X( 106)
     + X( 108) >=   0
56]- Y( 53) + X( 1) + X( 2) + X( 3) + X( 4) + X( 5) + X( 6) + X( 7)
     + X( 8) + X( 9) + X( 10) + X( 12) + X( 13) + X( 16) + X( 90)
     + X( 106) + X( 108) + X( 109) >=   0
57]- Y( 54) + X( 1) + X( 2) + X( 3) + X( 4) + X( 5) + X( 6) + X( 7)
     + X( 8) + X( 9) + X( 10) + X( 12) + X( 13) + X( 16) + X( 18)
     + X( 90) + X( 91) + X( 97) + X( 98) + X( 99) + X( 106) + X( 108)
     + X( 109) + X( 110) + X( 111) >=   0
58]- Y( 55) + X( 6) >=   0
59]- Y( 56) + X( 6) >=   0
60]- Y( 57) + X( 6) >=   0
61]- Y( 58) + X( 72) >=   0
62]- Y( 59) + X( 72) >=   0
63]- Y( 60) + X( 1) + X( 2) + X( 3) + X( 4) + X( 5) + X( 6) + X( 7)
     + X( 8) + X( 9) + X( 10) + X( 11) + X( 12) + X( 13) + X( 14)
     + X( 15) + X( 16) + X( 17) + X( 18) + X( 19) + X( 20) + X( 21)
     + X( 22) + X( 23) + X( 24) + X( 25) + X( 28) + X( 29) + X( 30)
     + X( 31) + X( 32) + X( 33) + X( 34) + X( 35) + X( 36) + X( 38)
     + X( 39) + X( 40) + X( 42) + X( 43) + X( 44) + X( 45) + X( 47)
     + X( 49) + X( 50) + X( 51) + X( 52) + X( 53) + X( 55) + X( 56)
     + X( 79) + X( 80) + X( 81) + X( 82) + X( 83) + X( 84) + X( 85)
     + X( 86) + X( 87) + X( 88) + X( 89) + X( 90) + X( 92) + X( 93)
     + X( 94) + X( 95) + X( 96) + X( 97) + X( 98) + X( 100) + X( 101)
     + X( 102) + X( 103) + X( 104) + X( 105) + X( 107) + X( 108)
     + X( 109) + X( 110) + X( 111) + X( 151) + X( 152) >=   0
64]- Y( 61) + X( 136) + X( 137) + X( 138) + X( 139) + X( 140)
     + X( 141) + X( 142) + X( 143) + X( 144) + X( 145) + X( 146)
     + X( 147) + X( 148) + X( 149) + X( 150) >=   0
65]- Y( 62) + X( 141) + X( 142) + X( 143) + X( 144) + X( 146)
     + X( 147) + X( 148) + X( 149) >=   0
66]- Y( 63) + X( 5) + X( 6) + X( 8) + X( 9) + X( 10) + X( 11) + X( 12)
     + X( 13) + X( 15) + X( 17) + X( 21) + X( 22) + X( 23) + X( 24)
     + X( 25) + X( 26) + X( 27) + X( 28) + X( 29) + X( 30) + X( 31)
     + X( 32) + X( 35) + X( 36) + X( 37) + X( 38) + X( 39) + X( 40)
     + X( 42) + X( 43) + X( 44) + X( 45) + X( 46) + X( 47) + X( 49)
     + X( 50) + X( 51) + X( 52) + X( 53) + X( 54) + X( 55) + X( 56)
     + X( 57) + X( 58) + X( 59) + X( 60) + X( 61) + X( 62) + X( 63)
     + X( 64) + X( 65) + X( 66) + X( 68) + X( 69) + X( 70) + X( 71)
     + X( 72) + X( 75) + X( 76) + X( 77) + X( 78) + X( 79) + X( 80)
     + X( 81) + X( 82) + X( 83) + X( 84) + X( 85) + X( 87) + X( 88)
     + X( 89) + X( 90) + X( 91) + X( 92) + X( 93) + X( 94) + X( 97)
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    + X( 98) + X( 99) + X( 102) + X( 103) + X( 152) >=   0
67]- Y( 64) + X( 72) >=   0
68]- Y( 65) + X( 72) >=   0
69]- Y( 66) + X( 1) + X( 2) + X( 3) + X( 4) + X( 5) + X( 6) + X( 7)
    + X( 8) + X( 9) + X( 10) + X( 11) + X( 12) + X( 13) + X( 14)
    + X( 15) + X( 16) + X( 17) + X( 20) + X( 21) + X( 22) + X( 24)
    + X( 25) + X( 26) + X( 27) + X( 28) + X( 29) + X( 30) + X( 31)
    + X( 32) + X( 33) + X( 34) + X( 35) + X( 36) + X( 37) + X( 38)
    + X( 39) + X( 40) + X( 44) + X( 45) + X( 46) + X( 53) + X( 80)
    + X( 81) + X( 82) + X( 83) + X( 85) + X( 86) + X( 87) + X( 88)
    + X( 89) + X( 90) + X( 91) + X( 92) + X( 93) + X( 94) + X( 95)
    + X( 97) + X( 99) + X( 100) + X( 101) + X( 102) + X( 103)
    + X( 106) + X( 108) + X( 109) + X( 111) + X( 119) + X( 121)
    + X( 152) >=   0
70]- Y( 67) + X( 5) + X( 6) + X( 7) + X( 8) + X( 9) + X( 10) + X( 11)
    + X( 12) + X( 13) + X( 15) + X( 20) + X( 22) + X( 23) + X( 24)
    + X( 25) + X( 26) + X( 29) + X( 30) + X( 31) + X( 32) + X( 33)
    + X( 34) + X( 35) + X( 37) + X( 38) + X( 39) + X( 45) + X( 47)
    + X( 52) + X( 53) + X( 56) + X( 81) + X( 84) + X( 87) + X( 90)
    + X( 91) + X( 106) + X( 152) >=   0
71]- Y( 68) + X( 52) + X( 53) + X( 56) + X( 60) + X( 61) + X( 62)
    + X( 63) + X( 64) + X( 69) + X( 70) + X( 71) + X( 72) >=   0
72]- Y( 69) + X( 6) + X( 7) + X( 8) + X( 10) + X( 11) + X( 13)
    + X( 14) + X( 15) + X( 20) + X( 22) + X( 23) + X( 24) + X( 25)
    + X( 26) + X( 27) + X( 28) + X( 29) + X( 30) + X( 31) + X( 32)
    + X( 33) + X( 34) + X( 35) + X( 36) + X( 37) + X( 38) + X( 39)
    + X( 40) + X( 41) + X( 42) + X( 43) + X( 45) + X( 46) + X( 49)
    + X( 50) + X( 51) + X( 52) + X( 53) + X( 54) + X( 55) + X( 56)
    + X( 57) + X( 59) + X( 60) + X( 61) + X( 62) + X( 63) + X( 64)
    + X( 71) + X( 72) + X( 75) + X( 76) + X( 77) + X( 80) + X( 82)
    + X( 83) + X( 84) + X( 85) + X( 86) + X( 90) + X( 91) + X( 92)
    + X( 103) + X( 106) + X( 152) >=   0
73]- Y( 70) + X( 1) + X( 4) + X( 5) + X( 6) + X( 7) + X( 8) + X( 9)
    + X( 10) + X( 12) + X( 13) + X( 16) + X( 33) + X( 34) + X( 38)
    + X( 90) + X( 106) >=   0
74]- Y( 71) + X( 33) + X( 34) >=   0
75]- Y( 72) + X( 1) + X( 2) + X( 3) + X( 4) + X( 5) + X( 6) + X( 7)
    + X( 8) + X( 9) + X( 10) + X( 11) + X( 12) + X( 13) + X( 14)
    + X( 15) + X( 16) + X( 17) + X( 18) + X( 19) + X( 20) + X( 21)
    + X( 22) + X( 23) + X( 24) + X( 25) + X( 31) + X( 33) + X( 34)
    + X( 38) + X( 86) + X( 87) + X( 89) + X( 91) + X( 92) + X( 94)
    + X( 97) + X( 98) + X( 99) + X( 105) + X( 108) + X( 109)
    + X( 110) + X( 111) >=   0
76]- Y( 73) + X( 6) >=   0
77]- Y( 74) + X( 36) + X( 39) + X( 41) + X( 43) + X( 47) + X( 49)
    + X( 50) + X( 51) + X( 52) + X( 53) + X( 54) + X( 55) + X( 57)
    + X( 58) + X( 59) + X( 60) + X( 61) + X( 62) + X( 63) + X( 64)
    + X( 65) + X( 66) + X( 67) + X( 68) + X( 69) + X( 70) + X( 71)
    + X( 72) + X( 73) + X( 74) + X( 75) + X( 76) + X( 77) + X( 78)
    + X( 79) + X( 112) + X( 114) + X( 115) + X( 116) + X( 117)
    + X( 118) + X( 119) + X( 120) + X( 121) + X( 122) + X( 123)
    + X( 124) + X( 125) + X( 126) + X( 127) + X( 128) + X( 130)
    + X( 131) + X( 132) + X( 133) >=   0
78]- Y( 75) + X( 63) + X( 68) + X( 69) + X( 70) + X( 71) + X( 113)
    + X( 117) >=   0
79]- Y( 76) + X( 60) + X( 61) + X( 62) + X( 63) + X( 64) + X( 68)
    + X( 69) + X( 70) + X( 73) + X( 74) + X( 112) + X( 116) + X( 117)
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+ X(118) + X(119) + X(120) + X(121) + X(122) + X(123)
+ X(124) + X(125) + X(126) + X(127) + X(128) + X(130)
+ X(131) + X(132) + X(133) + X(134) + X(135) + X(137)
+ X(140) + X(141) >= 0

