A MIXED LINEAR INTEGER MODEL FOR MILITARY FACILITY LAYOUT OPTIMIZATION PROBLEM

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

HÜSEYİN BAHADIR ECE

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
CIVIL ENGINEERING

JUNE 2015

Approval of the thesis:

A MIXED LINEAR INTEGER MODEL FOR MILITARY FACILITY LAYOUT OPTIMIZATION PROBLEM

submitted by **HÜSEYİN BAHADIR ECE** in partial fulfillment of the requirements for the degree of **Master of Science in Civil Engineering Department, Middle East Technical University** by,

Prof. Dr. Gülbin Dural Ünver _______________
Dean, Graduate School of **Natural and Applied Sciences**

Prof. Dr. Ahmet Cevdet Yalçıner _______________
Head of Department, **Civil Engineering**

Assoc. Prof. Dr. Rıfat Sönmez _______________
Supervisor, **Civil Engineering Dept., METU**

Asst. Prof. Dr. S.Tankut ATAN _______________
Co-Supervisor, **Industrial Engineering Dept., Işık University**

Examining Committee Members:

Assoc. Prof. Dr. Ali Murat Tanyer _______________
Architecture Dept., METU

Assoc. Prof. Dr. Rıfat Sönmez _______________
Civil Engineering Dept., METU

Asst. Prof. Dr. S.Tankut Atan _______________
Industrial Engineering Dept., Işık University

Assoc. Prof. Dr. Mehmet Kabak _______________
Industrial Engineering Dept., Gazi University

Asst. Prof. Dr. Aslı Akçamete Güngör _______________
Civil Engineering Dept., METU

Date: 30/06/2015

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last name : H.Bahadır ECE

Signature :

ABSTRACT

A MIXED LINEAR INTEGER MODEL FOR MILITARY FACILITY LAYOUT OPTIMIZATION PROBLEM

Ece, Hüseyin Bahadır
M.S., Department of Civil Engineering
Supervisor : Assoc. Prof. Dr. Rıfat Sönmez
Co-Supervisor : Asst. Prof. Dr. S.Tankut Atan

June 2015, 122 pages

The positioning and layout of facilities on a construction site has a significant impact on productivity, costs, and duration of construction projects. The main objective of general construction site layout planning problem is to arrange the temporary facilities such as office buildings, residences, and warehouse in such a way that the construction activities can be performed with minimal costs. The military facility layout planning problem which considers layout of military facilities is similar to the construction site layout problem.

This thesis presents a military facility layout model to optimize the distances that are frequently used both by military personnel and vehicles in their daily activities. Daily activities of military troops require continuous displacement according to the schedules in military terrain. Therefore, the model has been developed by considering the movement costs of the vehicles along with the distances travelled by the personnel. Moreover, the model established here considers vehicle types, vehicle and personnel quantities according to facility characters as well as distances between facilities and possible stations travelled on a monthly basis. Alternative zones for some stations have been included in the model to find the best placement for facilities and stations. Within this context, a mixed linear integer model is presented for the military facility layout problem. Then, the developed mixed integer formulation was solved by using AIMMS ver. 4.2. The results were compared with an already existing military facility layout planning method and advantages of the proposed model were discussed.

Keywords: Facility Layout, Layout Optimization, Mixed Linear Integer Model

ÖZ

ASKERİ TESİS YERLEŞİM OPTİMİZASYON PROBLEMİ İÇİN KARIŞIK BİR TAMSAYILI PROGRAMLAMA MODELİ

Ece, Hüseyin Bahadır
Yüksek Lisans, İnşaat Mühendisliği Bölümü
Tez Yöneticisi : Doç. Dr. Rıfat Sönmez
Ortak Tez Yöneticisi : Yrd. Doç. Dr. S.Tankut Atan

Haziran 2015, 122 sayfa

Şantiye tesislerinin yerleşimi ve düzeni, inşaat projelerinin verimliliği, maliyeti ve süresi açısından önemli bir etkiye sahiptir. Şantiye yerleşim problemlerinin genel olarak esas amacı, ofis binaları, konutlar ve depo gibi geçici tesislerinin yerlerini inşaat faaliyetlerini asgari maliyetle yapabilmek için düzenlemektir. Askeri tesislerin yerleşimini gerektiren askeri tesis planlama problemi de şantiye tesislerinin yerleşim problemi ile benzerdir.

Bu tez, hem askeri personel hem de askeri araçlar tarafından günlük aktivitelerde sıklıkla kullanılan mesafelerin optimizasyonu için uygun bir askeri tesis yerleşim modeli sunmaktadır. Askeri birliklerde günlük aktiviteler, mevcut programlara göre arazide sürekli bir yer değiştirmeyi gerektirir. Bu nedenle model, araçların yer değiştirme giderleri ile birlikte personelin yaptığı mesafeler düşünülerek oluşturulmuştur. Dahası, kurulan model, tesisler ile muhtemel istasyonlar arasındaki aylık bazda katedilen mesafelerin yanı sıra, tesis karakterlerine göre araç tipleri ile araç ve personel miktarlarını göz önünde bulundurmaktadır. Tesisler ve istasyonlar için en iyi yerleşim şeklini bulmak maksadıyla, bazı istasyonlara ait alternatif bölgeler modele dahil edilmiştir. Bu kapsamda, askeri tesis yerleşim problemi için karışık bir doğrusal tamsayılı model sunulmuştur. Devamında, oluşturulan karışık tamsayılı formül, AIMMS 4.2 versiyonu ile çözülmüştür. Alınan sonuçlar, hali hazırda bulunan askeri tesis yerleşim planı ile karşılaştırılmış ve sunulan modelin avantajları ele alınmıştır.

Anahtar Kelimeler: Tesis Yerleşimi, Yerleşim Optimizasyonu, Karışık Tamsayılı Doğrusal Model

To My Beloved Wife

ACKNOWLEDGEMENTS

First of all, being a member of Turkish Armed Forces, I would like to extend my gratitude to Land Forces Command, for giving me the opportunity to do this work.

I would like to give my deepest thanks to my supervisor Assoc. Prof. Dr. Rıfat SÖNMEZ, who has guided and encouraged me throughout this thesis as well as appreciating my studies during research and model developing procedure with his valuable advice and judgment.

I am grateful to Asst. Prof. Dr. S.Tankut ATAN for his instructions and experience on my thesis as well as his kind help in the model development process.

I would like to thank to Staff Lieut. Col. Nuri BÜYÜKYAZICI in project management department of General Staff, for his comments, directions, military experience and kind help in data collecting process for this study.

I am also grateful to Construction Engineering and Management division research assistant Saman AMINBAKHSH, for his great patience and assigning his computer whenever I needed throughout my computational trials.

I also want to express my special thanks to my source of life and beloved wife Begüm ECE, for her endless love and emotional support.

TABLE OF CONTENTS

LIST OF TABLES

TABLES

LIST OF FIGURES

FIGURES

LIST OF ABBREVIATIONS

ACO	Ant Colony Optimization
ADP	Approximate Dynamic Programming
AHP	Analytic Hierarchy Process
AIMMS	Advanced Integrated Multidimensional Modeling Software
APC	Armoured Personnel Carrier
ALDEP	Automated Layout Design Program
COFAD	Computerized Facilities Design
CORELAP	Computerized Relationship Layout Planning
CRAFT	Computerized Relative Allocation of Facilities Technique
DISCON	Dispersion Concentration
ELECTRE	Elimination and Choice Translating Reality English
ESS	Explosives Safety Siting
FLP	Facility Layout Problem
GA	Genetic Algorithm
GP	Goal Programming
km	Kilometer
LOGIC	Layout Optimization Using Guillotine-Induced Cuts
m	Meter
MIP	Mixed Integer Programming
MULTIPLE	Multi-Floor Plant Layout Evaluation
NP	Non-deterministic Polynomial-time
QAP	Quadratic Assignment Problem
RAMOS	Resource Allocation Model Over Space
SHAPE	Selection of Materials Handling Equipment and Area Placement Evaluation
TL	Turkish Lira
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
4DSMM	4D Site Management Model
4D-ISPS	4D Integrated Site Planning System
4D-MCPRU	4D Management for Construction Planning and Resource Utilization

CHAPTER 1

INTRODUCTION

Facilities can be described as buildings, producing a commodity with material and machines like warehouses or providing services. In order to manage them appropriately and according to system's objectives, they need to be placed with a convenient planning, that leads to important decision processes defined as facility layout problems (FLP). FLPs are studied with the name of facility layout, location or design problems since 1950s, but Heragu (2008) states that the ideas considering facility planning goes to 4000 BC. According to Heragu, the location of pyramids was studied by Egyptians with astrological calculations and some drawings used to construct Coliseum by Romans. After the introduction of operational research as a field in 1950s, quadratic assignment problem (QAP) was proposed by Koopmans and Beckman (1957) and large size location and layout problems have been started to be searched and developed by software applications (Heragu, 2008).

In literature, facility layout problem is acknowledged as one of the most studied and challenging field of manufacturing systems, including varied cost and distance indices in content. The aim of the facility layout problem is to place specific facilities to particular locations with the best manner that maximum benefit according to need will be reached throughout the life cycle of the system. The location plan can involve not only the facilities but also the departments such as work stations, fabrication shops and machines. It should be noted that, the decisions taken by these kind of problems, are the ones both with high cost and long term strategic importance, because properly managed facilities can satisfy the needs of the system. Therefore, objectives need to be identified appropriately and problem formulation and model selection should be evaluated accordingly. The layout plan can consist facilities to a plant area or machine or material distribution inside a facility as stated above. Thus, FLPs are generally addressed in manufacturing systems with the objection of optimizing material handling expenses or distances.

In the construction industry, facility layout problem takes part in many areas, one of which is site layout optimization. Especially, considering large size project sites, like dams, petrochemical plants and underground projects, location of facilities has a large impact on the duration of the construction and several costs related. Besides, construction site layout affects operational efficiency and the quality of construction. For this reason, inappropriate layouts can cause low productivity depending on distances used by labors, machines and equipment, which also arises safety deficiencies. Although construction sites built temporarily, their layout optimization problem should be performed with a decision making process, which includes a lot of decision variables and constraints. The constraints may appear because of site topography, location of permanent facilities and even legal obligations. Hence, the aim of the site layout problems are commonly to optimize either cost or distances as well as promoting productivity, decreasing project duration, improving job satisfaction by safety regulations and employee needs, that all are subject to the project itself or to the decision maker. These objectives usually conflict with each other that make the problem more complex.

The main objective of military units on the other hand, is to train the troops in accordance with daily schedules containing many activities inside. In order to achieve this objective, facility layout planning should streamline the flow of operations executed by military units, increase the effectiveness and minimize cost as much as possible.

In this study, in order to illustrate common world armies, a set of particular facilities is selected from a brigade level military unit and a location model with proper constraints is presented using mixed integer linear programming method. The model assigns selected facilities to locations as well as stations, located outside the facility area, to possible positions at the same time. Besides, model has facility group constraints that should be assigned together as well as adjacency relationships.

For the model developed, twenty main facilities and twenty locations for military facilities have been determined in the brigade area to illustrate the model and to obtain an exact solution for the problem. Most of the personnel and vehicles of the brigade do not stay in one location but travel between these facilities all day. Military facilities can vary from military vehicle garages, depots, headquarters buildings belonging to battalions or companies, to maintenance shops, helipads, boiler houses, dormitories, sports centers etc. Facility features, personnel numbers, vehicle types and quantities have been taken into consideration while defining unit costs to optimize in the problem eventually. Moreover, frequently used routes and stations have been identified according to daily activities and included in the problem. Thus, not only twenty facilities have been assigned, but also five stations have been assigned to the best options from eight possible positions. The model is solved with an optimization software and finally, the results of the model are discussed.

Subjects presented in this thesis are as follows: Chapter 2 starts with an extensive review of literature about facility layout problems, their classification, and continues with their types, FLP models and resolution approaches. Chapter 3 presents construction site layout problem types and related approaches. Chapter 4 includes the developed military facility layout problem model, the results of the problem and the model comparison. Finally, Chapter 5 ends with the conclusions, advantages of the model and future work.

CHAPTER 2

FACILITY LAYOUT PROBLEMS

Facility layout problem (FLP) is about locating facilities to appropriate locations in a plant area. FLP has a serious effect upon work in process, productivity, lead times and manufacturing and transportation costs (Drira et. al, 2007). Tompkins et al. (1996), suggested that a good location of facilities can save up to 50% of total operating expenses. Tompkins and White(1984) indicated that 8% of United States (US) gross national product has been spent on establishing new facilities apart from modifications. Additionally, 20-50% of the total operating expenses are referred as material handling costs and efficient facility layout planning could decrease this amount to 10-30% annually (Francis and White, 1974) (Tompkins et al., 2010). Tompkins et al. (1996) also add that by the application of effective facilities planning, annual manufacturing productivity of US could triple any last fifteen years values. Furthermore, they indicate that the effect of facility planning is much bigger on distribution operations with proper order picking systems and equipment (2010). Garey and Johnson (1979) expressed FLP to be known as complex and generally NP-Hard. Thus, vast amount of analysis has been carried out in the field of FLP. Singh and Sharma (2006) depict that facility layout research is an active area with 140 published papers in last 20 years.

2.1. Definition, Objectives and Classification of Facility Layout Problems

Singh and Sharma (2006) define facility layout problem as determining the physical organization of a production system. Drira et al. (2007), describe facility as an entity that facilitates the performance of any job, facility layout as an arrangement of everything needed for production of goods or delivery services and FLP as the placement of the facilities, departments or machines etc. in the plant area. According to them, FLP do not have an accepted and exact definition among researchers as a result of varied considerations.

The largest amount of formulations seen in the literature is static type of layout problems. This class of problems was first introduced by Koopmans and Beckmann in 1957. They described FLPs as a common industrial problem which helps to arrange facilities in order to minimize the cost of transporting materials between them. On the other hand, Meller et al. (1999), considered FLP to find a non-overlapping planar orthogonal adjustment of n rectangular shaped facilities in a rectangular site area for the sake of minimizing distance based measure. Azadivar and Wang (2000) characterized the FLP as deciding relative locations and allocations for some particular facilities in a certain area. Another definition made by Lee and Lee (2002) explains arrangement of n unequal-area for facilities with distinct sizes within a space dimensioned as a site area so as to decrease total material handling cost as well as slack area cost. FLP is also illustrated as an optimization problem which considers not only the interactions between facilities and also the material handling systems at the stage of designing layouts (Shayan and Chittilappilly, 2004).

Mainly, FLP is described as a combinatorial optimization problem that originates in a variety of layout designs and mostly finds place in manufacturing industrial plants in order to lessen material handling costs and improve productivity. Sule (2008) pointed out that, optimization of the facility layout is not enough for facility planners since material handling procedures, equipment and systems also play an important role in facility design. Data processing and information systems are also actors in manufacturing systems. Likewise, facilities planning is a context about supply chain management. According to Tompkins et al.(2010), supply chain includes customer as a final but very important internal element in the business environment. They pointed out that, customer satisfaction and profits gained from them is ignored especially in the last years by different public and company services. So they developed below objectives for facility planning (2010):

- Improving customer satisfaction and responding their needs quickly,
- Increasing return on assets by maximizing employee participation, continuous improvement, inventory turns and minimizing out-of-date inventory,
- Reducing costs and increasing supply chain profitability,
- Integrating supply chain through communications and partnerships,
- Improving material handling control and system,
- Utilizing equipment, personnel, space and energy effectively,
- Maximizing return on investment,
- Promotion and adaptation of maintenance,
- Providing employee safety, satisfaction, energy efficiency and environmental responsibility,
- Assuring sustainability and flexibility.

It is an important fact that, all of the objectives above cannot be reached simultaneously. Thus, an adjusted balance among them should be decided and implemented by the organizations. Heragu (2008) defined physical arrangement of departments to particular locations and stated the factors below to consider while developing the layout:

- Reducing congestion for continuous flow of people and material,
- Employing space efficiently,
- Establishing communication and supervision
- Ensuring safe environment conditions for personnel

It should also be remembered that, any facility planning is not superior than the other since every layout can handle different performance challenges and they should be evaluated carefully with appropriate criteria. Because facility layout design is a multi-effective decision which has reactions on multi-dimensional strategic determinations.