80]- Y(77) + X(65) + X(66) + X(67) + X(68) + X(69) + X(70)
+ X(71) + X(73) + X(74) + X(112) + X(113) + X(114)
+ X(115) + X(116) + X(117) + X(118) + X(119) + X(120)
+ X(122) + X(123) + X(124) + X(125) + X(126) + X(127)
+ X(128) + X(130) + X(131) + X(132) + X(133) + X(134)
+ X(135) + X(136) + X(137) + X(138) + X(140) + X(141)
+ X(142) >= 0

81]- Y(78) + X(73) + X(74) + X(111) + X(114) + X(115) + X(116)
+ X(117) + X(118) + X(119) + X(120) + X(121) + X(122)
+ X(123) + X(124) + X(125) + X(126) + X(127) + X(130)
+ X(132) + X(133) + X(134) + X(135) + X(136) + X(137)
+ X(140) + X(141) + X(142) >= 0

82]- Y(79) + X(112) + X(114) + X(115) + X(116) + X(117)
+ X(118) + X(119) + X(120) + X(121) + X(122) + X(123)
+ X(124) + X(125) + X(126) + X(127) + X(128) + X(130)
+ X(132) + X(133) + X(134) + X(135) + X(136) + X(137)
+ X(140) + X(141) + X(142) >= 0

83]- Y(80) + X(113) + X(114) + X(115) + X(116) + X(117)
+ X(118) + X(119) + X(120) + X(121) + X(122) + X(123)
+ X(124) + X(125) + X(126) + X(127) + X(128) + X(130)
+ X(131) + X(132) + X(133) + X(134) + X(135) + X(136)
+ X(137) + X(138) + X(139) + X(140) + X(141) + X(142)
+ X(143) + X(144) + X(145) + X(146) + X(147) + X(148)
+ X(149) + X(150) >= 0

84]- Y(81) + X(124) + X(126) + X(128) + X(130) + X(132)
+ X(133) + X(134) + X(135) + X(136) + X(137) + X(138)
+ X(139) + X(140) + X(141) + X(142) + X(143) + X(144)
+ X(145) + X(146) + X(147) + X(148) + X(149) + X(150)
>= 0

85]- Y(82) + X(134) + X(135) + X(136) + X(137) + X(138)
+ X(139) + X(140) + X(141) + X(142) + X(143) + X(144)
+ X(145) + X(146) + X(147) + X(148) + X(149) + X(150)
>= 0

86]- Y(83) + X(112) + X(113) + X(114) + X(115) + X(116)
+ X(117) + X(118) + X(119) + X(120) + X(121) + X(122)
+ X(123) + X(124) + X(125) + X(126) + X(127) + X(130)
+ X(131) + X(132) + X(133) + X(134) + X(135) + X(136)
+ X(137) + X(138) + X(139) + X(140) + X(141) + X(142)
+ X(143) + X(144) + X(145) + X(146) + X(147) + X(148)
+ X(149) >= 0

87]- Y(84) + X(63) + X(68) + X(69) + X(70) + X(71) + X(72)
+ X(73) + X(74) + X(112) + X(114) + X(115) + X(116)
+ X(117) + X(118) + X(119) + X(121) + X(123) + X(124)
+ X(125) + X(131) >= 0

88]- Y(85) + X(70) + X(73) + X(74) + X(112) + X(114) + X(115)
+ X(116) + X(117) + X(118) + X(119) + X(120) + X(121)
+ X(122) + X(123) + X(124) + X(125) + X(126) + X(127)
>= 0

89]- Y(86) + X(49) + X(53) + X(54) + X(55) + X(56) + X(57)
+ X(58) + X(59) + X(60) + X(61) + X(63) + X(68) + X(69)
+ X(70) + X(71) + X(72) + X(73) + X(74) + X(75) + X(112)
+ X(114) + X(115) + X(116) + X(117) + X(118) + X(119)
+ X(120) + X(123) + X(131) >= 0

```
90]- Y( 87) + X( 46) + X( 49) + X( 51) + X( 52) + X( 53) + X( 54)
     + X( 55) + X( 56) + X( 58) + X( 59) + X( 60) + X( 61) + X( 62)
     + X( 63) + X( 64) + X( 65) + X( 66) + X( 67) + X( 68) + X( 69)
     + X( 70) + X( 71) + X( 72) + X( 73) + X( 74) + X( 75) + X( 76)
     + X( 112) + X( 113) + X( 115) + X( 116) + X( 117) + X( 118)
     + X( 119) + X( 120) + X( 121) + X( 122) + X( 123) + X( 124)
     + X( 125) + X( 126) + X( 127) + X( 128) + X( 131) >=   0
91]- Y( 88) + X( 139) + X( 140) + X( 141) + X( 142) + X( 143)
     + X( 144) + X( 145) + X( 146) + X( 147) + X( 148) + X( 149)
     + X( 150) >=   0
92]- Y( 89) + X( 57) + X( 58) + X( 59) + X( 60) + X( 61) + X( 62)
     + X( 63) + X( 64) + X( 66) + X( 67) + X( 68) + X( 73) + X( 74)
     + X( 112) + X( 113) + X( 114) + X( 115) + X( 116) + X( 117)
     + X( 118) + X( 119) + X( 120) + X( 121) + X( 122) + X( 123)
     + X( 124) + X( 125) + X( 126) + X( 127) + X( 128) + X( 130)
     + X( 131) + X( 132) + X( 133) + X( 134) + X( 135) + X( 136)
     + X( 137) + X( 138) + X( 139) + X( 140) + X( 141) + X( 142)
     + X( 143) + X( 144) >=   0
93]- Y( 90) + X( 61) + X( 62) + X( 64) + X( 68) + X( 69) + X( 70)
     + X( 71) + X( 72) + X( 112) >=   0
94]- Y( 91) + X( 113) + X( 116) + X( 117) + X( 118) + X( 119)
     + X( 120) + X( 121) + X( 122) + X( 123) + X( 124) + X( 126)
     + X( 130) + X( 132) + X( 133) + X( 134) + X( 135) + X( 136)
     + X( 137) + X( 138) + X( 139) + X( 140) + X( 141) + X( 142)
     + X( 143) + X( 144) + X( 145) >=   0
95]- Y( 92) + X( 124) + X( 126) + X( 127) + X( 128) + X( 130)
     + X( 132) + X( 133) + X( 134) + X( 135) + X( 136) + X( 137)
     + X( 138) + X( 139) + X( 140) + X( 141) + X( 142) + X( 143)
     + X( 145) + X( 146) + X( 147) + X( 148) + X( 149) + X( 150)
     >=   0
96]- Y( 93) + X( 113) + X( 114) + X( 115) + X( 116) + X( 117)
     + X( 118) + X( 119) + X( 120) + X( 121) + X( 122) + X( 123)
     + X( 124) + X( 125) + X( 126) + X( 127) + X( 128) + X( 130)
     + X( 132) + X( 133) + X( 134) + X( 135) + X( 136) + X( 137)
     + X( 138) + X( 139) + X( 140) + X( 141) + X( 142) + X( 143)
     + X( 144) + X( 145) + X( 146) + X( 147) + X( 148) + X( 149)
     + X( 150) >=   0
97]- Y( 94) + X( 68) + X( 69) + X( 70) + X( 71) + X( 72) + X( 73)
     + X( 74) + X( 112) + X( 113) + X( 114) + X( 115) + X( 116)
     + X( 117) + X( 118) + X( 119) + X( 120) + X( 121) + X( 122)
     + X( 123) + X( 124) + X( 125) + X( 126) + X( 127) + X( 128)
     + X( 130) + X( 131) + X( 132) + X( 133) + X( 134) + X( 135)
     + X( 136) + X( 137) + X( 138) + X( 139) + X( 140) + X( 141)
     + X( 142) + X( 143) + X( 144) >=   0
98]- Y( 95) + X( 120) + X( 123) + X( 124) + X( 125) + X( 126)
     + X( 127) + X( 128) + X( 130) + X( 132) + X( 133) + X( 134)
     + X( 135) + X( 136) + X( 137) + X( 138) + X( 139) + X( 140)
     + X( 141) + X( 142) + X( 143) + X( 144) + X( 145) + X( 146)
     + X( 147) + X( 148) + X( 149) + X( 150) >=   0
99]- Y( 96) + X( 134) + X( 136) + X( 137) + X( 139) + X( 141)
     + X( 142) + X( 143) + X( 144) + X( 145) + X( 146) + X( 147)
     + X( 148) + X( 149) >=   0
100]- Y( 97) + X( 112) + X( 113) + X( 114) + X( 115) + X( 116)
     + X( 117) + X( 118) + X( 119) + X( 120) + X( 123) + X( 124)
     + X( 126) + X( 127) + X( 128) + X( 130) + X( 133) + X( 134)
     + X( 137) + X( 140) + X( 141) + X( 142) >=   0
101]- Y( 98) + X( 68) + X( 69) + X( 70) + X( 71) + X( 72) + X( 73)
```

```
     + X( 74) + X( 112) + X( 114) + X( 115) + X( 116) + X( 117)
     + X( 118) + X( 119) + X( 120) + X( 121) + X( 123) + X( 124)
     + X( 125) + X( 126) + X( 131) >=   0
102]- Y( 99) + X( 57) + X( 60) + X( 61) + X( 62) + X( 63) + X( 64)
     + X( 65) + X( 66) + X( 67) + X( 68) + X( 69) + X( 70) + X( 71)
     + X( 72) + X( 73) + X( 74) + X( 112) + X( 113) + X( 114)
     + X( 115) + X( 116) + X( 117) + X( 118) + X( 119) + X( 120)
     + X( 121) + X( 122) + X( 123) + X( 124) + X( 125) + X( 126)
     + X( 127) + X( 128) + X( 131) >=   0
103]- Y( 100) + X( 59) + X( 60) + X( 61) + X( 62) + X( 63) + X( 64)
     + X( 65) + X( 66) + X( 67) + X( 68) + X( 69) + X( 70) + X( 71)
     + X( 72) + X( 73) + X( 74) + X( 112) + X( 114) + X( 115)
     + X( 116) + X( 117) + X( 118) + X( 119) + X( 120) + X( 121)
     + X( 122) + X( 123) + X( 124) + X( 131) >=   0
104]- 10 X( 1) - 8 X( 2) - 10 X( 3) - 9 X( 4) - 10 X( 5) - 10 X( 6)
     - 9 X( 7) - 10 X( 8) - 9 X( 9) - 8 X( 10) - 9 X( 11) - 8 X( 12)
     - 7 X( 13) - 9 X( 14) - 10 X( 15) - 8 X( 16) - 7 X( 17)
     - 7 X( 18) - 6 X( 19) - 9 X( 20) - 7 X( 21) - 10 X( 22)
     - 10 X( 23) - 7 X( 24) - 10 X( 25) - 8 X( 26) - 7 X( 27)
     - 7 X( 28) - 8 X( 29) - 7 X( 30) - 7 X( 31) - 8 X( 32) - 7 X( 33)
     - 8 X( 34) - 7 X( 35) - 7 X( 36) - 7 X( 37) - 7 X( 38) - 8 X( 39)
     - 7 X( 40) - 7 X( 41) - 7 X( 42) - 7 X( 43) - 8 X( 44) - 8 X( 45)
     - 8 X( 46) - 10 X( 47) - 10 X( 48) - 9 X( 49) - 8 X( 50)
     - 7 X( 51) - 9 X( 52) - 9 X( 53) - 8 X( 54) - 8 X( 55) - 9 X( 56)