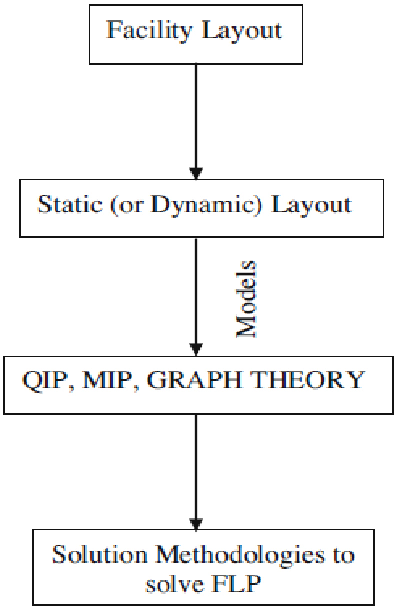

Figure 2.1 : Classification Scheme of FLPs

In facility layout literature, one can find numerous articles consisting different classifications depending on the works addressed in papers. FLP can be seen as the design of the facilities under facilities planning apart from the facilities location problem, which consists searching appropriate location to open a facility in order to serve to a set of demand points.

Singh and Sharma (2006) summarized classification scheme basically as shown in Fig. 2.1. On the other hand, in order to give a broad aspect, Drira et al. (2007) proposed a more detailed tree representation classification (Fig. 2.2) considering important features of the facility layout problems. Thus, they developed a helpful research tool in order to characterize existing works.

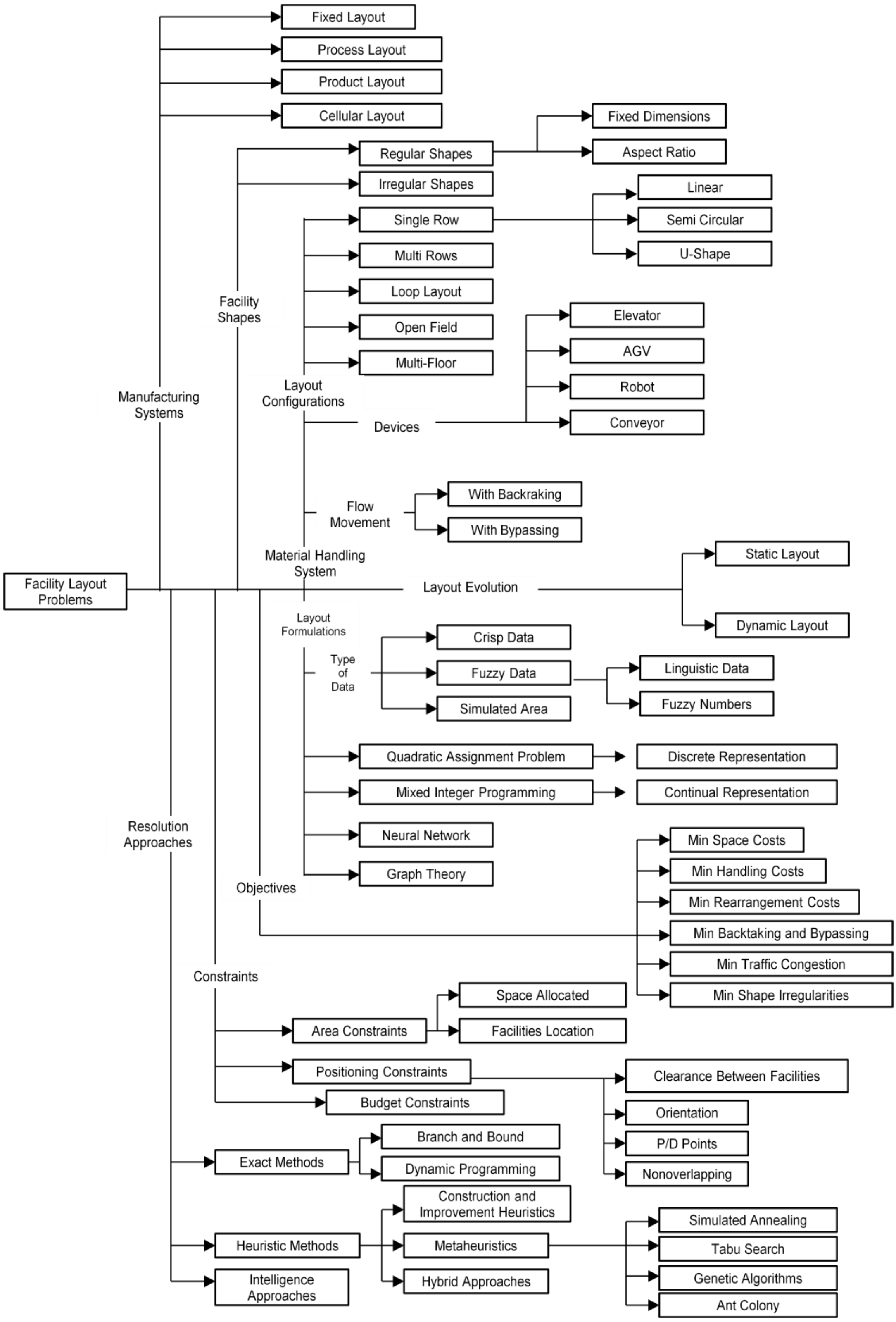

Figure 2.2 : Tree Representation of FLPs

Meller and Gau (1996) studied ten years trends in facility layout area. They described FLP research scheme in three categories seen below. In part "A", they gathered studies about algorithms as also mentioned by Kusiak and Heragu (1987). Later part extends the problem to such an area that consists some factors like time element (dynamic layout), uncertainty (stochastic layout) and multi-criteria layout. In the last part they brought together a thorough inspection about integrated manufacturing systems like flow-lines, machine and cellular layouts. Moreover, they also remark that some of the titles can be divided into analogous sections according to researchers since there is not a dominant classification category (Meller and Gau, 1996).

A. Facility Layout Models and Heuristics for Block Layout

1.Model

a. QAP-based

b. Graph-theoretic

c. Mixed-integer programming

2. Heuristic

a. QAP-based

b. Graph-theoretic

c. Mixed-integer programming

d. QAP-only (equal-area departments only)

B. Facility Layout Model Extensions

1. Dynamic Layout

a. Model

b. Heuristic

2. Stochastic Layout

a. Model

b. Heuristic

3. Multi-criteria, Robust and Flexible Layout
    a. Model
    b. Heuristic

C. Special Cases
1. Flow-lines, Row and Loop Layout
    a. Model
    b. Heuristic
2. Machine Layout
    a. Model
    b. Heuristic
3. Cellular Layout
    a. Model
    b. Heuristic

2.2. Types of FLP

According to Drira et al. (2007), there are several workshops for FLP studied in the literature many of which deals with particular aspects of manufacturing systems. The essence of the problem change pursuant to several factors and issues related to design such as: material flow parts, number of floors, material handling system, amount and diversity of products, facility body etc.

The classification of these factors are detailed according to their significance by Drira et al. (2007) below:

- Products variety and volume
- Facility shapes and dimensions
- Material handling systems
- Multi-floor layout
- Backtracking and bypassing
- Pick-up and drop-off locations

2.2.1. Products Variety and Volume

The design of the facility layout commonly affected by the production volume and the products diversity (Drira et al., 2007). According to Dilworth (1996), there are four types of organizations cited differently by the authors in the current articles which are: fixed product layout, process layout, product layout and cellular layout.

In fixed product layout, different resources move to products to execute operations on them. As a result, the product that is spread into the production facility, machine or workers, does not move. The examples of this kind of layouts are ship or aircraft manufacturing industries. In process layout type, facilities with similar features, such as same type of resources, are grouped. This kind of layout is recommended when there is a wide divergence in product type. The systems with huge amount of production and small divergence in product type uses product layout. In product layout systems facilities are arranged according to the flow of the succeeding manufacturing operations. In cellular layout, there are cells in which some machines are grouped. There may be a necessity to locate cells on the factory floor. The reason to group these machines in a cell is to process the operation for a department of similar parts. Hamann and Vernadat (1992), interpreted intra cells machine layout problem for these kind of layouts. The main idea is to search the best settlement of machines placed in each cell (Drira et al., 2007). In this area, Tavakkoli-Moghaddam et al. (2007) formulated a mathematical model for cellular manufacturing systems to optimize cost for material movement inside and between cells.

2.2.2. Facility Shapes and Dimensions

For Drira et al., generally there are two distinct shapes of facilities (2007) (Fig. 2.3). Regular ones that are usually rectangular (Kim and Kim, 2000) and irregular ones that are usually polygons, including $270°$ angle (Lee and Kim, 2000). According to Chwif et al. (1998), a facility can be named as fixed or rigid block essential to have dimensions defined with a fixed length (L_i) and a fixed width (W_i). Additionally, they explain the same facility with different parameters. These are, its aspect ratio "$a_i = L_i/W_i$" which is also used by Meller et al. (1999), and an upper bound "a_{iu}" and a lower bound "a_{il}" with the constraint $a_{il} < a_i < a_{iu}$. Relevant to subject, Chwif et al. (1998) specifies fixed shape blocks case in the event of $a_i < a_{il} < a_{iu}$.

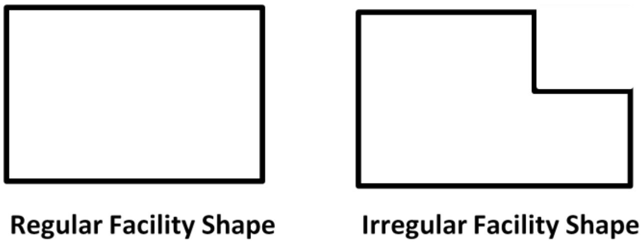

Figure 2.3 : Regular and Irregular Facility Shapes

2.2.3. Material Handling Systems

Material handling system deals with the distribution of a material from one place to another. This process is a continuous one as well as consisting different parameters and elements. El-Baz (2004) states material handling equipment as conveyors, robots, automated guided vehicles etc. Sule (2008) propose that 30-75% of a products cost constitute material handling expenses within manufacturing sector. On the other hand, Tompkins and White (1984), Francis and White (1974) and Tompkins et al. (2010) state that 20-50% of total operating expenses are referred to material handling expenses and convenient facilities planning can decrease these costs to 10-30%.

The main and significant problem within a material handling system, lies on the placement of the facilities for the path of material handling. Picking the right handling equipment and assigning the appropriate facility layout gathers two problems (Drira et al., 2007). Material handling device type plays an important role while selecting the locations of machines (Devise and Pierreval, 2000). Likewise Co et al. (1989) proposed that the facility layout has an impact on the decision of handling equipment. Since solving the problem together is painful, Hassan (1994) considered to deal with them continuously. The most used layout settlements, according to material handling system, can be single row layout, multi-rows layout, loop layout and open-field layout (Yang et al., 2005).

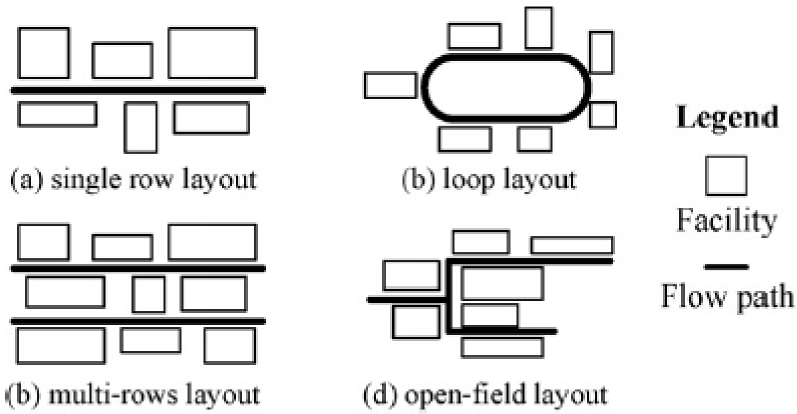

Figure 2.4 : Layout Design Considering Material Handling Devices

As it is seen in Fig. 2.4, single row layout is considered when facilities need to be placed throughout a line (Kim et al., 1996). It is a NP-hard problem that arranges n departments with specific lengths on a single line to minimize distances between departments (Amaral, 2006) (Amaral, 2009). This is the basic type that other designs, like straight line, semi circular or U-shape, can be created (Hassan, 1994). The loop layout problem is about locating the facilities in a circular way in which materials transported in one direction (Cheng and Gen, 1998). In this type of problem there are m facilities and m possible locations. When facilities gather on more than one row, this shape forms multi-row layout (Hassan, 1994). The transportation of materials occurs between both same and different rows. If there is not any restraint about locating as single or loop layout then open field layout can be managed (Yang et al., 2005).

2.2.4. Multi-Floor Layout

Land supply is an important element in the process of construction and facility location. As Drira et al. (2007) stated, it is usually seen as a costly and inadequate subject. Since horizontal space is limited, firms tend to use vertical dimensions of the site. So this helps to place more facilities on different floors. By this way, some parts can be transported in the same floor as well as different floors at different levels by the help of elevators. Therefore, unique assignments of facilities for each floor and levels need to be evaluated. This kind of problems leads to multi-floor layout problems (Kochhar and Heragu, 1998).

Multiple-floor layout problem can be said to be used first by Johnson in 1982. He tried to constitute analogous locations for facilities in a multiple-floor construction. After him, other practitioners also studied vertical transportation of materials between different levels (Meller and Bozer, 1996) (Meller and Bozer, 1997). Elevators are usually used as a vehicle for material handling system (Lee et al., 2005). The position of the elevators and their numbers are also defined by an optimization process or noted before (Lee et al., 2005, Matsuzaki et al., 1999). In the study of Matzusaki et al. (1999), the capacity of the elevators is regarded as a constraint. Like the elevators, in their research, Patsiatzis and Papageorgiou (2002) determined floor numbers according to their areas, besides calculating the size and number of the facilities.

2.3. Static and Dynamic Layout Problems

As it is mentioned before distinctive features of facilities have a great effect on the design of the layout. Besides that, manufacturing workshops have to deal with growing and changing circumstances, demand conditions, production amounts and varieties. Page (1991) stated that, new products constitute 40% of a company's sales on average. Nevertheless, alterations in product variety lead to change the production flow and this fact affects facility layout as a result. As Gupta and Seifoddini (1990) reported, in every 2 years, one third of USA firms go through reorganization for the facilities of production. As a consequence, many researchers have considered this fact when they design the layout. Most of the articles in the literature about layout problems are formulated as static problems that mean the workshop will continue to produce same product for a long period. With respect to this fact, nowadays, dynamic layout problems are being considered by many of authors (Drira et al.,2007). According to the papers of Balakrishnan et al. (2003), Braglia et al. (2003), and Meng et al. (2004), these kind of problems deal with potential alterations in the material handling flow through numerous periods. For this reason, planning period is usually divided into stages as weeks, months or years. For each stage, flow data is considered to be stable. Briefly, dynamic layout problem includes different facility layouts which are specific for different time periods. For Baykasoglu et al. (2006), the objective of dynamic layout problems is to create a layout for each period while decreasing the total material handling cost as well as minimizing total rearrangement expenses for all periods. Additional to this statement, Baykasoglu and Gindy (2001) proposed that, rearrangement costs should be taken into account when there is a need for facilities to be removed between locations.

2.4. FLP Models

Facility layout problems are mostly modeled as QAP, MIP or graph theory model in literature. These terms are described in the following sections.