     - 9 X( 57) - 7 X( 58) - 9 X( 59) - 9 X( 60) - 10 X( 61)
     - 10 X( 62) - 10 X( 63) - 10 X( 64) - 10 X( 65) - 8 X( 66)
     - 9 X( 67) - 9 X( 68) - 10 X( 69) - 10 X( 70) - 10 X( 71)
     - 9 X( 72) - 8 X( 73) - 8 X( 74) - 7 X( 75) - 7 X( 76) - 7 X( 77)
     - 6 X( 78) - 6 X( 79) - 6 X( 80) - 7 X( 81) - 6 X( 82) - 7 X( 83)
     - 7 X( 84) - 8 X( 85) - 8 X( 86) - 7 X( 87) - 10 X( 88)
     - 7 X( 89) - 8 X( 90) - 7 X( 91) - 7 X( 92) - 6 X( 93) - 7 X( 94)
     - 7 X( 95) - 7 X( 96) - 8 X( 97) - 8 X( 98) - 8 X( 99)
     - 7 X( 100) - 7 X( 101) - 7 X( 102) - 6 X( 103) - 7 X( 104)
     - 7 X( 105) - 9 X( 106) - 6 X( 107) - 8 X( 108) - 9 X( 109)
     - 8 X( 110) - 8 X( 111) - 10 X( 112) - 10 X( 113) - 5 X( 114)
     - 9 X( 115) - 9 X( 116) - 10 X( 117) - 10 X( 118) - 8 X( 119)
     - 9 X( 120) - 8 X( 121) - 7 X( 122) - 9 X( 123) - 9 X( 124)
     - 10 X( 125) - 10 X( 126) - 8 X( 127) - 9 X( 128) - 8 X( 129)
     - 8 X( 130) - 7 X( 131) - 8 X( 132) - 8 X( 133) - 8 X( 134)
     - 9 X( 135) - 7 X( 136) - 7 X( 137) - 9 X( 138) - 8 X( 139)
     - 7 X( 140) - 8 X( 141) - 9 X( 142) - 10 X( 143) - 8 X( 144)
     - 8 X( 145) - 10 X( 146) - 10 X( 147) - 8 X( 148) - 8 X( 149)
     - 8 X( 150) - 10 X( 151) - 10 X( 152) + G =    0
105]  G >=   70
106]- 7 X( 1) - 10 X( 2) - 8 X( 3) - 8 X( 4) - 10 X( 5) - 9 X( 6)
     - 7 X( 7) - 8 X( 8) - 8 X( 9) - 8 X( 10) - 10 X( 11) - 8 X( 12)
     - 8 X( 13) - 8 X( 14) - 7 X( 15) - 8 X( 16) - 8 X( 17) - 8 X( 18)
     - 9 X( 19) - 9 X( 20) - 8 X( 21) - 7 X( 22) - 10 X( 23)
     - 7 X( 24) - 8 X( 25) - 8 X( 26) - 8 X( 27) - 8 X( 28) - 8 X( 29)
     - 8 X( 30) - 7 X( 31) - 8 X( 32) - 7 X( 33) - 8 X( 34) - 8 X( 35)
     - 7 X( 36) - 8 X( 37) - 9 X( 38) - 8 X( 39) - 7 X( 40) - 7 X( 41)
     - 8 X( 42) - 7 X( 43) - 7 X( 44) - 8 X( 45) - 7 X( 46) - 7 X( 47)
     - 7 X( 48) - 9 X( 49) - 8 X( 50) - 8 X( 51) - 8 X( 52) - 9 X( 53)
     - 8 X( 54) - 8 X( 55) - 8 X( 56) - 9 X( 57) - 8 X( 58) - 8 X( 59)
     - 9 X( 60) - 9 X( 61) - 7 X( 62) - 10 X( 63) - 5 X( 64)
     - 6 X( 65) - 9 X( 66) - 10 X( 67) - 6 X( 68) - 9 X( 69)
     - 7 X( 70) - 8 X( 71) - 6 X( 72) - 7 X( 73) - 6 X( 74) - 7 X( 75)
```

```
     - 8 X( 76) - 7 X( 77) - 9 X( 78) - 7 X( 79) - 7 X( 80) - 9 X( 81)
     - 9 X( 82) - 7 X( 83) - 9 X( 84) - 9 X( 85) - 9 X( 86) - 9 X( 87)
     - 10 X( 88) - 7 X( 89) - 8 X( 90) - 9 X( 91) - 8 X( 92)
     - 8 X( 93) - 8 X( 94) - 8 X( 95) - 8 X( 96) - 8 X( 97) - 8 X( 98)
     - 8 X( 99) - 8 X( 100) - 8 X( 101) - 7 X( 102) - 7 X( 103)
     - 8 X( 104) - 6 X( 105) - 8 X( 106) - 7 X( 107) - 8 X( 108)
     - 9 X( 109) - 9 X( 110) - 9 X( 111) - 10 X( 112) - 6 X( 113)
     - 7 X( 114) - 8 X( 115) - 6 X( 116) - 6 X( 117) - 8 X( 118)
     - 8 X( 119) - 8 X( 120) - 8 X( 121) - 6 X( 122) - 6 X( 123)
     - 9 X( 124) - 8 X( 125) - 6 X( 126) - 10 X( 127) - 8 X( 128)
     - 8 X( 129) - 8 X( 130) - 7 X( 131) - 7 X( 132) - 6 X( 133)
     - 7 X( 134) - 8 X( 135) - 8 X( 136) - 8 X( 137) - 6 X( 138)
     - 8 X( 139) - 9 X( 140) - 8 X( 141) - 9 X( 142) - 8 X( 143)
     - 8 X( 144) - 8 X( 145) - 10 X( 146) - 10 X( 147) - 8 X( 148)
     - 9 X( 149) - 9 X( 150) - 10 X( 151) - 10 X( 152) + L =    0
107]  L >=   70
108]- 7 X( 1) - 7 X( 2) - 8 X( 3) - 8 X( 4) - 7 X( 5) - 8 X( 6)
     - 7 X( 7) - 8 X( 8) - 8 X( 9) - 8 X( 10) - 9 X( 11) - 8 X( 12)
     - 9 X( 13) - 9 X( 14) - 10 X( 15) - 8 X( 16) - 9 X( 17)
     - 9 X( 18) - 10 X( 19) - 9 X( 20) - 9 X( 21) - 10 X( 22)
     - 10 X( 23) - 7 X( 24) - 9 X( 25) - 9 X( 26) - 8 X( 27)
     - 8 X( 28) - 8 X( 29) - 8 X( 30) - 7 X( 31) - 7 X( 32) - 7 X( 33)
     - 8 X( 34) - 7 X( 35) - 7 X( 36) - 7 X( 37) - 7 X( 38) - 8 X( 39)
     - 7 X( 40) - 7 X( 41) - 7 X( 42) - 7 X( 43) - 7 X( 44) - 8 X( 45)
     - 7 X( 46) - 7 X( 47) - 9 X( 48) - 8 X( 49) - 8 X( 50) - 8 X( 51)
     - 9 X( 52) - 9 X( 53) - 8 X( 54) - 8 X( 55) - 8 X( 56) - 9 X( 57)
     - 8 X( 58) - 10 X( 59) - 10 X( 60) - 10 X( 61) - 10 X( 62)
     - 10 X( 63) - 10 X( 64) - 10 X( 65) - 10 X( 66) - 10 X( 67)
     - 10 X( 68) - 10 X( 69) - 10 X( 70) - 10 X( 71) - 10 X( 72)
     - 10 X( 73) - 10 X( 74) - 8 X( 75) - 7 X( 76) - 8 X( 77)
     - 8 X( 78) - 7 X( 79) - 7 X( 80) - 9 X( 81) - 7 X( 82) - 7 X( 83)
     - 8 X( 84) - 9 X( 85) - 9 X( 86) - 6 X( 87) - 10 X( 88)
     - 7 X( 89) - 7 X( 90) - 9 X( 91) - 8 X( 92) - 7 X( 93) - 8 X( 94)
     - 8 X( 95) - 8 X( 96) - 8 X( 97) - 8 X( 98) - 8 X( 99)
     - 8 X( 100) - 8 X( 101) - 7 X( 102) - 9 X( 103) - 7 X( 104)
     - 8 X( 105) - 8 X( 106) - 8 X( 107) - 7 X( 108) - 7 X( 109)
     - 7 X( 110) - 7 X( 111) - 10 X( 112) - 10 X( 113) - 10 X( 114)
     - 10 X( 115) - 10 X( 116) - 10 X( 117) - 10 X( 118) - 10 X( 119)
     - 9 X( 120) - 7 X( 121) - 10 X( 122) - 10 X( 123) - 9 X( 124)
     - 9 X( 125) - 10 X( 126) - 10 X( 127) - 8 X( 128) - 8 X( 129)
     - 7 X( 130) - 7 X( 131) - 8 X( 132) - 9 X( 133) - 10 X( 134)
     - 9 X( 135) - 9 X( 136) - 9 X( 137) - 10 X( 138) - 8 X( 139)
     - 8 X( 140) - 10 X( 141) - 10 X( 142) - 9 X( 143) - 8 X( 144)
     - 10 X( 145) - 10 X( 146) - 10 X( 147) - 8 X( 148) - 10 X( 149)
     - 10 X( 150) - 10 X( 151) - 10 X( 152) + W =    0
109]  W >=   70
END
ALL VARIABLES ARE BINARY.
```