2.4.1. Quadratic Assignment Problem

QAP is the first formulation for FLPs introduced by Koopmans and Beckman (1957) and widely used since then. It is a NP-complete problem that is hard to solve as well as being a classical combinatorial optimization problem (Garey and Johnson, 1979). Non-deterministic polynomial-time hard (NP-hard) problems cover NP-complete problems and they require hard polynomial algorithms to be solved in polynomial times. This can be deducted as, solution time increases with the size of the problem. The objective of QAP can be to minimize cost, distance between facilities, time or flows. Singh and Sharma (2006) states that, a large size problem cannot be handled even by a powerful computer. According to Kettani and Oral (1993), only the problems including less than 18 departments have optimal solutions. Moreover, Burkard et al. (2009) pointed out that the largest benchmark example for QAP with an optimal solution has been developed with the size $n \approx 30$. Therefore, formulating sophisticated problems with QAP led practitioners to heuristic solutions in order to find near optimal solutions or good suboptimal ones.

Meller and Gau (1996) pointed out that, problems modeled by QAP are special since all facilities have equal areas and assigned locations are fixed. However, Kusiak and Heragu (1987) proposed dividing departments into small ones with same grid sizes and assigning artificial material flows between grids within a specific department in order to bring them together in the optimized solution. Koopmans and Beckman formulated objective function of QAP as follows (1957):

$$\text{Min TF} = \frac{1}{2} \cdot \sum_{\substack{i=1 \\ i \neq k}}^{n} \sum_{\substack{j=1 \\ j \neq l}}^{n} \sum_{k=1}^{n} \sum_{l=1}^{n} F_{ik} \cdot D_{jl} \cdot X_{ij} \cdot X_{kl} \tag{2.1}$$

Subject to:

$$\sum_{j=1}^{n} X_{ij} = 1 \; for \; all \; i = 1 \dots n \tag{2.2}$$

$$\sum_{i=1}^{n} X_{ij} = 1 \; for \; all \; j = 1 \dots n \tag{2.3}$$

$$X_{ij} = \begin{cases} 1, if\ facility\ i\ is\ assigned\ to\ location\ j \\ 0, if\ facility\ i\ is\ not\ assigned\ to\ location\ j \end{cases} \tag{2.4}$$

where $F_{ik} = Flow\ between\ facilities\ i\ and\ k$

$D_{jl} = Distance\ between\ locations\ j\ and\ l.$

Constraints (2.2) and (2.3) provide that only one facility can be placed at one location and each location will be allocated one facility. Objective function (2.1) minimizes distances traveled by total flow. Singh and Sharma (2006) multiplied solution by "1/2" since the indices from 1 to n will be summed and assignments will be counted twice.

Burkard et al. (2009) also includes the cost of placing facilities to a certain site to equation (2.1) and reformulates it with same constraints as:

$$\min \sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{k=1}^{n}\sum_{l=1}^{n} F_{ik} . D_{jl} . x_{ij} . x_{kl} + \sum_{i=1}^{n}\sum_{j=1}^{n} c_{ij} . x_{ij} \tag{2.5}$$

where; $c_{ij} = Cost\ of\ placing\ facility\ i\ at\ location\ j.$

Tate and Smith (1995) defined QAP developing a particular cost while assigning two specific departments simultaneously. This cost is regarded as a function of locating facility *i* to site *j* and facility *k* to site *l* as well as considering interaction between facilities or departments. Besides they describe QAP as a nonlinear assignment problem and associate with heuristic to achieve good solutions. In their research GA based heuristic approach is used for QAP. Loiola et al. (2007) explained QAP as being one of the most challenging combinatorial optimization problems, and stated that for more than 30 facility sized problems, solution times were unreasonable. In their paper, they studied widely used formulation types of QAPs and presented adopted solutions. Burkard (2008) also gave a comprehensive knowledge about QAP, supporting with many applications.

2.4.2. Graph Theory

In this model, each department or structure is defined as a node within a graph network neglecting their shape or size constraints. After the nodes are defined, pair-wise relations are decided and a desirable adjacency, which is known the beginning, between pairs of these departments are created (Foulds, 1991). Hassan and Hogg (1989) developed three steps to formulate a FLP with graph theory approach: defining adjacency relations with a graph, representing departments with their adjacent pairs as particular regions and specifying them with particular shapes and areas. Meller and Gau (1996) stated that, graph theory objective function is maximized, if the pair-wise departments, with positive material flows, have an arc between each other, but still, like QAP models, unequal area problems cannot have optimal solutions within this approach.

2.4.3. Mixed Integer Programming

Mixed Integer/Linear Programming (MIP/MILP) modeling is another way of modeling facility layout problems. If all or some of the decision variables at the optimal solution are compelled to be integer values with linear formed constraints then it can be defined as MIP problem. Montreuil formulated MIP for a FLP at a material handling research conference in 1990 (Meller and Gau, 1996). He used a distance-based objective with his problem in a continuous layout, which differs from traditional discrete QAP. In another words, he extended discrete QAP using distance-based objective in a continuous plane and considered rectilinear distances between centers of two departments (Montreuil, 1990). On the other hand, Meller and Gau

(1996) state that although Montreuil's approach is powerful and compelling, it can only deal with problems with six or less departments.

Heragu and Kusiak (1991) specialized Monteruil's MIP adding dimensions and orientations for the departments. Lacksonen (1994) defined a two-step algorithm for a dynamic facility layout with the acceptance that all department areas are rectangular. Furthermore, he developed a model to solve problems with unequal areas and rearrangement costs (Lacksonen, 1997). But he added that his model was appropriate for only small problems. In order to minimize total transportation distance, Kim and Kim (1999) proposed placing input and output points for each department in the plant area which is a block layout. However, according to Singh and Sharma (2006), simultaneous optimization of block layout and input-output points layout problems have not been specified yet. Konak et al. (2006) developed an exact approach build on a flexible bay structure (FBS), that locates departments parallel to each other with different areas to represent them in a continuous layout and claimed that his approach was the first with an optimal solution.

2.5. Formulation of FLPs

There are different and many approaches to formulate layout problems mathematically according to their static or dynamic characteristics. Drira et al. (2007) suggest that the formulation of the model as static or dynamic, relies on the complicated relationships of elements included in the problem. Therefore, some researchers like Kim and Kim (1995) included graph theory while others like Tsuchiya et al. (1996) used neural networks. The aim of all studies is to propose different solutions to the FLPs, also stated as optimization problems. The solutions can include single or multiple objectives. Even though the types change as discrete or continuous, most of the formulations in the literature takes us to the most used ones called Quadratic Assignment Problems known as "QAP" and Mixed Integer Programming known as "MIP". Few researchers suggest that, even in both cases, fuzzy formulations can be used in the event of not having convenient data (Drira et al., 2007).

2.5.1. Discrete Formulation

If the plane of the facility that is going to be located is discrete, then the problem regarding this case is mostly formulated as QAP. Fruggiero et al. (2006) formulated this area by dividing it into same sized rectangular shapes, also called as blocks, for each facility. In the case that facilities do not have same dimensions they can fill distinctive blocks (Wang et al., 2005). Balakrishnan et al. (2003) used the same typical formulation, as stated in QAP section, in order to minimize the total handling cost while locating facilities.

Braglia (1996) used discrete formulation to decrease backtrack operations in single type row layouts. Besides, Afentakis (1989) designed a loop layout with the same idea in order to decrease traffic congestion. He tried to minimize the travel times, before all operations regarding a part are fulfilled. On the other hand for Cheng et al. (1996), there are two types of congestions measures usually used in loop layout problems: "Min-Sum" which minimizes total congestion for all materials and "Min-Max" which minimizes the maximum congestion for a family of parts.

Discrete formulation of layout problems is generally preferred by dynamic layout problems. According to Lacksonen and Enscore (1993), these problems use facilities with equal size. Additionally, the use of constraints to locate one facility to one location like above is a must (Baykasoglu and Gindy, 2001). As Balakrishnan et al. (1992) pointed out, budget conditions can also be added as constraints with respect to not exceed a particular level. Some researchers like Lacksonen (1997) explained that discrete formulations can be adequate in some situations like representing the definite location of facilities or modeling constraints regarding the orientation or clearance between them. So these cases lead most authors to investigate continuous representations for layout problems.

2.5.2. Continuous Formulation

There are several articles in the literature using continuous formulation which is mostly thought as Mixed Integer Programming (Das, 1993). However Drira et al. (2007) describe continuous representation used dynamic layout problems are not much. Meller et al. (1999) and Das (1993) stated that facilities that will be located do not overlap each other in the plain area in continuous formulation.

According to Chwif et al. (1998), facilities are located with two ways in the site area. In order to define coordinates of the facilities, either center of the facility or bottom left corner can be used, which are described by "x_i" and "y_i". After that, they made the expression below to identify the rectilinear distance between two facilities:

$$d_{ij}\left((x_i, y_i), (x_j, y_j)\right) = |x_i - x_j| + |y_i - y_j| \tag{2.6}$$

Drira et al. (2007) expressed that total facility areas may be equal or less than the plant area. This time the constraints regarding areas should be considered. Additionally, Lacksonen (1997) pointed out that the area for a machine should also include such spaces for the resources of that machine or material. Adding the spaces between facilities to the facility surface is also feasible (Heragu and Kusiak, 1991).

There are also some constraints about overlapping conditions that many papers include. Two constraints were used by Welgama and Gibson (1993), beneficial to overlap conditions. These constraints help to locate facilities without overlapping (Welgama and Gibson, 1993):

$$(x_{jt} - x_{ib})(x_{jb} - x_{it}) \geq 0 \tag{2.7}$$

$$(y_{jt} - y_{ib})(y_{jb} - y_{it}) \geq 0 \tag{2.8}$$

(x_{it}, y_{it}) and (x_{jt}, y_{jt}) = top left corner coordinates of facility *i* and *j*

(x_{ib}, y_{ib}) and (x_{jb}, y_{jb}) = bottom right corner coordinates of the same facilities

2.5.3. Fuzzy Formulation

Data required for layout problems can be insufficient in most of the cases. As mentioned by Meng et al. (2004), stochastic approaches are not widely encountered. Some researchers like Evans et al. (1987) and Grobelny (1987) proposed fuzzy approaches in order to cope with the uncertainties and deceptions seen usually. However according to Drira et al. (2007) there are not many researches on fuzzy logic about layout design.

Location of unequal sized facilities to the planned site is mentioned by Evans et al. (1987). The relationships between each group of facilities are formulated by fuzzy variables with which they expressed importance and closeness. According to them, by the help of these relations, researcher can determine importance for every couple of facilities placed with different distances at the plain area. Besides that, they modeled a fuzzy formulation and heuristic algorithm for the solution. On the other hand, Grobelny (1987) studied to place n facilities to n constant locations so that material handling cost can be reduced. Again, some parameters like traffic situation and closeness of facilities which affect layout design are formulated with fuzzy approaches. These approaches led to heuristic procedures so as to place selected facilities to appropriate locations by using binary fuzzy variables. By this way, Raoot and Rakshit (1991) considered inter-relationships of facilities with the help of linguistic variables so that they can arrange the layout of facilities in the plant. When clearance cannot be well defined like the study of Gen et al. (1995), involving optimization of multi-row layout with unequal areas, fuzzy considerations are taken into account. Likewise, Dweiri and Meier (1996) used the slack areas between facilities, flow of data and amount of material handling accessories as fuzzy implications in their discrete layout problem. Moreover, they established a system called ARC (Activity Relationship Chart), which is attached to popular heuristic 'CORELAP' afterwards, by the help of experts about the relationships among pair wise facilities to find the best arrangement. On the other hand, Aiello and Enea (2001) defined market demand for products with fuzzy numbers since they are not clear. Again, they tried to decrease total material handling cost of a single row layout with the production capacity constraints for each unit. Additionally, fuzzy demands are divided and calculated for every potential layout by them. Arrangement of facilities having pick-up and drop off points in a continuous plane, with the same aim of minimizing material handling cost, is studied by Deb and Bhattacharyya (2005).

According to authors, some of the elements affecting facility location are personnel relationships, environmental and supervision relationships and personnel flow which are formulated by linguistic variables. Some of them created IF-THEN type rules for fuzzy decision support systems which led using a construction heuristic to define best solution for locating facilities in a site area (Drira et al., 2007).

2.5.4. Multi-Objective FLPs

Many of the articles consider to optimize only one part of the related layout problem such as; material handling cost, distance between facilities and departments or time for this travel. However, some analysts preferred to deal with more than one objective to be more reasonable. To illustrate, in their study at 1996, Dweiri and Meier tried to decrease material handling while minimizing equipment and information flow. In order to associate various objectives and define as a single one, some researchers used the methodology of AHP (Analytic Hierarchy Process) (Yang and Kuo, 2003) while others proposed linear combinations for different objectives (Chen and Sha, 2005).

Hadi-Vencheh and Mohamadghasemi (2013) developed a nonlinear programming model combining with a multi attribute decision making process, AHP, with the aim of incorporating qualitative and quantitative criteria for facility layout problems. Quantitative factors like material handling distance and size ratio were obtained by Spiral, a commercial software, where qualitative issues like flexibility and accessibility were achieved by AHP.

2.6. Resolution Approaches

There are many studies in the literature about layout problem formulations and solutions. These studies consider either deciding an optimized solution with specific constraints or proposing a global or local optimal solution for more than one objective. Thus, heuristic methodologies or different algorithms for optimization problems are formed. On the other hand, some studies proposed artificial intelligence approaches for layout problems (Drira et al., 2007). Expert systems, studied by Heragu and Kusiak (1991), can be an example for this type of approach. Additional to this approach, Chung (1999) used artificial neural networks to form an expert system in a manufacturing problem about facility layout design.

Although there are different and many types of facility layout optimization studies, most of them are gathered under two main methodologies which are exact approaches and heuristic and meta-heuristic approaches.

2.6.1. Different Exact Approaches

Exact methods are used widely within various studies, generally for small size problems with optimal solutions. For example, Kouvelis and Kim (1992) proposed a branch and bound algorithm for their loop layout problem with different directions. Xie and Sahinidis (2008) used same algorithm for continuous facility layout problem. Meller et al. (1999) used branch and bound approach in order to locate n facilities with rectangular shapes to a rectangular site area. In their study, general classes of valid inequalities, with a structure of acyclic sub-graph, was developed to maximize the range of solvable problems. Moreover, Solimanpur and Jafari (2008) also developed same type algorithm for two-dimensional layout problems with small and medium sizes. On the other hand, Kim and Kim (1999) developed a problem about pick-up and drop-off locations for the facilities with fixed dimensions in a plant area. Their aim was to optimize the material flow distance between pick-up and drop-off points and proposed a branch and bound algorithm which helps to determine an optimum location for the facilities' P/D points. Further, Rosenblatt (1986) tried to solve a dynamic layout problem, consisting equal sized facilities, with dynamic programming. However, the model developed optimal solutions for small type problems.

2.6.2. Heuristic and Meta-Heuristic Approaches

Several studies regarding heuristics and meta-heuristics, have been developed by many researchers. Drira et al. (2007) classified meta-heuristic approaches under heuristics according to Fig. 2.2. However, meta-heuristics will be explained with a different outline in this study.

2.6.2.1. Heuristics

Being stated under heuristics, construction approaches and improvement heuristics differ from each other with their methodology. In the first one, sequence of the facilities is determined continuously till the full area of layout is employed and solution is developed from scratch (Singh and Sharma, 2006), whereas, the latter one begins with a first basic solution for layout design and this solution is improved by later trials, managing interchange of single assignments to solve the problem. Drira et al. (2007) specify some of construction heuristics as: CORELAP, ALDEP, COFAD, SHAPE and adds CRAFT and DISCON as improvement heuristics. On the other hand, Singh and Sharma (2006) define construction type heuristics as being the simplest and oldest one in the solution of QAP besides having unsatisfactory solutions. Further, they point out that improvement and construction type approaches can be easily combined. In their related paper, they classify adjacency and distance based algorithms giving examples of MATCH and SPIRAL for adjacency and CRAFT, SHAPE, MULTIPLE and LOGIC for distance based algorithms. More facility layout packages can be found in their research. They differentiate these algorithms by their objective function.

Adjacency based algorithms:

$$Max \sum_{i} \sum_{j} r_{ij} \, . \, x_{ij} \tag{2.9}$$

In equation (2.9), "$x_{ij} \in (0,1)$" defines whether departments "i" and "j" are adjacent or not. The important part of this function is, when two departments are adjacent, material handling cost is extremely decreased.