II. Formulations for the Combined Solutions

These formulations for all scenarios are the same as the separate formulations. Only difference is the variables X1, X6, X33, X34, X56, X63, X72, X73, X118, X123, and X142 are given the value of 1, and the total number of the SAR stations is 11.

APPENDIX D: Computer Representation

```
MODEL:
SETS:
CANDIDATE / 1..152 / : X,GEO,LOJ,WX;
DEMAND / 1..100 / : Y;
MATRIX (DEMAND,CANDIDATE):COEFF;
ENDSETS
MAX = @SUM (DEMAND(I):Y(I));
A=@SUM (CANDIDATE(K):X(K)) ;
A<5;
@FOR(DEMAND(J):
@SUM(CANDIDATE(P):COEFF(J,P)*X(P))>=Y(J));
G=@SUM (CANDIDATE(E):X(E)*GEO(E));
G>35;
L=@SUM (CANDIDATE(S):X(S)*LOJ(S));
L>35;
W=@SUM (CANDIDATE(D):X(D)*WX(D));
W>35;
@FOR( CANDIDATE( I): @BIN( X));
@FOR( DEMAND( J): @BIN( Y));
DATA:
! X COLUMN   1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49
50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74
75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99
100 101 102 103 104 105 106 107 108 109 110 111 112 113 114 115 116 117 118
119 120 121 122 123 124 125 126 127 128 129 130 131 132 133 134 135 136 137
138 139 140 141 142 143 144 145 146 147 148 149 150 151 152;

COEFF= !Y1;  1 1 1 1 1 1 1 1 1  1  1  1  1  1  1  1  1  1  1  0  1  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  1  1  1  0  0  0  0  0  0  1
0   0   0   0   0   0   1   0   1   1   1   1   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
       !Y2;  1 1 1 1 1 1 1 1 1  1  1  1  1  1  0  1  1  1  1  1  1  1  1  1
1  0  0  0  0  0  1  0  1  1  0  0  0  1  0  0  0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  1  1  1  1  1  1  1  1  1  1  1  1  1  0  1  0  0
1   1   0   0   1   1   1   1   0   1   1   1   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   1   0
       !Y3;  1 1 1 1 1 1 1 1 1  1  1  1  1  0  1  1  0  0  0  0  1  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0  0  1  0  0  0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  1  0  0  0  1  0  1  0  0  0  0  1  1  1
0   0   0   0   0   0   1   0   1   1   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
       !Y4;  1 1 1 1 1 0 1 1 1  1  1  1  1  0  1  1  1  1  1  0  1  0  0  1
0  0  0  0  0  0  1  1  1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  1  1  1  1  1  0  1  1  1  1  1  1  1  1  1  1  1
```

```
0 0 0 0 1 1 1 0 1 1 1 1 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
      !Y5; 1 0 0 1 0 1 1 1 1 1 1 1 1 1 1 1 0 0 0 1 1 0 1 0
1 0 0 0 0 0 1 0 1 1 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 1 0 1 0 0 0 0 0 1 0
0 0 0 0 0 0 1 0 1 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
      !Y6; 0 0 0 0 1 1 1 1 1 1 0 1 1 1 1 0 0 0 0 1 0 1 1 1
1 0 0 0 0 1 1 1 1 1 1 0 1 1 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 1 1 1 0 0 0 0 0 0 0
0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 1
      !Y7; 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 1 1 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
      !Y8; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 1 1 1 1 1 0 1 1 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
      !Y9; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 1 1 1 1 1 0 1 1 0 0 0 0 0 0 0 0 0 0 0
0 0 1 1 0 0 1 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
      !Y10; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 1 0 1 1 1 0 1 1 0 0 0 0 0 0 0 0 0 0 0
0 0 1 1 0 0 1 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
      !Y11; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
      !Y12; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 1 1 1 1 1 0 1 1 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
```

```
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
    !Y13; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 1 0 0
0 0 1 1 0 0 1 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 1 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
    !Y14; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 1 1 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0
0 0 1 1 0 0 1 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 1 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
    !Y15; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 1 1 1 0 1 0 0 0 0 0 0 0 0 0 1 0 0
0 0 1 1 0 0 1 0 0 0 0 1 1 0 0 0 0 0 0 0 0 1 1 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
    !Y16; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 1 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
    !Y17; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
    !Y18; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 1 1 1 0 1 0 0 0 0 0 0 0 0 0 1 0 0
0 0 1 1 0 1 1 0 0 1 1 1 1 1 0 0 0 0 0 0 0 1 1 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
    !Y19; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 1 1 1 0 1 0 0 0 0 0 0 0 0 1 1 1 0
0 0 0 1 0 1 1 0 0 1 1 0 1 0 1 0 0 0 0 0 0 1 1 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
    !Y20; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 1 0 1 0 1 0 0 0 0 0 0 0 0 0 1 1 0
0 0 0 1 0 1 1 0 0 1 1 1 1 1 1 0 0 0 0 1 1 1 1 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
```

```
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
      !Y21; 0 0 0 0 0 0 0 0 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0  0  1  1  0  1  1  0  0  0  1  1  1  0  0  0  0  0  0  0  1  1  1  1  0
0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
      !Y22; 0 0 0 0 0 0 0 0 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0  0  1  0  0  0  0  0  0  0  0  1  0  0
0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
      !Y23; 0 0 0 0 0 0 0 0 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  1  1  1  0  0  0  0  0  1  1  1  1  0  0
0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
      !Y24; 0 0 0 0 0 0 0 0 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0  1  1  0  0  0  0  0  0  1  1  1  0  0
0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
      !Y25; 0 0 0 0 0 0 0 0 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  1  0  0
0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
      !Y26; 1 1 0 1 1 1 1 1 1  0  0  1  1  0  1  1  0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0  0  1  0  0  0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  1  1  0  0  0  0  0  0  0  1
0    0    0    0    0    0    1    0    1    1    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
      !Y27; 1 0 0 0 1 1 1 1 1  0  0  0  1  0  0  0  0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0    0    0    0    0    0    1    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
      !Y28; 0 0 0 0 0 1 1 1 1  0  0  1  1  0  0  0  0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  1  1  0  0  0  1  0  0  0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  1  0  0  0  0  0  0  0  0  0
0    0    0    0    0    0    1    0    0    0    0    0    0    0    0    0    0    0    0
```

```
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
      !Y29; 0 0 0 0 1 1 1 1 1 1 0 1 1 0 1 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 1 0 1 1 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
      !Y30; 0 0 0 0 0 1 1 1 1 0 0 1 1 0 1 0 0 0 0 0 0 0 0 0
1 0 0 0 0 0 1 1 1 1 1 0 1 1 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
      !Y31; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 1 1 1 1 1 0 1 1 1 1 1 0 0 0 0 1 1 1 1 1 1 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 1 0 1 0 1 1 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
      !Y32; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1
0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 1 0 1 1 1 1 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
      !Y33; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 0 0 0 1 0 1 0 1
1 1 1 1 1 1 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 1 0 1 1 1 1 1
1 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0


      !Y34; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 1 0 0 0 1 0 1 1 1
0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 1 0 1 1 1 1 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
      !Y35; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 1 0 0 1 1 1 1 1 1 0 1 0 1 1 0 0 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 0 0 0 1 1 1 1 1 0 0 0 0 0 1
1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 1
      !Y36; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 1 1 1 0 1 1 1 1 1 1 0 0 0 1 1 1 0 0 1 1 0 0 1
1 1 1 1 1 1 1 1 1 1 1 1 1 0 1 1 1 1 1 1 1 1 1 1 1
1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
```

```
0 0 0 0 0 0 0 0 0 0 0 0 1 0 1 1 1 1 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 1
    !Y37; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 1 1 1 1 1 1 1 0 1 1 1 1 0 0 1 1 1 1 0 1 0 0 1
0 1 0 0 1 0 0 1 1 1 0 0 0 0 1 1 1 1 1 1 1 0 0 0 0
1 1 1 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 1 0 1 1 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 1
    !Y38; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 1 0 1 1 1 0 1 1 1 0 1 1 0 0 0 0 1 1 1 0 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 1 1 1 1 1 0 1
1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 1
    !Y39; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 0 0 1 0 1 0 0
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 1 0 1 1 1 1 1
1 1 1 1 1 1 1 0 0 0 0 0 1 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

! X COLUMN  1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49
50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74
75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99
100 101 102 103 104 105 106 107 108 109 110 111 112 113 114 115 116 117 118
119 120 121 122 123 124 125 126 127 128 129 130 131 132 133 134 135 136 137
138 139 140 141 142 143 144 145 146 147 148 149 150 151 152;

    !Y40; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 1 1 0 0 1 0 0 1 1 1 0 1 1 1 1 1 0 1 1 1 0 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 1 1 1 1 1 1 1
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0 0 0 0 0 0 0 0 0 0 0 0 1 0 1 1 1 1 1
1 1 1 1 1 1 1 0 0 0 0 0 1 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 1
    !Y41; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 1 1 1 1 1 1 1 1 0 1 1 1 1 0 1 1 1 1 1 1 1 1 0 1
1 1 0 1 1 1 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
0 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 1 0 1 1 1 1 1
1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 1
    !Y42; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
1 1 1 1 1 1 1 1 0 1 1 1 1 1 1 1 1 1 1 1 0 1 1 0 1
0 1 1 1 1 0 0 1 1 0 1 1 1 0 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 1 0 1 1 1 0 0
1 1 1 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 1
    !Y43; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
1 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 1 1 0 0 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 1
```

```
1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 1
!Y44; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 1 1 1 1 1 1 1 1 1 1 0 1 1 1 1 1 0 1 1 1 0 0 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 1 1 1 1 0 0 0
1 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 1
!Y45; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 1 1 1 0 1 1 0 1 0 1 1 1 1 0 0 0 1 0 1 0 0
0 0 1 1 1 1 1 0 0 1 1 1 0 1 1 0 0 0 0 0 0 1 1 0 0
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!Y46; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 1 1
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!Y47; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 1 1
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!Y48; 0 0 0 0 0 0 0 1 1 0 0 1 1 0 1 0 0 0 0 0 0 0 1 1
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!Y49; 0 0 0 0 0 0 0 1 1 0 0 1 1 1 1 0 0 0 0 1 0 1 1 1
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!Y50; 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 0 0 0 0 1 1 1 0 0
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!Y51; 1 0 0 1 1 1 1 0 1 1 1 1 1 1 1 0 1 0 0 0 1 1 1 1
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      !Y59; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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    !Y61; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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    !Y67; 0 0 0 0 1 1 1 1 1 1 1 1 1 0 1 0 0 0 0 1 0 1 1 1
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0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0
```