Distance based algorithms:

$$\text{Min TC} = \frac{1}{2} \, . \sum_{\substack{i=1 \\ i \neq k}}^{n} \sum_{\substack{j=1 \\ j \neq l}}^{n} \sum_{k=1}^{n} \sum_{l=1}^{n} C_{ik} \, . \, D_{jl} \, . \, X_{ij} \, . \, X_{kl} \tag{2.10}$$

In the function (2.10), total traveling cost increases with the distance. Material handling cost index (C_{ik}) can also be replaced with flow index (F_{ik}) according to objective. Furthermore, if the problem is about a multi floor layout, then the formula can be changed to:

$$\text{Min} \sum_{\substack{i=1 \\ i \neq k}}^{n} \sum_{\substack{j=1 \\ j \neq l}}^{n} \sum_{k=1}^{n} \sum_{l=1}^{n} \left(C_{ikH} \, . \, D_{jlH} \, + \, C_{ikV} \, . \, D_{jlV} \right) . \, X_{ij} \, . \, X_{kl} \qquad (2.11)$$

where horizontal handling cost and horizontal distance are defined by C_{ikH}, D_{jlH}, and vertical cost and distances are by C_{ikV} , D_{jlV} (Singh and Sharma, 2006).

2.6.2.2. Meta-Heuristics

Meta-heuristics are widely handled in many papers as they can deal with large size problems with realistic constraints and quickly provide approximate solutions. Meta-heuristic approaches are grouped as global search methods and evolutionary approaches by Drira et al., (2007). He distinguished tabu search and simulated annealing methods in the first one and genetic algorithms and ant colony algorithms in the second one.

Tabu search algorithm is studied by Chiang and Kouvelis (1996) within a facility layout problem which considers the exchange of two facility locations with a neighborhood algorithm including diversification strategies, intensification criteria, a dynamic tabu list and a long term memory structure. Liang and Chao (2008) defined tabu search as a meta-heuristic technique for combinatorial optimization problems depending on neighborhood relations. They differentiate this technique from GA, since it relies on algorithm's parameters. In their related paper, they searched tabu search strategies for the facility layout problems and compared results with GA and annealing neural networks (Liang and Chao, 2008).

On the other hand, Chwif et al. (1998) suggested a simulated annealing algorithm that uses aspect ratios of facility dimensions. In their related paper, they considered two types of neighborhood relations to develop solutions: a pair-wise exchange between facilities and random shifts to four different directions. Additionally, dynamic layout problems with equal size facilities, McKendall et al. (2006) proposed two simulated annealing approaches. Likewise, the first one used pair-wise exchange method that includes adjustment of the location of two facilities as well as improving solution where the other method is thought to be a combination with the first one and called "look-ahead and look-back strategy" (Drira et al., 2007).

Using genetic algorithms (GA) is a popular technique in facility layout optimization. GAs iteratively search for the global optimum solution starting from a small set of feasible solutions, and their performance is dependent on the nature and type of the problem (Singh and Sharma, 2006). With the help of some steps, like mutation, selection, crossover, new solutions are generated randomly as to reach near optimum results.

Drira et al. (2007) have given examples of the papers related to usage of genetic algorithms for static layout problems (Wang et al., 2005) and dynamic layout problems (Balakrishnan et al., 2003). They also pointed out that genetic algorithms to be developed for the floor plans are also significant for continuous layouts like slicing tree representations. Slicing tree representations are widely used in the continuous layouts (Shayan and Chittilappilly, 2004). They have either horizontal or vertical internal nodes representing slices, and external nodes used for facilities (Drira et al., 2007). Scholz et al. (2009) combined slicing tree and tabu search algorithm for the layouts with fixed and flexible shapes.

For Singh and Sharma (2006), GA is more popular than other evolutionary algorithms since it uses fixed binary coding parameters while searching global optimum from a set of feasible solutions. They indicate that, GA's performance depends on the problem type since parameters and representations are relevant. A wide survey of meta-heuristic and other approaches between 1982-2003 can be found in their related paper. Tate and Smith (1995), used evolution steps of genetic algorithm, which are defined as selecting parents, breeding or reproducing offspring, mutating members and culling them, for their QAP research.

Wong et al. (2010) compared GA features with MIP modeling approach and determined that MIP approach provides better results as optimal solution where GA gives suboptimal for the same FLP. Further, they stated that MIP is more capable of including more design requirements and constraints.

Ant colony optimization (ACO) is also a methodology for layout optimization. This methodology is used by Solimanpur et al. (2005) at the search of an algorithm for a sequence dependent single-row machine layout problem and by Baykasoglu et al. (2006) while solving a dynamic layout problem with and without budget constraints.

According to Drira et al. (2007), the objective function in the evolutionary approaches (genetic and ant colony algorithms) is usually expressed by a mathematical cost function derived from the formulization of the problem. For Azadivar and Wang (2000), simulation models have been combined with evolutionary methods, while evaluating solutions, in order to consider system performance more reasonable.

Hybrid methods can be thought as a combination of different approaches which is also formulated for layout problems. In order to decrease material handling cost, Mahdi et al. (1998) suggested a hybridization of three procedures: simulated annealing algorithm for the geometrical issues in the problem, a genetic algorithm for material handling system and an exact method to optimize total material handling cost. Likewise, Mir and Imam (2001) used a multi stage decision process, starting with the solution of simulated annealing algorithm and continued with analytical search approach in order to determine the optimal locations of the facilities. Moreover, Lee and Lee (2002) studied a fixed shape facility layout problem with unequal area, proposing a hybrid algorithm including tabu search, simulated annealing and genetic algorithm technique, serving for an optimum global solution. Balakrishnan et al. (2003) also presented a hybrid genetic algorithm for a previously studied dynamic layout problem by Rosenblatt (1986).

CHAPTER 3

CONSTRUCTION SITE LAYOUT PROBLEMS

Site-level facility layout problems concern about allocating temporary site facilities at the construction stage. These facilities can vary from warehouses, parking areas, batch plants to job offices, stores, fabrication shops and numerous workshops (Yeh, 1995)(Tommelein et al., 1992). Location of facilities has a huge impact on the cost and construction time of the project. If the project is a large one, the design on site turns into a very critical decision. Because travelling time for personnel, vehicles and machines can be at serious level, which affects sources of the project and makes the problem challenging. Hegazy and Elbeltagi (1999) defined site space as a resource like material, money, time, labor and equipment. To place particular facilities to applicable locations in an available plane, can lead lots of alternatives. Yeh (1995) pointed out that allocating 10 facilities can create more than 3.6 million possible assignments which can be derived from "10!".

Mawdesley et al. (2002) described the relevance of site layout problems with project planning aspects. They defined the purposes of planning site layout as reduction in the project cost, improvement of quality, safety and environmental features. Besides, the changing nature of construction projects leads to plan specific layouts regarding dynamic characters of them. Furthermore, site layouts are interrelated with other management issues and highly dependent decisions.

Tommelein et al. (1992) arranged that, a convenient layout should reduce material handling costs, decrease travel frequencies of labor, material and equipment, increase productivity and improve safety and quality. In addition, El-Rayes and Khalafallah

(2005) stated that, site layout must be updated during the planning and construction phases.

The main difference between facility and site layout problems is having temporary facilities in the construction site layouts. Facility layout problems are mostly about manufacturing or material handling systems and industrial purposes. With FLP, researchers try to optimize locations in a plant area as well as departments in the facilities. On the other hand, site layout problems are usually used to determine static or dynamic locations for construction facilities throughout the project. Even though, the concept and the scope of the works to minimize cost (material handling or movement costs) and traveling distances are similar. Therefore approaches and solution methods of both problems are same.

3.1 Types of Site Layout Problems

As it is mentioned above, like FLPs, there are many algorithms searched in the literature for complex site layouts. Sirinaovakul and Thajchayapong (1996) made a classification for layout algorithms as follows: layout improvement, entire layout and partial layout. An initial layout is handled and new ones are generated by relocating the facilities in layout improvement model in order to improve layout. On the other hand, entire layout algorithms require selecting a facility according to its priority and placing it. This pre-determination strategy is represented by a fitness to locate a facility to a specific area. In partial layout algorithms, a facility is located to all appropriate locations to set up possible alternatives. The best option is selected from possible layouts and after this process, another facility is located to the best layout by the same method (Li and Love, 1998). In their research, Sirinaovakul and Thajchayapong (1996) used partial improvement algorithm, where Buffa et al. (1964) developed layout improvement algorithm and Hassan and Hogg (1991) proposed entire layout algorithm.

3.2 Different Approaches to Site Layout Problems

There are different kinds of researches about construction site-level facility layout problems. However, they used same type of formulation approaches like FLPs mainly.

Li and Love (1998) tried to optimize the total traveling distance of the site personnel in a site area. They determined 11 facilities to be located to equal or more locations. With the help of a developed genetic algorithm, that includes reproduction, crossover and mutation steps, they studied a combinatorial optimization problem about a site facility layout. According to their paper, a large size construction project can have 40 temporary facilities and can be handled by GA approach. The objective function used in their research minimizes total distance considering flows between facilities as follows:

$$\text{Minimize TD} = \sum_{i=1}^{n}\sum_{x=1}^{n}\sum_{j=1}^{n} \delta_{xi} \,.\, f_{ij} \,.\, d_{mn} \qquad (3.1)$$

Subject to:

$$\sum_{x=1}^{n} \delta_{xi} = 1, \qquad i = 1,2,3,\dots,n \qquad (3.2)$$

where

n = Number of facilities

δ_{xi} = Permutation matrix variable

f_{ij} = Frequency of trips between facilities *i* and *j*

d_{mn} = Distance between locations *m* and *n* (*i* and *j* assigned)

TD = Total traveling distance of construction personnel

Yeh (1995) described a static construction layout problem consisting *n* resources to be placed to *n* possible positions according to their certain operation and set up costs, so as to optimize total cost. He defined the problem as a discrete combinatorial optimization problem and used a neural network to formulate. Same author formulated a QAP with different facility and location quantities in which possible locations are equal or more than facility number. In order to prevent miscalculations, he developed dummy facilities with zero transportation and set-up costs for the case of exceeding locations (Yeh, 1995). He described the objective function as below:

$$\text{Min F} = \sum_{x}\sum_{i} \delta_{xi} \,.\, C_{xi} + \sum_{x}\sum_{i}\sum_{y}\sum_{j} \delta_{xi} \,.\, \delta_{yj} \,.\, A_{ij} \,.\, D_{xy} \tag{3.3}$$

Subject to:

$$\delta_{yj} = 0 \quad if \quad \delta_{xi} = 1 \;\; and \; y \neq x \tag{3.4}$$

$$\delta_{yj} = 0 \quad if \quad \delta_{xi} = 1 \;\; and \; j \neq i \tag{3.5}$$

where $\delta_{xi} = 1$ if facility *x* is assigned to location i, C_{xi} is the cost of assignment for *x* to location i, $A_{ij} = 1$ if *i* is adjacent to j, D_{xy} is the interactive cost of assigning *x* to the location adjacent to y.

Mawdesley et al. (2002) defined a site area with small grids and allocated them by the facilities that are also described by grid sizes and developed a genetic algorithm. Within their research, they specify two main constraint sets: department and floor area requirements and location restrictions like fixed locations or overlap conditions.

Moreover, multiple-floor problems can include height constraints and floor loading restrictions that one should consider not only horizontal but also vertical distances. In their related paper to illustrate the problem according to genetic algorithm, they use coordinate system as the location area and give specific coordinates for facilities which are taken as rectangular shapes parallel to the axes. Within the site area, facilities are defined by their two opposite corners and their areas. Figure 3.1 shows the site area and example facilities with their coordinates.

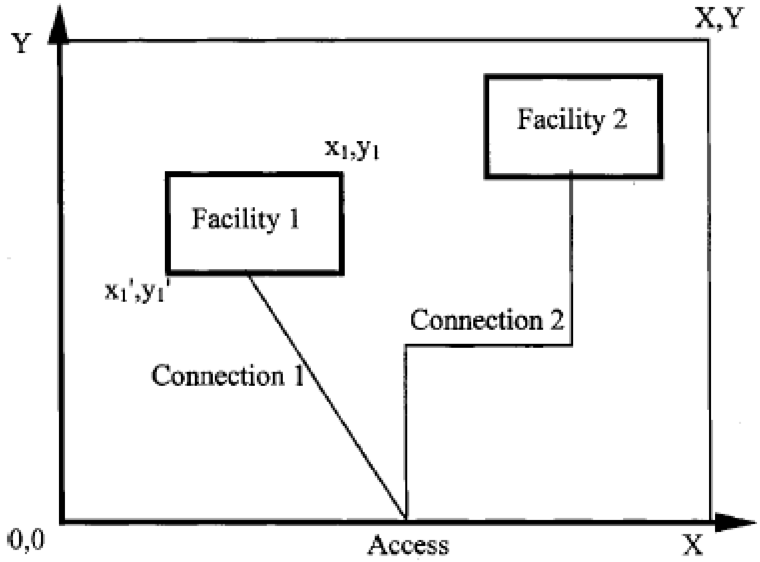

Figure 3.1 : Rectangular Site Area

The areas of facilities are defined as:

$$|(x_i - x_i')(y_i - y_i')| = a_i$$

In most of facility layout problems, the distance between facilities are either "Connection 1" type, in other words "rectilinear" or "Manhattan", or "Connection 2" type, also called "euclidian". This is dependent on the road connections of the facilities. So the distance is described as:

$$d_{ij} = \sqrt{\left[\left(x_i - x_j \right)^2 + \left(y_i - y_j \right)^2 \right]}$$

Finally they formulate the objective function, sometimes called fitness function, by summation of material transport, set up, removal and travel costs:

$$\sum_i \sum_j \left[d_{ij} \sum_k p_{ijk} \,.\, q_{ijk} \right] + \sum_i s_i(x_i, y_i) + \sum_i r_i(x_i, y_i) + \sum \sum u_{ij} \,.\, f_{ij} \,.\, d_{ij} \qquad (3.6)$$

where

d_{ij}= distance between facility *i* and *j*

q_{ijk}= quantity of material *k* transported from facility *i* to *j*

p_{ijk} = transportation price of material *k* from facility *i* to *j*

$s_i(x_i, y_i)$ = setup cost of facility *i* at location (x_i, y_i)

$r_i(x_i, y_i)$ = removal cost of facility *i* at location (x_i, y_i)

u_{ij} = utility value of a personnel visit from facility *i* to *j*

f_{ij}= frequency of personnel visits from facility *i* to *j*

Likewise, Mawdesley and Al-Jibouri (2003) proposed a sequence-based genetic algorithm for a twelve-facility problem and suggested to use more parameters for the dynamic nature of the sites so as to gain more benefit from moving facilities. Zouein et al.(2002) studied GA for constrained and rectangular facilities with different operators. Hegazy and Elbeltagi (1999), proposed an evolutionary based genetic algorithm to formulate site layout and optimally place facilities. Harmanani et al. (2000), modeled a static layout problem with genetic approach, considering geometric constraints between facilities. El-Rayes and Khalafallah (2005) formulated a GA, demonstrating trade-off relationship between safety and travel cost. In their research, safety conditions have been quantified with some criteria about crane operations, hazardous material and separation of road intersections for frequently used ones in order to prevent possible accidents. El-Ansary and Shalaby (2014) used GA for the optimization of two dimensional site planning for private residential housing projects.

On the other hand, Osman and Georgy (2005) specified a goal programming (GP) approach to consider several planning factors simultaneously. They thought to include site layout objectives, like personnel movement, transport costs, material handling and safety issues, in order to develop a heterogeneous result and search a solution which is suitable not only for one single goal but also for whole case. Furthermore, they applied related model to a project in Toronto, Canada. Zhang and Wang (2008) suggested particle swarm optimization (PSO) in order to cope with sites' unequal area layouts and compared solutions with usual GAs. Zhou et al. (2009) integrated GA, as a site layout optimization system, with a simulation environment (Simphony) used in tunneling projects and applied it to a tunneling system in Edmonton/Canada.

A decision-making system is improved and tested on a residential building by Ning et al. (2011) in order to deal with a multi objective, dynamic and unequal area construction site layout problem. They identified multiple objectives as well as site conditions and used max-min ant system and ACO tools to model the case. At the final stage, fuzzy TOPSIS methodology is applied to evaluate and select best site layout option.

Even though there are several researches about static site layout optimization, dynamic programming approaches also exist in the literature. As it is mentioned before, dynamic site layouts consider future demands and changes during the project duration in order to achieve a global optimal solution in a dynamic site-layout and estimate and optimize future costs. It is defined as reorganizing temporary facilities locations and area sizes at different schedule intervals so that activities dynamic performance would be met (Elbeltagi et al., 2004). El-Rayes and Said (2009) developed an Approximate Dynamic Programming (ADP) model. They classified the facilities as fixed, stationary and moveable ones and considered such geometric constraints like boundary, overlap, min/max distance constraints with different possible positioning options. Moreover, in the year 2013, same authors compared ADP with GAs with the aim of searching effectiveness of reaching optimum solutions besides decreasing computational time (Said and El-Rayes, 2013). Zouein and Tommelein (1999) proposed a hybrid model for constrained dynamic site layouts considering time and space aspects without creating conflicts. Yahya and Saka (2014) developed an artificial bee colony algorithm for a dynamic site layout problem with two objectives which are optimizing flow costs between facilities and minimizing safety damaging factors. Elbeltagi et al. (2004) considered safety and productivity factors within a dynamic site layout and optimized GA model for temporary facilities of a hospital project in Tanta/Egypt.

There are also other approaches focused on different management and planning needs. Razavialavi et al. (2014) searched a simulation technique to estimate temporary site facility sizes that are not determined before the project and can change during the construction phase. Sadeghpour et al. (2006) developed a site layout planning system based on a CAD model in order to help site design and allocation process. Ma et al. (2005) introduced Four-Dimensional Integrated Site Planning System (4D-ISPS) linking schedules, 3D models, site area and resources to increase effective planning efforts and provide visual judgment. Similarly, Wang et al.(2005) proposed a computerized model, called 4D Site Management Model (4DSMM), and developed a platform, 4D Management for Construction Planning and Resource Utilization (4D-MCPRU), in order to integrate dynamic resources and decision making process.

CHAPTER 4

MILITARY FACILITY LAYOUT OPTIMIZATION PROBLEM

4.1. Military Facility Layout Researches and Description of the Study

The objective of military units is to train the troops in accordance with daily schedules containing many activities inside. Most of the world armies train troops so as to be ready for any threat within and outside the country borders according to strategic and security decisions. There is no doubt that military units use government funds, which is a large amount considering different types of war machines like combat aircrafts, rocket launch units, war ships, cannons, tanks, varied wheeled and track laying vehicles, kinds of guns, communication and engineering elements etc. These units use different proportions from the same source, money, while moving from one place to another. Therefore, location of these units in a region and their layout within a military base is an important strategic decision like any other private or public organization. However private sector bases their activities and operations mainly on profit, public bodies try to give best service and gain more benefit beside cost issues.

There are not many studies about military facility layout in literature. Other than facility layout, some of the researches discuss facility location or site selection. Segal (2000) searched the location of military emergency medical facilities and their health personnel capacity over a planned region. He used a mathematical model called RAMOS (Resource Allocation Model Over Space) while determining patient flows and use of hospitals and compared six alternatives according to statistical results (Segal, 2000). On the other hand, Ezell and Davis (2001) studied both base camp site selection and facility layout in their paper where they defined base camp as a military facility which supports operations of a deployed military unit and maintains necessary service. In their related paper, they compared generated layouts between CRAFT solution, an old management system (Theatre Construction Management System), and a sample military camp according to proximity relations between fifteen common military facilities (Ezell and Davis, 2001) (Robertson et al., 2001). Moreover, Stewart (2015) developed an optimization model for military installations site planning regarding explosive safety distances. He proposed a genetic algorithm to be used as a design tool with ESS (Explosives Safety Siting) software that is used by United States Department of Defense (Stewart, 2015). As a matter of fact, none of these studies include the most important elements of military units which are vehicle and personnel flow inside the military base. Moreover, they are not exact studies concerning adjacency relationships as well. Therefore, traveling distances and related costs within a military base is an aspect related to this research which can be a significant component while deciding layout structure of a military unit.

Daily activities in military troops require continuous displacement according to schedules in military terrain. In order to execute daily activities within time, there is numerous flow of personnel, vehicle, equipment or material between different facilities in a military base that can be repeated every day. For this reason, facility layout planning of a military unit should streamline the flow of operations executed by military units, increase the effectiveness and minimize cost as much as possible.

In order to achieve this objective, a proper military facility layout has been analyzed in order to optimize distances both for military personnel and vehicles in their daily activities. To illustrate common world armies, a set of particular facilities is selected from a brigade level military unit and a location model has been formulated using mixed integer linear programming method that is mentioned in previous chapters. The plan of the brigade used in this study can be found in Figure 4.1.

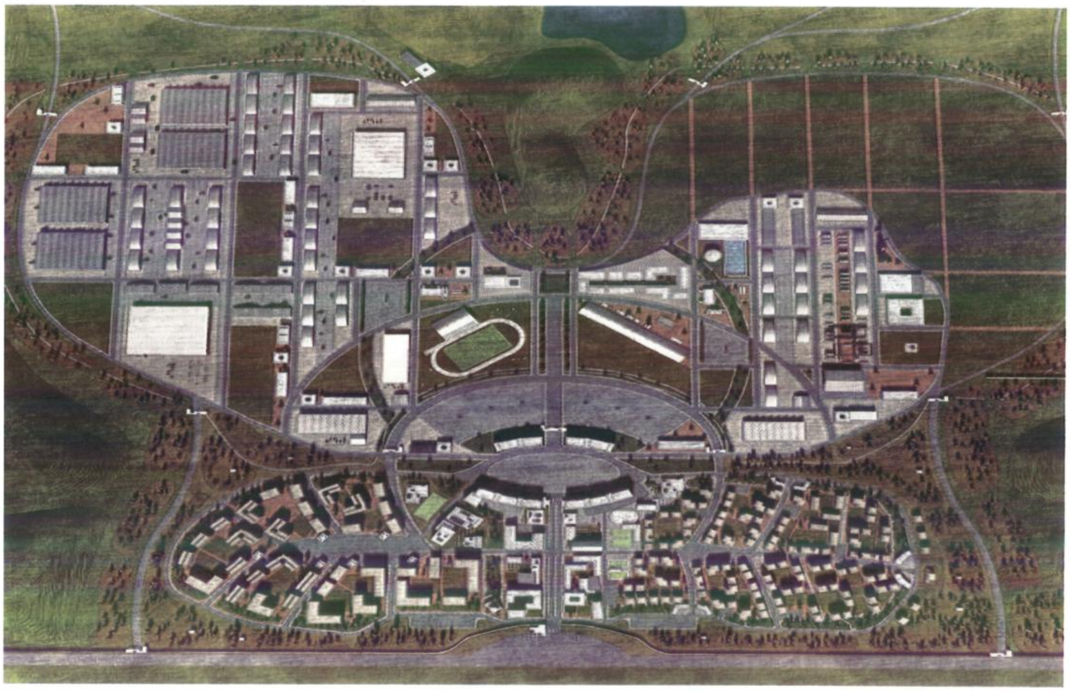

Figure 4.1 : Brigade Area Plan

As a military unit, brigade has lots of buildings inside, such as varied battalions (troops), shooting ranges, training areas, headquarters, stokehold, dining halls, sports facilities, medical and residential facilities, warehouses, maintenance shops etc.

Rather than including all the buildings, only most important twenty facilities and same numbered locations have been considered in the brigade area to formulate the unit area model and obtain an exact solution. Unit area used in the model is presented in Figure 4.2.

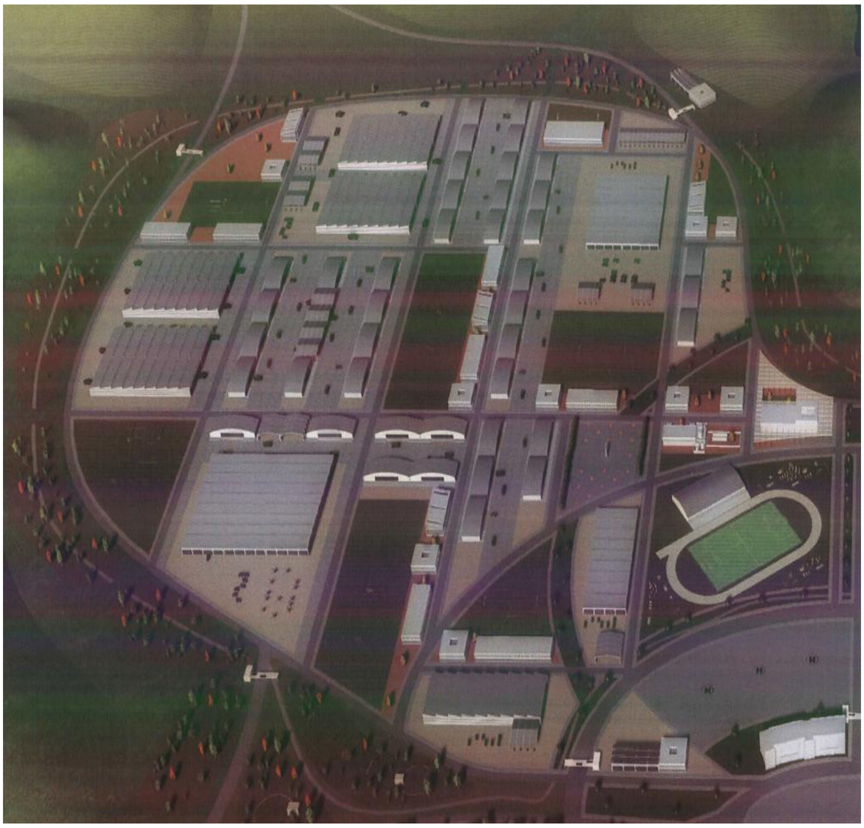

Figure 4.2 : Unit Area

Vehicle types, vehicle and personnel numbers of the facilities, their monthly travelling frequencies and distances between facilities and possible stations have been considered to formulate the problem. In order to determine a common understanding and a calculation unit, unit costs have been determined for each vehicle and personnel that have been derived from fuel consumption rates as a cost measurement and evaluated for personnel as well. The facilities, their personnel and vehicle amounts and weights, unit sizes and station distances are determined by the experts. Appropriate data have been compiled for vehicle specifications.

The aim of the study is to assign a facility/unit to a proper location so that its' vehicles and personnel will have the shortest route, and total traveling cost regarding the facility is minimized while visiting other facilities and stations in a monthly period within the military base. In other words, the military units will be allocated to available locations in such a way that the total travel cost for all facilities are minimized. Therefore, optimized locations will cause less consumption of fuel for daily activities and this parameter will be taken as "cost" both for vehicles and personnel in order to use specific type of unit in the problem formulation.

The developed mixed integer model is solved by AIMMS 4.2 software. Computational performance and results of the problem are presented in the last section with the comparision of the existing plant model. The problem is defined and formulated in the following sections.

4.2. Problem Definition

After considering different nations' armies, a case brigade has been selected for the study. 20 facilities that can share the same part of the area in the brigade terrain have been selected and rectangular zones have been determined to locate the units. The 20 facilities that will be assigned to locations are shown in Table 4.1:

Table 4.1 : Military Facilities

Facility No	Facility/Unit
1	1st and 2nd Mechanized Infantry Battalion Headquarters and Sports Facility
2	1st Mechanized Infantry Battalion Garage
3	2nd Mechanized Infantry Battalion Garage
4	1st and 2nd Mechanized Infantry Battalion Depots
5	1st and 2nd Tank Battalion Headquarters and Sports Facility
6	1st Tank Battalion Garage
7	2nd Tank Battalion Garage
8	1st and 2nd Tank Battalion Depots
9	Artillery Battalion Headquarters and Sports Facility
10	Artillery Battalion Garage
11	Artillery Battalion Depots
12	Command and Support Battalion Headquarters and Sports Facility
13	Command and Support Battalion Garage
14	Command and Support Battalion Depots
15	Logistics Support Headquarters and Sports Facility
16	Logistics Support Garage
17	Logistics Support Depots and Maintenance Area
18	Training Support Unit Headquarters and Depots
19	Dog Team Headquarters and Depots
20	Sports Facility

The dimensions of the total area has been decided on average according to the military bases as 500x1000 meters and divided into 20 locations by the experts. Although some unit areas can be larger or smaller than the others, the dimensions have been selected equal for all locations to present an objective assignment. Adopting the table type Figure 4.3, each location area will be same and any facility can be located anywhere in the planned zone:

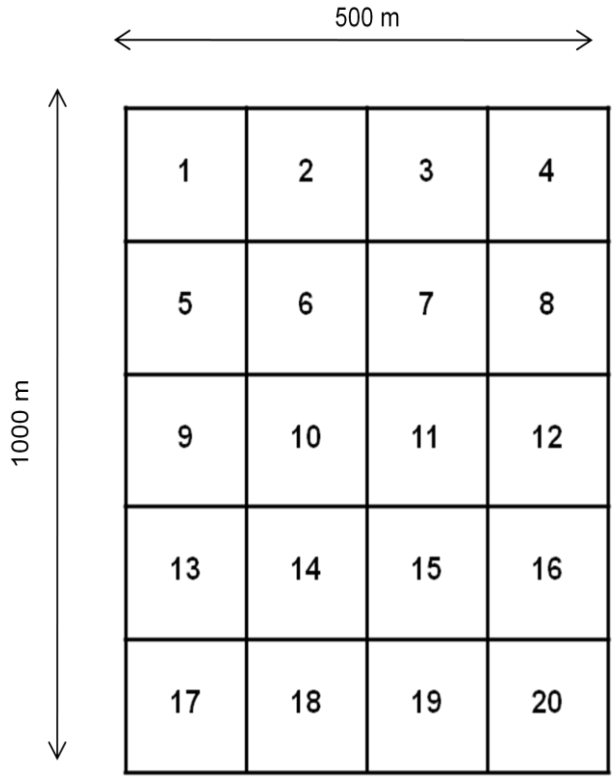

Figure 4.3 : Locations in the Unit Area

There are four stations for vehicles and three stations for personnel that are used frequently in routine daily trainings. The stations for vehicles are; "Exercise Area", "Training and Shooting Area", "Main Gate" and "Refuelling Area". The stations for personnel are; "Training Center", "Sports Facility" and "Dormitories Building". However, Training Center and Sports Facility are represented by "Facility 18" and "Facility 20" which means these buildings are not located outside the unit area. So, only Dormitories Building will be outside the unit area and will be represented like vehicle stations.

Including one personnel station discussed previously, we will have five stations outside the unit area whose positions will not be constant. Eight possible alternative positions have been developed for each station and these eight different possible positions of the stations are represented by sets. Each set has the same average distance from the center of the unit area. These distances have been determined by the experts. The primary reason for these constant distances is safety issues. Therefore, each of the five stations will be located to a position from eight possible alternatives defined as A, B, C, D or E sets. So, 20 facilities will be assigned to 20 locations while five stations will be assigned to five positions with eight alternatives at the same time. The distances from the center of the location area and sets are shown in Table 4.2:

Table 4.2 : Defined Sets and Distances Between Stations and Center of the Unit Area

Station	Distance	Set Used
Exercise Area	5000	A
Training/ Shooting Area	3000	B
Main Gate	750	C
Refuelling Area	600	D
Dormitories, Dinig Hall and Cafeteria	650	E

Since the positions of the stations have not been considered to be constant, different position possibility sets in eight directions are demonstrated in Figure 4.4 with same distances from the center of the unit area with 20 facilities.