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0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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    !Y70; 1 0 0 1 1 1 1 1 1 1 0 1 1 0 0 1 0 0 0 0 0 0 0 0
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0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0
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    !Y71; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
    !Y72; 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
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0 0 0 0 0 0 0 0 0 0 0 1 1 0 1 0 1 1 0 1 0 0 1 1 1
0 0 0 0 0 1 0 0 1 1 1 1 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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    !Y73; 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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    !Y74; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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1 1 1 1 1 1 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
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0 0 0 0 0 0 0 0 0 0 0 0 1 0 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 0 1 1 1 1 0 0 0 0
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    !Y75; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 1 0
```

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0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
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0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 0 0 0 1 1 1 0 0 1 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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      !Y77; 0 0 0 0 0 0 0 0 0 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 0 1 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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      !Y78; 0 0 0 0 0 0 0 0 0 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0   0   0   0   0   0   0   0   0   0   0   1   0   0   1   1   1   1   1
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      !Y79; 0 0 0 0 0 0 0 0 0 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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1   1   1   1   1   1   1   1   1   1   0   1   0   1   1   1   1   1   1
0   0   1   1   1   0   0   0   0   0   0   0   0   0   0

! X COLUMN   1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49
50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74
75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99
100 101 102 103 104 105 106 107 108 109 110 111 112 113 114 115 116 117 118
119 120 121 122 123 124 125 126 127 128 129 130 131 132 133 134 135 136 137
138 139 140 141 142 143 144 145 146 147 148 149 150 151 152;

      !Y80; 0 0 0 0 0 0 0 0 0 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
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0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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1 1 1 1 1 1 1 1 1 0 0 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 0 0 0
      !Y84; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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      !Y85; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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0 0 0 0 0 0 0 0 0 0 0 0 1 0 1 1 1 1 1
1 1 0 0 1 0 0 0 0 0 0 0 1 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
      !Y87; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 1
0 1 1 1 1 1 1 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
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0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 0 1 1 1 0 0 0 0 1 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 0 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 0 0 0 0 0 0 0 0
      !Y90; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 1 1 0 1 0 0 0 1 1 1 1 1 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0
```