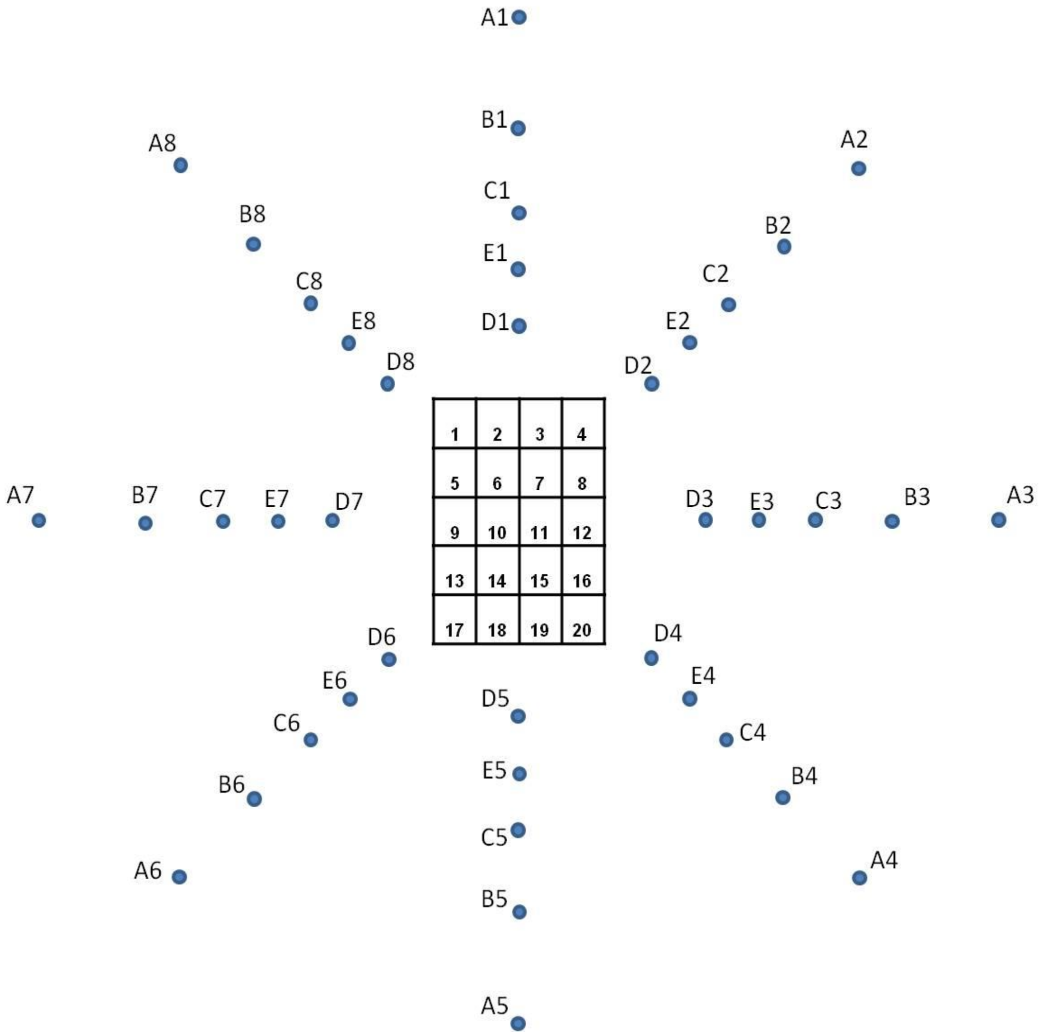

Figure 4.4 : Possible Positions for the Stations

Although there are 20 facilities, only seven of them have different kind of vehicles whose unit cost will help us to decide the location of that unit. Unsurprisingly, these units are all garages where vehicles stay. These vehicles have the highest consumption and maintenance rate and eventually biggest travel cost, that has an impact on total brigade's monthly travel cost. Types and quantities of vehicles are shown in Table 4.3:

Table 4.3 : Number of Vehicles of Seven Facilities

Facility No	Military Unit	Vehicle Type				
		Tank	APC	Unimog	Land Rover	Van
2	1st Mechanized Infantry Battalion Garage	-	60	53	6	-
3	2nd Mechanized Infantry Battalion Garage	-	60	53	6	-
6	1st Tank Battalion Garage	40	14	49	5	-
7	2nd Tank Battalion Garage	40	14	49	5	-
10	Artillery Battalion Garage	-	28	83	7	-
13	Command and Support Battalion Garage	2	51	94	8	1
16	Logistics Support Garage	-	11	170	17	1

Route frequencies for each vehicle to the stations have been considered average in a monthly period which can be seen in Table 4.4:

Table 4.4 : Average Monthly Trips

Vehicle Type	Monthly Trip Routes			
	Training/Shooting Area	Exercise Area	Refueling Area	Main Gate
Tank	15	5	1	-
APC	15	5	1	-
Unimog	40	10	1	3
Land Rover	30	20	1	10
Van	-	-	1	40

Here one can ask about the fuel tank capacities, that might be higher than only these traffic to the stations. Obviously, the fuel capacities of the vehicles are enough to meet these trips. But, other tasks like maintenance or patrolling, also requires these vehicles to refuel at least once in a month. Since these maintenance and patrolling tasks change according to annual plans, they have been ignored intentionally.

Each vehicle uses the same type of fuel. So, consumptions have been calculated by taking 1 liter of diesel fuel as 4 TL average, according to Turkey conditions and presented in Table 4.5. Additionally, types of the vehicles are the ones that are mostly encountered in common world armies and brigades which can resemble the problem for real cases.

Table 4.5 : Average Fuel Consumptions

Vehicle Type	Model	Av.Fuel Cons. (l/m)	Av.Fuel Cons. (TL/m)	Av.Fuel Cons. (TL/km)
Tank	Leopard 2A4	0.0041	0.0164	16.4
APC	M113 A1	0.0008	0.0032	3.2
Truck	Mercedes Unimog	0.0002	0.0008	0.8
Off-road 4x4	Land Rover	0.00013	0.00052	0.52
Van	Ford Connect	0.00006	0.00024	0.24

Each vehicle has also another expenditure that affects its importance and cost per km while being used in the facility. This expenditure includes maintenance costs, such as filters or rings as well as oil that must be changed periodically (i.e. every one or two years). The maintenance costs of vehicles are estimated using military sources. For spare parts, this cost has been calculated per km., however some oil types are changed annually. This type of annual expenses have been divided by travelled kilometer value per year for that vehicle according to frequencies stated in Table 4.4, and average distances in Table 4.2, so as to find per km. cost. Finally they have been added to the consumption rates in order to find final unit costs (Table 4.6).

Table 4.6 : Unit Costs

Vehicle Type	Av. Fuel Cons. (TL/km)	Av. Maint. Value (TL/km)	Total Cost (TL/km)	Unit Cost (TL/m)
Tank	16.4	4.6646	21.0646	0.02106
APC	3.2	0.3078	3.5078	0.00351
Unimog	0.8	0.0095	0.8095	0.00081
Land Rover	0.52	0.0085	0.5285	0.00053
Van	0.24	0.0111	0.2511	0.00025
Each Personnel	-	-	-	0.00005

As described previously, in order to minimize both vehicle fuel consumption and personnel walking distances, a general unit must be used. Because objective function of the formulation should develop a minimum value for the same unit both for personnel and for vehicles. So, as it is mentioned above, the total of each vehicle's consumption value and maintenance value, is rated and a unit cost is given to them besides evaluating another unit cost for the personnel. In a military facility, personnel trips can be by walking as well as by transportation vehicles such as Lands, Vans or Unimog trucks. Mostly, in order to be fast and gain time for daily activities, carrying personnel with a vehicle is preferred. For this reason, a person's unit cost has been defined according to the smallest vehicle, which is a Van taking five personnel at the same time. Therefore, a personnel's unit transportation cost is thought to be 0.05 TL/km. Unit costs of vehicles and personnel can be seen in Table 4.6.

The personnel amounts for the facilities are estimated by the experts and given in Table 4.7. Except the facilities in Table 4.7, other facilities do not have any personnel since they are depot or garage facilities.

Table 4.7 : Facility Personnel Capacities

Facility No	Facility/Unit	Per.Amount
1	1st and 2nd Mechanized Infantry Battalion Headquarters and Sports Facility	1200
5	1st and 2nd Tank Battalion Headquarters and Sports Facility	1200
9	Artillery Battalion Headquarters and Sports Facility	600
12	Command and Support Battalion Headquarters and Sports Facility	300
15	Logistics Support Headquarters and Sports Facility	500
18	Training Support Unit Headquarters and Depots	20
19	Dog Team Headquarters and Depots	7
20	Sports Facility	5

Beside personnel capacity, personnel trip routes and times in a monthly period are given in Table 4.8:

Table 4.8 : Monthly Personnel Trips

Facilities With Personnel		Monthly Trip Route		
		Training Center (Fac.18)	**Sports Facility (Fac.20)**	**Dining Hall, Dormitories and Cafeteria**
1	1st and 2nd Mechanized Infantry Battalion Headquarters and Sports Facility	4	20	60
5	1st and 2nd Tank Battalion Headquarters and Sports Facility	4	20	60
9	Artillery Battalion Headquarters and Sports Facility	4	20	60
12	Command and Support Battalion Headquarters and Sports Facility	4	20	60
15	Logistics Support Headquarters and Sports Facility	4	20	60
18	Training Support Unit Headquarters and Depots	4	20	60
19	Dog Team Headquarters and Depots	4	20	60
20	Sports Facility	4	20	60

The distances in the facility or site layout problems can be added to formulations by either euclidean or rectilinear form. Basically, in military facility layout, roads are designed linearly between facilities, constituting both horizontally and vertically right angels to reach each facility. However, station roads are based on euclidean distances since they are out of unit area and assumed to have no obstacle on their way. Besides, Euclidean distances enable minimum vehicle movement between facilities. Therefore, according to location and facility sizes and shapes determined in Figure 4.1, since vehicle movement has a huge impact on the determination of facility locations regarding their unit cost, the euclidean distances have been taken into account both among locations and between locations and stations.

Distances among location center points have been calculated and shown in Table 4.9. while distances between each location centers and possible station positions are given in Table 4.10.

Table 4.9 : Euclidean Distances Between Locations

Locations	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	125	250	375	200	236	320	425	400	419	472	548	600	613	650	708	800	810	838	884
2		125	250	236	200	236	320	419	400	419	472	613	600	613	650	810	800	810	838
3			125	320	236	200	236	472	419	400	419	650	613	600	613	838	810	800	810
4				425	320	236	200	548	472	419	400	708	650	613	600	884	838	810	800
5					125	250	375	200	236	320	425	400	419	472	548	600	613	650	708
6						125	250	236	200	236	320	419	400	419	472	613	600	613	650
7							125	320	236	200	236	472	419	400	419	650	613	600	613
8								425	320	236	200	548	472	419	400	708	650	613	600
9									125	250	375	200	236	320	425	400	419	472	548
10										125	250	236	200	236	320	419	400	419	472
11											125	320	236	200	236	472	419	400	419
12												425	320	236	200	548	472	419	400
13													125	250	375	200	236	320	425
14														125	250	236	200	236	320
15															125	320	236	200	236
16																425	320	236	200
17																	125	250	375
18																		125	250
19																			125

Table 4.10 : Euclidean Distances Between Facility Locations and Possible Station Positions

	Positions																			
Locations	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8**	**C1**	**C2**	**C3**	**C4**
Center Point of Unit Area	**5000**	**5000**	**5000**	**5000**	**5000**	**5000**	**5000**	**5000**	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**	**750**	**750**	**750**	**750**
1	4604	4867	5203	5418	5403	5167	4829	4587	2607	2880	3213	3419	3405	3178	2841	2589	397	730	1019	1175
2	4600	4773	5078	5332	5400	5249	4954	4679	2601	2781	3089	3336	3401	3255	2965	2684	356	607	906	1103
3	4600	4679	4954	5249	5400	5332	5078	4773	2601	2684	2965	3255	3401	3336	3089	2781	356	486	795	1041
4	4604	4587	4829	5167	5403	5418	5203	4867	2607	2589	2841	3178	3405	3419	3213	2880	397	367	690	991
5	4804	4999	5191	5274	5203	5016	4817	4726	2806	3004	3194	3274	3205	3021	2820	2726	581	790	959	1024
6	4800	4906	5066	5187	5200	5101	4942	4815	2801	2909	3069	3187	3201	3103	2944	2816	554	679	837	941
7	4800	4815	4942	5101	5200	5187	5066	4906	2801	2816	2944	3103	3201	3187	3069	2909	554	573	716	867
8	4804	4726	4817	5016	5203	5274	5191	4999	2806	2726	2820	3021	3205	3274	3194	3004	581	476	597	807
9	5004	5134	5188	5134	5004	4869	4813	4869	3006	3135	3188	3135	3006	2870	2813	2870	773	892	938	892
10	5000	5044	5063	5044	5000	4956	4938	4956	3001	3045	3063	3045	3001	2956	2938	2956	753	795	813	795
11	5000	4956	4938	4956	5000	5044	5063	5044	3001	2956	2938	2956	3001	3045	3063	3045	753	707	688	707
12	5004	4869	4813	4869	5004	5134	5188	5134	3006	2870	2813	2870	3006	3135	3188	3135	773	631	563	631
13	5203	5274	5191	4999	4804	4726	4817	5016	3205	3274	3194	3004	2806	2726	2820	3021	968	1024	959	790
14	5200	5187	5066	4906	4800	4815	4942	5101	3201	3187	3069	2909	2801	2816	2944	3103	952	941	837	679
15	5200	5101	4942	4815	4800	4906	5066	5187	3201	3103	2944	2816	2801	2909	3069	3187	952	867	716	573
16	5203	5016	4817	4726	4804	4999	5191	5274	3205	3021	2820	2726	2806	3004	3194	3274	968	807	597	476
17	5403	5418	5203	4867	4604	4587	4829	5167	3405	3419	3213	2880	2607	2589	2841	3178	1165	1175	1019	730
18	5400	5332	5078	4773	4600	4679	4954	5249	3401	3336	3089	2781	2601	2684	2965	3255	1152	1103	906	607
19	5400	5249	4954	4679	4600	4773	5078	5332	3401	3255	2965	2684	2601	2781	3089	3336	1152	1041	795	486
20	5403	5167	4829	4587	4604	4867	5203	5418	3405	3178	2841	2589	2607	2880	3213	3419	1165	991	690	367

Table 4.10 : Euclidean Distances Between Facility Locations and Possible Station Positions

	Positions																			
Locations	**C5**	**C6**	**C7**	**C8**	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**E1**	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**	**E8**
Center Point of Unit Area	**750**	**750**	**750**	**750**	**600**	**600**	**600**	**600**	**600**	**600**	**600**	**600**	**650**	**650**	**650**	**650**	**650**	**650**	**650**	**650**
1	1165	991	690	367	274	612	883	1026	1017	858	575	238	313	650	928	1076	1067	902	611	279
2	1152	1041	795	486	210	487	774	957	1002	900	670	363	258	526	817	1006	1052	947	711	402
3	1152	1103	906	607	210	363	670	900	1002	957	774	487	258	402	711	947	1052	1006	817	526
4	1165	1175	1019	730	274	238	575	858	1017	1026	883	612	313	279	611	902	1067	1076	928	650
5	968	807	597	476	442	652	813	874	822	668	458	326	488	697	861	924	870	714	504	376
6	952	867	716	573	405	536	692	792	802	722	574	426	454	583	740	841	852	770	621	474
7	952	941	837	679	405	426	574	722	802	792	692	536	454	474	621	770	852	841	740	583
8	968	1024	959	790	442	326	458	668	822	874	813	652	488	376	504	714	870	924	861	697
9	773	631	563	631	629	744	788	744	629	486	413	486	677	794	838	794	677	534	463	534
10	753	707	688	707	603	646	663	646	603	558	538	558	653	696	713	696	653	607	588	607
11	753	795	813	795	603	558	538	558	603	646	663	646	653	607	588	607	653	696	713	696
12	773	892	938	892	629	486	413	486	629	744	788	744	677	534	463	534	677	794	838	794
13	581	476	597	807	822	874	813	652	442	326	458	668	870	924	861	697	488	376	504	714
14	554	573	716	867	802	792	692	536	405	426	574	722	852	841	740	583	454	474	621	770
15	554	679	837	941	802	722	574	426	405	536	692	792	852	770	621	474	454	583	740	841
16	581	790	959	1024	822	668	458	326	442	652	813	874	870	714	504	376	488	697	861	924
17	397	367	690	991	1017	1026	883	612	274	238	575	858	1067	1076	928	650	313	279	611	902
18	356	486	795	1041	1002	957	774	487	210	363	670	900	1052	1006	817	526	258	402	711	947
19	356	607	906	1103	1002	900	670	363	210	487	774	957	1052	947	711	402	258	526	817	1006
20	397	730	1019	1175	1017	858	575	238	274	612	883	1026	1067	902	611	279	313	650	928	1076

4.3. Determination of Sets, Parameters, Decision Variables and Constraints

The specific problem studied in this thesis has 20 facilities to be located to 20 locations. For this reason, the problem can be thought as similar to QAP. However, QAP includes paired facilities and the material flow relations in its formulization and also cost parameter for this flow process. On the other hand, facilities in military layout optimization problem have adjacency relations with specific groups and personnel and vehicle travels have been planned for different stations. It has been assumed that there is not any vehicle movement among facilities and personnel movement except towards s_6 and s_7 facilities. Since first five stations have eight different possible locations, they have been defined as separate sets according to Figure 4.2 and named as A,B,C,D and E. Here, as stated in previous sections, vehicles have four different stations to route: Training and Shooting Area, Exercise Area, Refueling Area and Main Gate, where, personnel have three: Training Center, Sports Facility and Dormitories, Dining Hall and Cafeteria. Sets, parameters and variables of the military facility layout problem can be seen in Table 4.11:

Table 4.11 : Sets, Parameters and Decision Variables

i, h	$facilities \in N = \{Facility\ 1, \ldots., Facility\ 20\}$
j, l, a, b	$locations \in L = \{Location\ 1, \ldots., Location\ 20\}$
v	$vehicle\ type \in V = \{Tank, APC, Unimog, Land\ Rover, Van\}$
s	$stations \in S = \{s1, .., s7\}$
s_1	$"Training\ and\ Shooting\ Area"$
s_2	$"Exercise\ Area"$
s_3	$"Refueling\ Area"$
s_4	$"Main\ Gate"$
s_5	$"Dormitories, Dining\ Hall\ and\ Cafeteria"$
s_6	$"Training\ Center"$
s_7	$"Sports\ Center"$

p	$Positions$
p_1	$Position\ alternatives\ for\ s_1\ \in\ \{A1, A2, \ldots, A8\}$
p_2	$Position\ alternatives\ for\ s_2\ \in\ \{B1, B2, \ldots, B8\}$
p_3	$Position\ alternatives\ for\ s_3\ \in\ \{C1, C2, \ldots, C8\}$
p_4	$Position\ alternatives\ for\ s_4\ \in\ \{D1, D2, \ldots, D8\}$
p_5	$Position\ alternatives\ for\ s_5\ \in\ \{E1, E2, \ldots, E8\}$
k_{iv}	$v\ type\ vehicle\ amount\ of\ facility\ i$
r_i	$personnel\ amount\ of\ facility\ i$
f_{vs}	$frequency\ of\ v\ type\ vehicle\ trips\ to\ stations\ s_1, s_2, s_3, s_4$
f_{ns}	$frequency\ of\ personnel\ trips\ to\ stations\ s_5, s_6, s_7$
c	$cost\ (c_v{:}\ for\ vehicles, c_n{:}\ for\ personnel)$
d_{jp}	$distance\ between\ location\ j\ and\ position\ p$
d_{js}	$distance\ between\ location\ j\ and\ station\ s$
w_{vi}	$vehicle\ cost\ of\ facility\ i$
x_{ij}	$binary\ variable\ for\ the\ assignment\ of\ facilities\ to\ locations$
y_{sp}	$binary\ variable\ for\ the\ assignment\ of\ stations\ to\ positions$

"x_{ij}" is used as a binary decision variable to indicate whether facility "i" is located on location "j" or not. Likewise, "y_{sp}" is the second decision variable to indicate whether stations are assigned to positions or not.

Since the problem consists of a unit area of a military base, the facilities have to have some requirements. The main constraints regarding the problem are:

1. Facilities with same battalions should be grouped together since they share some of their buildings like headquarters and sports facilities or depots. So facilities between 1-4, 5-8, 9-11, 12-14, 15-17 should be grouped which constitute one type of military unit.
2. Since the battalions should be grouped, their facilities also have to be located adjacent to each other. These allocations can create different combinations

depending on the number of facility. Figure 4.5 and 4.6 shows all possible combinations which can occur to four and three facility groups:

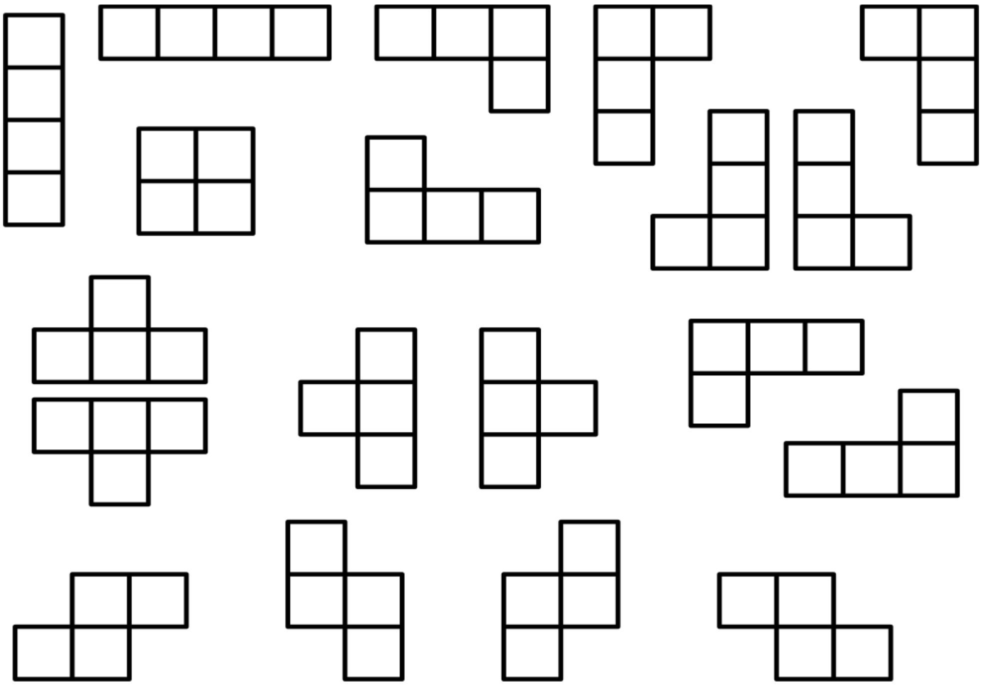

Figure 4.5 : Groups with Four Facilities

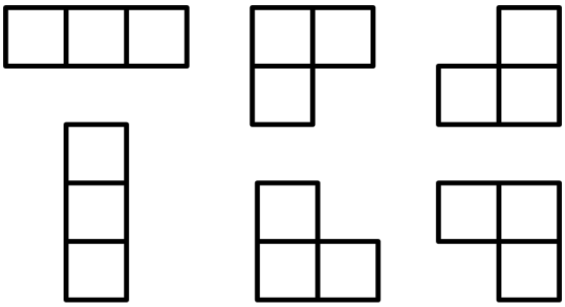

Figure 4.6 : Groups with Three Facilities

3. Facilities 2-3 and 6-7 should be adjacent to each other since they are both garage facilities and all vehicles of the same battalion should be gathered together.
4. Facilities 18, 19 and 20 can be considered as single units.

4.4. Mathematical Model

The objective function has been formulated by adding the total vehicle costs and total personnel transportation cost for each facility as follows:

$$Min\ Z = \sum_{i=1}^{20}\sum_{j=1}^{20}\sum_{p_1=1}^{8}\sum_{v=1}^{5} x_{ij}\ .\ y_{s_1p_1}\ .\ w_{vi}\ +\ \sum_{i=1}^{20}\sum_{j=1}^{20}\sum_{p_2=1}^{8}\sum_{v=1}^{5} x_{ij}\ .\ y_{s_2p_2}\ .\ w_{vi}\ +$$

$$\sum_{i=1}^{20}\sum_{j=1}^{20}\sum_{p_3=1}^{8}\sum_{v=1}^{5} x_{ij}\ .\ y_{s_3p_3}\ .\ w_{vi}\ +\ \sum_{i=1}^{20}\sum_{j=1}^{20}\sum_{p_4=1}^{8}\sum_{v=1}^{5} x_{ij}\ .\ y_{s_4p_4}\ .\ w_{vi}\ + \qquad (4.1)$$

$$\sum_{i=1}^{20}\sum_{j=1}^{20}\sum_{p_5=1}^{8} x_{ij}.\ y_{s_5p_5}\ .\ r_i\ .\ c_n\ \left(f_{ns_5}.\ d_{jp_5} + f_{ns_6}.\ d_{js_6} + f_{ns_7}.\ d_{js_7}\right)$$

Where:

$$w_{vi} = c_v\ .\ k_{iv}\ .\ f_{vs_n}.\ d_{jp_n} \quad n \in \{1,2,3,4\} \qquad (4.2)$$

Subject to:

$$\sum_{i=1}^{N} x_{ij} = 1 \quad \forall i \tag{4.3}$$

$$\sum_{j=1}^{N} x_{ij} = 1 \quad \forall j \tag{4.4}$$

$$x_{ij} = \begin{cases} 1, if\ facility\ i\ is\ assigned\ to\ location\ j \\ 0, otherwise \end{cases} \tag{4.5}$$

$$x_{ij} \in \{0,1\} \tag{4.6}$$

$$\sum_{p_1=1}^{8} y_{s_1p_1} = 1 \tag{4.7}$$

$$\sum_{p_2=1}^{8} y_{s_2p_2} = 1 \tag{4.8}$$

$$\sum_{p_3=1}^{8} y_{s_3p_3} = 1 \tag{4.9}$$

$$\sum_{p_4=1}^{8} y_{s_4p_4} = 1 \tag{4.10}$$

$$\sum_{p_5=1}^{8} y_{s_5p_5} = 1 \tag{4.11}$$

$$y_{s_1p_1}, y_{s_2p_2}, y_{s_3p_3}, y_{s_4p_4}, y_{s_5p_5} = \begin{cases} 1, if\ station\ s\ is\ assigned\ to\ position\ p \\ 0, otherwise \end{cases} \tag{4.12}$$

$$y_{s_1p_1}, y_{s_2p_2}, y_{s_3p_3}, y_{s_4p_4}, y_{s_5p_5} \in \{0,1\} \tag{4.13}$$

$$x_{2a} + x_{3b} \leq 1 \tag{4.14}$$

$$x_{6a} + x_{7b} \leq 1 \tag{4.15}$$

$$d_{ab} \geq 201 \tag{4.16}$$

$$a \neq b \tag{4.17}$$

In the objective function (4.1), vehicle costs are added according to the assignment of stations to first four positions. The need to group them in four equation sets, originates from the necessity to assign each station (Exercise Area, Training Area, Refueling Area, Main Gate) to one position among eight possible locations. The costs are calculated for each facility and vehicle types by multiplying the quantities of vehicles, their unit costs, frequencies and distances to these stations (4.2). At the last part of the objective function, total personnel transportation cost is calculated for three stations. According to constraints (4.3)-(4.6), each facility can be assigned to one location and there is only one facility at each location. Similarly, equations (4.7)-(4.13) provide that each station would be assigned to only one position. So facilities would be assigned to locations while stations would be assigned to positions. (4.14)-(4.17) make it possible to locate "Facility 2, 3" and "Facility 6, 7" adjacent. These facilities cannot be located separately if their assigned location distances are not between 125m horizontally and 200m vertically.

The product of the binary variables in objective function (4.1) "$x_{ij} \,.\, y_{sp}$", has been represented by some constraints for "x_{ij}" and "y_{sp}", in order to make the model expression linear. These constraints make it possible to multiply two binary variables while keeping the model linear. For example, let "x", "y" and "z" be the binary decision variables, among which "z" is the product of first two terms. Below constraints can be written for "z" (Bisschop, 2014):

$$z \leq x_{ij} \tag{4.18}$$

$$z \leq y_{sp} \tag{4.19}$$

$$z \geq x_{ij} + y_{sp} - 1 \tag{4.20}$$

$$x_{ij}, y_{sp}, z \in \{0,1\} \tag{4.21}$$

Adjacency of two facilities has been defined as the product of assignment of these variables as mentioned above. The adjacency of "Facility 1" and "Facility 2" in "Location 1" and "Location 2" is shown below:

$$Adj\_1(i,h) \leq x_{i1} \tag{4.22}$$

$$Adj\_1(i,h) \leq x_{h2} \tag{4.23}$$

$$Adj\_1(i,h) \geq x_{i1} + x_{h2} - 1 \tag{4.24}$$

$$Adj\_1(i,h), x_{i1}, x_{h2} \in \{0,1\} \tag{4.25}$$

Other adjacent locations like 1-5, 2-3, 2-6, 4-8 etc. (Adj_2, Adj_3, ..., Adj_31) have all been defined as binary variables. First group constraint for "Facility 1,2,3 and 4", shown in Figure 4.5, is given below:

$$\sum_{t_1=1}^{3} Adj\_1(1,t_1) + \sum_{t_1=1}^{3} Adj\_2(1,t_1) + \sum_{t_1=1}^{3} Adj\_3(1,t_1) + \cdots \geq 1 \tag{4.26}$$

$$\sum_{t_1=1}^{3} Adj\_1(4,t_1) + \sum_{t_1=1}^{4} Adj\_2(4,t_1) + \sum_{t_1=1}^{3} Adj\_3(4,t_1) + \cdots \geq 1 \tag{4.27}$$

where $t_1 = \{\text{Facility } 1, Facility\ 2, Facility\ 3, Facility\ 4\}$ and $t_1 <> "Facility\ 1"$ in expression (4.26) and $t_1 <> "Facility\ 4"$ in expression (4.27). In this group, "Facility 2" and "Facility 3" have already been assigned adjacently according to constraint (4.14). So, by (4.26) and (4.27), "Facility 1 and 4" can be adjacent to at least one of other 3 facilities in one of "Adj_" adjacency variable positions.

The model has been attempted to be solved to optimally by using AIMMS 4.2 optimization modeling software and adopting GUROBI 6.0 and CPLEX 12.6 solvers. Software was launched in a computer with the i7 2.7 Ghz processor and 6gb RAM. After three days, AIMMS 4.2 could not decrease the gap between linear bound and solution below 74,20% with an unconfirmed solution of "246,521.48 TL", which means serious computational time for an exact method. Therefore following assumptions and constraints have applied to the model in order to reach an optimal solution.

4.4.1. Assumption-1

It is obvious that constraints decrease solution sets of the problems and eventually makes the models to be solved in shorter computational times. So, for the model mentioned, one of the single facility, "Sports Facility" or "Facility 20", has been located to the assigned location in the suspended model with the solution "246,521.48". When the model ceased the assignment location for "Facility 20" was "Location 20". Therefore, constraint (4.28) has added to the model. This arrangement has been applied to decrease computational time and reach an optimal solution since "Sports Facility" has the lowest personnel amount without group relationship.

$$x_{20,20} = 1 \tag{4.28}$$

With constraint (4.28), the model reached an unconfirmed solution of "246,118.04 TL" on day three and did not change since it has been stopped manually on day twelve. But the total traveling cost of the brigade reached a better value comparing the model without constraint (4.28). So the location input turned out to demonstrate an unconfirmed optimal solution. Thus, same method has been tried again with Assumption-2 to let the software reach an optimal solution.