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
!Y91; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 1 1 1
1 1 1 1 1 1 0 1 0 0 0 1 0 1 1 1 1 1 1
1 1 1 1 1 1 1 1 0 0 0 0 0 0 0
!Y92; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 1 0 1 1 1 0 1 0 1 1 1 1 1 1
1 1 1 1 1 1 0 1 1 1 1 1 1 0 0
!Y93; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 0 1 0 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 0 0
!Y94; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 0 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 0 0 0 0 0 0 0 0
!Y95; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 1 0 0 1 1 1 1 1 1 0 1 0 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 0 0
!Y96; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 1 1
0 1 0 1 1 1 1 1 1 1 1 1 0 0 0
!Y97; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1
1 1 0 0 1 1 0 1 1 1 0 1 0 0 1 1 0 0 1
0 0 1 1 1 0 0 0 0 0 0 0 0 0 0
!Y98; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 1 0 1 1 1 1 1

```
1   1   1   0   1   1   1   1   0   0   0   0   1   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
        !Y99; 0 0 0 0 0 0 0 0 0 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  1  0  0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0   0   0   0   0   0   0   0   0   0   0   0   1   1   1   1   1   1   1
1   1   1   1   1   1   1   1   1   1   0   0   1   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
        !Y100;0 0 0 0 0 0 0 0 0 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0   0   0   0   0   0   0   0   0   0   0   0   1   0   1   1   1   1   1
1   1   1   1   1   1   0   0   0   0   0   0   1   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0;

! X COLUMN   1  2  3  4  5  6  7  8  9  10 11 12 13 14 15 16 17 18 19 20 21
22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46
47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71
72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96
97 98 99 100 101 102 103 104 105 106 107 108 109 110 111 112 113 114 115
116 117 118 119 120 121 122 123 124 125 126 127 128 129 130 131 132 133 134
135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152;


GEO=         10 8  10 9  10 10 9  10 9   8  9  8  7  9 10  8  7  7  6  9  7
10 10  7 10  8  7  7  8  7  7  8  7  8  7  7  7  7  8  7  7  7  7  8  8  8
10 10  9  8  7  9  9  8  8  9  9  7  9  9 10 10 10 10 10  8  9  9 10 10 10
9  8  8  7  7  7  6  6  6  7  6  7  7  8  8  7 10  7  8  7  7  6  7  7  7
8  8  8   7   7   7   6   7   7   9   6   8   9   8   8  10  10   5  9   9
10   10  8   9   8   7   9   9   10  10  8   9   8   8   7   8   8   8   9
7   7   9   8   7   8   9  10   8   8  10  10   8   8   8  10  10;

LOJ=         7  10 8  8  10 9  7  8  8   8  10 8  8  8  7  8  8  8  9  9  8
7 10  7  8  8  8  8  8  8  7  8  7  8  8  7  8  9  8  7  7  8  7  7  8  7
7  7  9  8  8  8  9  8  8  8  9  8  8  9  9  7 10  5  6  9 10  6  9  7  8
6  7  6  7  8  7  9  7  7  9  9  7  9  9  9  9 10  7  8  9  8  8  8  8  8
8  8  8   8   8   7   7   8   6   8   7   8   9   9   9  10   6   7  8   6
6   8  8   8   8   6   6   9   8   6  10  8   8   8   7   7   6   7   8
8   8   6   8   9   8   9   8   8   8  10  10   8   9   9  10  10;

WX=          7  7  8  8  7  8  7 .8  8   8  9  8  9  9 10  8  9  9  10 9  9
10 10  7  9  9  8  8  8  8  7  7  7  8  7  7  7  7  8  7  7  7  7  7  8  7
7  9  8  8  8  9  9  8  8  8  9  8  10 10 10 10 10 10 10 10 10 10 10 10 10
10 10 10 8  7  8  8  7  7  9  7  7  8  9  9  6 10  7  7  9  8  7  8  8  8
8  8  8   8   8   7   9   7   8   8   8   7   7   7   7  10   10  10  10
10  10  10  10  9   7   10  10  9    9  10  10  8   8   7   7   8   9  10
9   9   9   10  8   8   10  10  9   8   10 10  10   8   10  10 10  10;

ENDDATA
END
```

Model Explanation

```
1) MODEL
2) SETS:
3) CANDIDATE / 1..152 / : X,GEO,LOJ,WX;
4)DEMAND / 1..100 / : Y;
5)MATRIX (DEMAND,CANDIDATE):COEFF;
6)ENDSETS
7)MAX = @SUM (DEMAND(I):Y(I));
8)A=@SUM (CANDIDATE(K):X(K)) ;
9)A<30;
10)@FOR(DEMAND(J):
11)@SUM(CANDIDATE(P):COEFF(J,P)*X(P))>=Y(J));
12)G=@SUM (CANDIDATE(E):X(E)*GEO(E));
13)G>210;
14)L=@SUM (CANDIDATE(S):X(S)*LOJ(S));
15)L>210;
16)W=@SUM (CANDIDATE(D):X(D)*WX(D));
17)W>210;
18)@FOR( CANDIDATE( I): @BIN( X));
19)@FOR( DEMAND( J): @BIN( Y));
```

In LINGO, all formulations begin with MODEL statement like shown in line 1. In line 2, SETS statement declares the sets that are used in the model. These sets also define the variables of the model. In LINGO all variables have to be defined whether they are known or unknown. Basically, unknown variables are the ones that do not have data sets, and known variables are the ones that have data sets. In line 3, CANDIDATE set one (X) is unknown, while the three known sets are GEO, LOJ, and WX. Therefore optimizer engine tries to find optimum selection among X variables and uses GEO, LOJ, and WX variables in the corresponding constraints. The same rule also applies in line 4. Here, the Y variable is unknown; however the BON variable is also added to the DEMAND set later on to define the bonus values as discussed above. At last, the MATRIX set in line 5 defines the coefficients (A matrix) of X variables that form a 100 X 152 matrix. Set definition ends with the ENDSETS statement in line 6.

Line 7 defines the objective function. In addition, when BON variable is introduced, the objective function will become Y(I)*BON(I). Lines 8 and 9 depict the minimum number constraint for the candidate points. A is compared with 30 in this case, however 30 may be changed to another numerical value.

In lines 10 and 11, coverage constraints are defined. @FOR makes a loop for the DEMAND set and @SUM statement sums all corresponding variables. In other words, covering X variables, and the >= sign compares them to relevant Y variables. In lines between 12 and 17, additional constraints (weather, logistic, and geography constraints) are defined. Finally, lines 18 and 19 define the variable types, which for this case, both unknown variables are binary.

Appendix E: Tabu Search

Tabu Search

Tabu search (TS) is a higher level heuristic procedure for solving optimization problems, and it is designed to guide other methods (or their component processes) to escape the trap of local optimality. It can be applied to almost every type of operations research problem. Therefore, a brief introduction of this concept is presented in this research. The philosophy of TS is to derive and exploit a collection of principles of intelligent problem solving. In this sense, it can be said that TS is based on selected concepts that unite the fields of artificial intelligence and optimization.

TS is still in an early stage of development, with a substantial majority of its applications occurring only since 1989. However, TS methods have enjoyed successes in a variety of problem settings such as scheduling, transportation, layout and circuit design, bandwidth packing, stable sets in large graphs, neural networks, and integer programming.[7]

Furthermore, we observe that TS can be used to modify decision rules for basis exchange (pivoting) methods, and therefore can be applied to solving mixed (0-1) integer programming (IP) problems and various nonlinear programming problems. Such applications exploit the fact that optimal solutions to these special (0-1) discrete and nonlinear problems can be found at extreme points, and that pivoting methods provide a mechanism to move from one extreme point to another. In addition, TS can be applied to solve IP's in other ways[5].

The Basics of TS

TS tries to find the best solution among the candidate solutions by changing the solution environments called neighborhoods through operations called moves. There are several strategies to find the most productive neighborhood that also leads to the best solution, such as intensification, diversification and strategic oscillation. Moves should be defined to explore the solution space, and this definition also explains the neighborhood.

In TS we should define our aspiration criteria with respect to our moves. Aspiration criteria is a term that also defines the objective. An aspiration criterion is the threshold that makes the objective function stay in the desired solution set. Among many candidate points we may develop an algorithm to drop and add the points to find optimal or near optimal solutions. This adding and dropping action might also be considered as our moves, and these moves will also indicate our success in applying TS.

Intensification strategies are based on modifying choice rules to encourage move combinations and solution features historically found good. They may also initiate a return to attractive regions to search them more thoroughly. Since elite solutions must be recorded in order to examine their immediate neighborhoods, explicit memory is closely related to the implementation of intensification strategies. In other words, the intensification phase focuses on examining neighborhoods of elite solutions.

The term "neighbors" has a broader meaning than in the usual context of "neighborhood search". That is, in addition to considering solutions that are adjacent or close to elite solutions by means of standard move mechanisms, intensification strategies generate "neighbors" by either grafting together components of good solutions or by using modified evaluations that favor the introduction of such components into a current solution.

Diversification strategies increase the effectiveness in exploring the solution space. Some of these are designed with the chief purpose of preventing searching processes from cycling, such as, from endlessly executing the same sequence of moves or revisiting the set of solutions.

TS diversification strategies are designed to drive the search into new regions. Often they are based on modifying choice rules to bring attributes into the solution that are infrequently used. Alternatively, they may introduce such attributes by periodically applying methods that assemble subsets of these attributes into candidate solutions for continuing the search, or by partially or fully restarting the solution process. Diversification strategies are particularly helpful when better solutions can be reached only by crossing barriers in the solution space.

Strategic oscillation is closely linked to the origins of tabu search and it provides a means to achieve an effective interplay between intensification and diversification. Strategic oscillation operates by orienting moves to a critical level, as identified by a stage of construction or chosen interval of functional values. Such a critical level or oscillation boundary often represents a point where the method would normally stop. Instead of stopping when this boundary is reached, however; the rules for selecting moves are modified to permit the region defined by the critical level to be crossed. The approach then proceeds for a specified depth beyond the oscillation boundary, and turns around. The oscillation boundary again is approached and crossed, this time from the opposite direction, and the method proceeds to a new turning point.[5]

Tabu List is the memory of previous path that the TS algorithm has searched through. It contains reverse actions of previous moves. The length of tabu list and the operators to modify the list play an important role in TS's performance. Operators decide the behavior of how to add a new tabu move, how and when to remove a tabu move. [9]

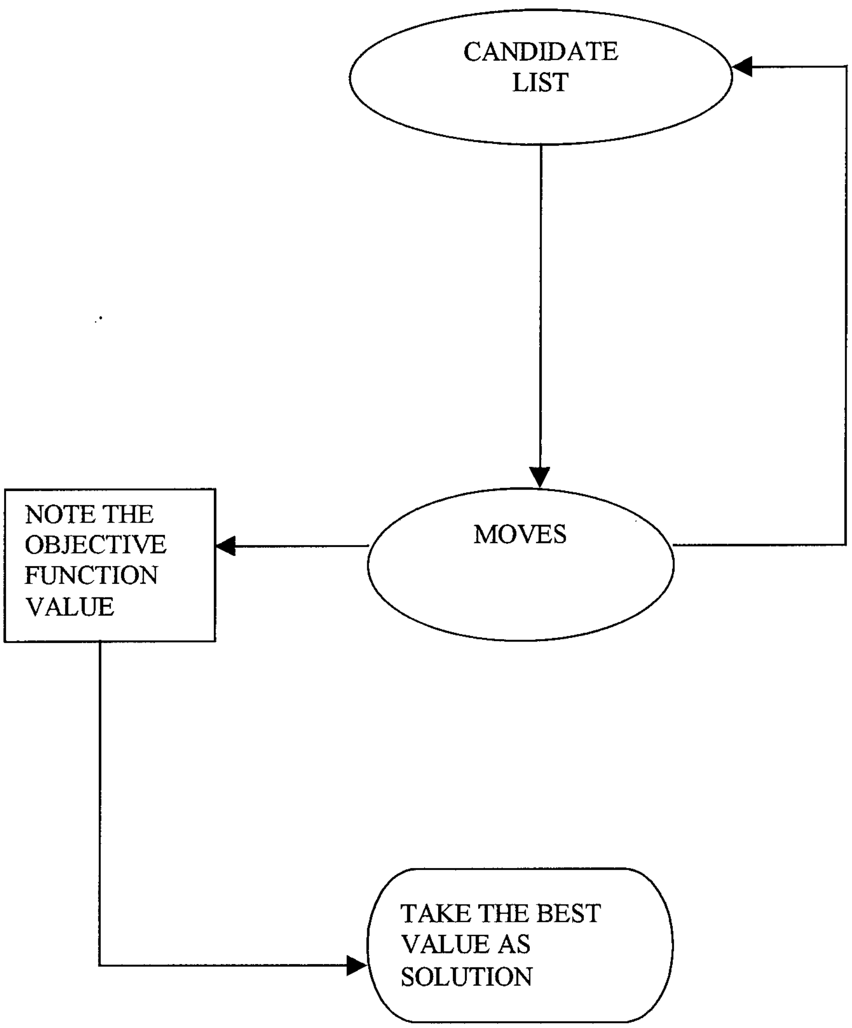
Based on local search, it revolves around the use of history to guide the search. When evaluating the neighborhood of a solution we classify some potential solutions as *tabu* based on recent history. At each iteration we take the best move possible that is not tabu, even if this means an increase in the cost. The idea here is that when we reach a local minimum we wish to escape via a different path. This allows us to fully explore a local optimum and hopefully move to any other local optima nearby. [7]

Tabu list also defines the roles of the strategies discussed above. Intensification and diversification strategies update the tabu list with add/drop moves, aspiration criteria focuses on the list elements that improve the solution. Therefore, tabu list is a useful tool to keep track of solution improvement.

Tabu Search Application

There are many settings where operations of adding and dropping paired elements are the cornerstone of useful neighborhood definitions. Add/drop moves also apply to the omnipresent class of multiple choice problems, which require that exactly one element must be chosen from each member setting, since whenever a new element is chosen from a given set, the element previously chosen must be replaced. An add/drop move in this case consists of choosing a new variable to equal 1 and setting the dropped variable to 0.

As shown in figure below, a simple application of TS may be initiated with a *candidate list*, then candidates are processed through the *moves*, and finally *noting the objective function values,* after certain number of iterations the *best value* may be taken as the solution.



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