4.4.2. Assumption-2

Because optimal solution could not be reached with Assumption-1, constraint (4.29) included in the model as well.

$$x_{18,13} = 1 \tag{4.29}$$

With this constraint, another single facility, "Facility 18", has been located to "Location 13" where the model with Assumption-1 assigned "Facility 18". Using both constraints (4.28) and (4.29), an exact solution of "246,118.04 TL" has been found after fourteen hours. The solution indicated the best assignment when both facilities have been fixed because same value has been found since it was not confirmed with the previous assumption. It can be predicted that the model would verify the assignment as optimal if the locations of these facilities had not been changed. The results of Assumption-2 is presented in Figure 4.11.

4.4.3. Assumption-3

With this assumption, the effect of assignments for same single facilities ("Facility 18 and 20") have been searched for their locations in the existing plan. Assignments of these facilities in the existing plan can be seen in Figure 4.13. As shown in Figure 4.13, "Facility 18" has been located to "Location 16" where "Facility 20" to "Location 20". So, in order to compare the total traveling cost of the military base regarding these two facilities in existing plan locations and assumptions above, "Facility 18" and "Facility 20" have been assigned to planned design locations by constraints (4.30) and (4.31).

$$x_{18,16} = 1 \tag{4.30}$$

$$x_{20,20} = 1 \tag{4.31}$$

With the constraints above, the optimal solution reached to a value of "246,243.27 TL" after seventeen hours of computational process. Planned locations for these facilities could not reach a better value than Assumption-2. The results of Assumption-3 is presented in Figure 4.12. The comparison of Assumption-2, Assumption-3 and planned design are detailed in the following part.

4.5. Computational Results and Comparison

The results of the model, including constraints (4.28) and (4.29), for the decision variable "x_{ij}" is presented in Figure 4.7 and the other decision variable "y_{sp}" in Figure 4.8 :

j / i	Location 1	Location 2	Location 3	Location 4	Location 5	Location 6	Location 7	Location 8	Location 9	Location10	Location11	Location12	Location13	Location14	Location15	Location16	Location17	Location18	Location19	Location20
Facility 1	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☑	☐	☐	☐	☐
Facility 2	☐	☐	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Facility 3	☐	☐	☐	☐	☐	☐	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Facility 4	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐
Facility 5	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐
Facility 6	☐	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Facility 7	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Facility 8	☐	☐	☐	☐	☐	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Facility 9	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☑	☐
Facility 10	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☑	☐	☐	☐	☐	☐
Facility 11	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☑	☐	☐
Facility 12	☐	☐	☐	☐	☐	☐	☐	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Facility 13	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Facility 14	☐	☐	☐	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Facility 15	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☑	☐	☐	☐	☐	☐	☐
Facility 16	☐	☐	☐	☐	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Facility 17	☐	☐	☐	☐	☐	☐	☐	☐	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Facility 18	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☑	☐	☐	☐	☐	☐	☐	☐
Facility 19	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☑	☐	☐	☐
Facility 20	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☑

Figure 4.7 : Assignment of Facilities

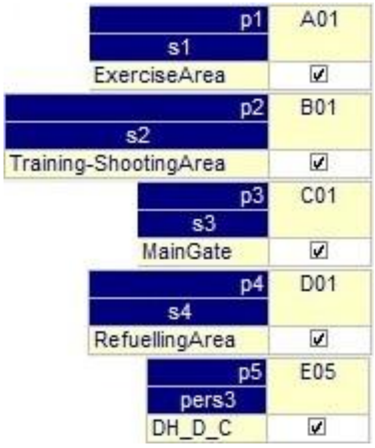

Figure 4.8 : Assignment of Stations

The solutions are provided in Figure 4.9. With over 22 million iterations, both facilities and stations have been located to appropriate places ensuring all constraints and solving time appeared to be fourteen hours.

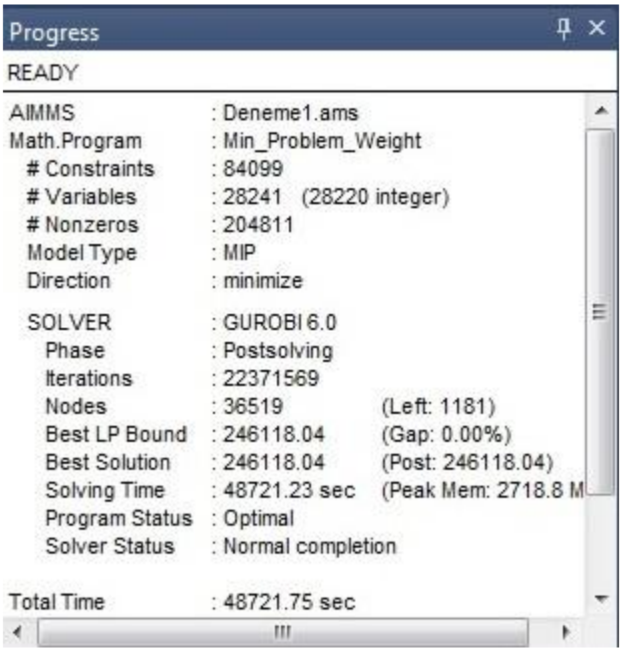

Figure 4.9 : AIMMS Solution

The value "246,118.04 TL" is the total travel cost of all vehicles and personnel belonging 20 facilities. This value can be considered as "TL" expense of a brigade regarding mostly vehicle expenses for 20 defined facilities, in a month. Of course, personnel cost is also included in this value and it is only "7,286.58 TL" where total vehicle cost is "238,831.46 TL". Figure 4.10 shows each facility total cost. It can be seen that even the highest value for personnel cost is "2,930" with "Facility 5", the lowest cost for vehicles is "20,212.38" with "Facility 2". Since facilities 4, 8, 11, 14 and 17 do not have any vehicle or personnel, they did not get any value. Results have also been verified manually in MS Excel, by using selected station and location distances derived from the optimized model.

Suffix i	Level	basic
Facility 1	2086.8	Basic
Facility 2	20212.37757	Basic
Facility 3	21583.58181	Basic
Facility 4		Basic
Facility 5	2930.4	Basic
Facility 6	61942.45792	Basic
Facility 7	61942.45792	Basic
Facility 8		Basic
Facility 9	577.8	Basic
Facility 10	20483.43722	Basic
Facility 11		Basic
Facility 12	785.7	Basic
Facility 13	26099.26343	Basic
Facility 14		Basic
Facility 15	853.5	Basic
Facility 16	26567.8861	Basic
Facility 17		Basic
Facility 18	37.78	Basic
Facility 19	9.478	Basic
Facility 20	5.12	Basic

Figure 4.10 : Total Facility Costs

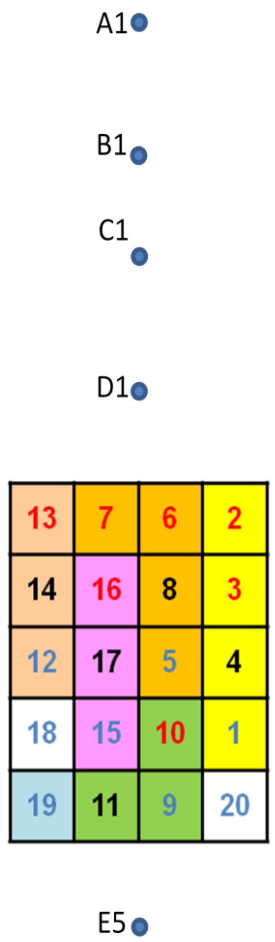

Figure 4.11 : Optimized Assignment

According to the results, facilities and stations are located as it is shown in Figure 4.11. Colored boxes represent facility groups that should be adjacent at least one another. White colored boxes represents fixed facilities (Facility 18 and 20). Facilities with vehicles can be seen in red colored numbers (Facility 2, 3, 6, 7, 10, 13, 16) where blue colored ones (Facility 1, 5, 9, 12, 15, 18, 19, 20) represent facilities with personnel. Numbers in black neither have vehicle nor personnel.

The results demonstrate that stations have been dispersed in a linear direction. The facilities having considerable amount of Tanks and APC are located at the north side locations of the unit area which are the nearest positions to the stations. The same is true for personnel facilities and station as well. Besides, the result do not change if "Facility 6 and 7" or "Facility 2 and 3" are replaced owing to the fact that they have same amount of vehicle type and frequency values. Since "set E" represents the station for personnel, most of the facilities with personnel have been assigned to the bottom part of the facility area. Even though eight possible positions have been taken into account for each station, selected positions provides lowest total travel cost.

Figure 4.12 : Assumption-3 Assignment

As mentioned previously, another model has also been run by the software using constraint (4.30) and (4.31). This model fixes "Facility 18" and "Facility 20" according to existing plan. The representation of this model is in Figure 4.12. The solution reached by this model is 246,243.27 TL which is 125.23 TL less than the optimized model in Assumption-2. This small difference constitutes 1,502.76 TL extra expense each year.

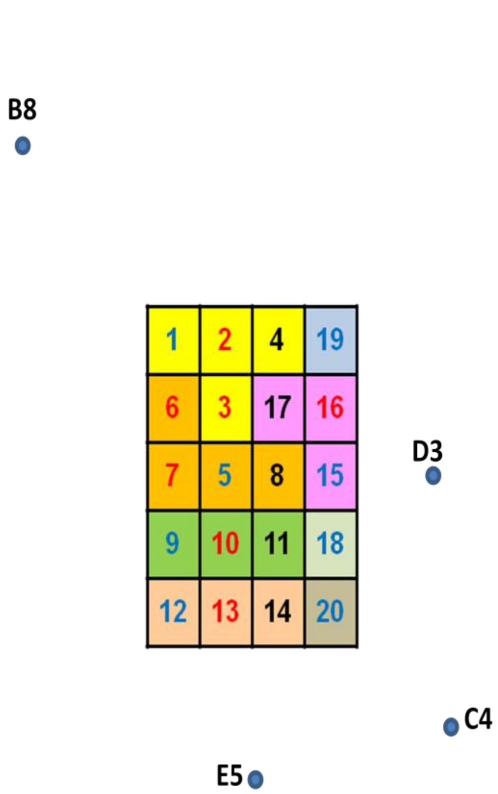

Figure 4.13 : Existing Plan

The representation of existing plan has been given in Figure 4.13. It can be seen that, stations are dispersed around unit area since there are other administrative and residential facilities in the brigade area. Comparing the model with this plan, the most used stations like "Exercise Area" (Position-A1) and "Training-Shooting Area" (Position B1) have turned out to be located at the positions adjacent to the existing plan (A2 and B8). Personnel station has been positioned at the exact place according to the existing plan which is Position-E5. Total travel cost of the planned design is calculated as 269,414.06 TL. Comparing this value with the optimal solution (246,118.04) it can be seen that there is a 23,296.02 TL difference in a month which means 279,552.24 TL annually. The difference constitutes 8.64% of the existing plan. Moreover, the difference between Figure 4.12 and 4.13 is 23,170.79 TL monthly and 278,049.48 annually. Consequently, even though only facilities "18" and "20" are fixed in the planned model, other station and facility assignments shows 8.60% lower value than the existing plan. As it is mentioned before, there may be lots of other constraints and variables considering a brigade layout problem regarding site and terrain conditions. So, more facilities, distance and frequency relations as well as needs could be evaluated according to the facts. The idea here is to represent a model suitable for adjacency and group relationships including different stations. The model has been applied to a military base including realistic factors and parameters. The details of parameters, constraints and variables can be found in the output of the model in Appendix-A.

CHAPTER 5

CONCLUSION

Most of the studies about facility layout optimization or facility design use heuristic or meta-heuristic approaches in order to obtain near optimal solutions. These approaches show themselves in construction area as well. As a result of dynamic nature of sites, construction site layout problems usually involve algorithms in their models. Considering the significance of these problems, exact procedures for layout optimization processes are less in number comparing to heuristic and meta-heuristic searches. This thesis study, aimed to develop an optimization model with an exact solution involving more facilities than common layout problems. The model applied to a specific military facility in order to optimize total traveling costs by locating sample military facilities. A wide literature review has been initiated before the study about construction and facility layout optimization approaches, formulizations, models and solution methods. Depending on the objective function with integer variables, a mixed integer linear programming model has been developed and solved with an optimum layout scenario for a brigade level military facility.

Considering the objectives specific to military units, personnel, vehicle, daily schedules, facility sizes, their relationships and efficiency issues have been evaluated. Then, related data have been gathered and analyzed with military personnel.

There are not many researches concerning military base layouts. Studied ones generally involve less significant decision elements in their layout formulations. The problem discussed is unique since an uncommon public institute is subjected in its scope. The elements of the model and travel costs worked in this study is a significant approach in a military layout decision making process. Developed model includes not only the most important facilities in a military base, but also some determined stations, both for personnel and vehicles, routes of which used frequently in daily activities and exercises. The model required supporting data to locate facilities and stations at the same time. Besides increasing solving time, the model became applicable for twenty facilities and extra five stations. This problem size, regarding facilities included, is significant when it is compared with $n \leq 10$ sized assignment or QAP problems in the area of FLPs. But it should be emphasized that, certain dimensions of locations and total area, and equal facilities made remarkable support in the formulation of the problem.

Moreover, the MIP model considers placing five stations with eight different possible positions. Decision variables both with binary (0/1) and integer values in the objective function led problem to mixed integer modeling that is widely used in site and facility layout problems. However, using two different decision variables in the same model is a strategy for the assignment of all facilities and stations while keeping the model still linear.

Although gathered information have been turned into parameters and made the problem easy to define, adjacency relationships, group assignments and station placements have made the problem difficult and increased the computational time requirement. Grouping some facilities and constraining them with at least one adjacency is also one of the novel contributions of this research. Modeling groups with different sizes and giving adjacency constraints to them can be applied to any related department group with more than one element. The adjacency relationships presented can also be applied to construction layout optimization problems requiring adjacency constraints. The model results have been compared with an already existing layout plan. Solutions have shown that appropriate assignment of facilities can decrease total travel cost up to 8.64% of planned assignment with 279,552.24 TL income value annually which is a considerable one. Unlike the characteristic of site layouts, military facility layout requires a long-term decision. As can be derived from model solution, similar to site machines, total travel costs of military vehicles, including consumption and maintenance expenses, as well as personnel transportation costs, are important factors in decision making processes that should not be ignored.

Military facility layout optimization problem can be extended by including movable units for the military bases established for assistance tasks abroad, especially in the member countries of special agreements, and also for short time domestic duties or large scale exercises. Similar to site facilities, dynamic feature of the layout for movable units like immediate reaction force or emergency service teams can be studied and involved in the model. Besides, facility constraints can be improved for their location decisions considering soil structure and geological conditions of the layout. This may lead to the representation of three dimensional military layout consisting different decision variables. Construction expenses like excavation works can be included for each facility and station to increase efficiency. Since roads inside the unit area have been ignored as they would not be used by vehicles, different road alternatives and trips can be taken as flow elements of the model regarding environmental security systems like watchtowers. Moreover, military layout analysis can be determined according to different facility dimensions that are not fixed. Thus, layout can be divided into small grids that can be allocated facilities with distinct grid numbers. All of these parameters may cause difficulties for an exact solution and lead to the search of meta-heuristic approaches in order to reach near-optimal results considering specific needs of each layout design.

Future work regarding any public facility layout problem can be developed by increasing parameters or demanded constraints mentioned above according to organization objectives and department relations. Adding more variables into the model can be an option for any organization to gain exact solutions as long as computational times can be reduced. Efficient modeling can decrease computation times as well as giving appropriate design solutions. Linear models can make it easy to assess and develop problem, however other methods, like branch and bound, can also be applied for exact solutions. Computational time can be decreased by using suitable software, solvers and improved computer processors.

REFERENCES

Afentakis, P.A., (1989). "Loop Layout Design Problem for Flexible Manufacturing Systems", International Journal of Flexible Manufacturing Systems, v1, pp. 143-175.

Aiello, G., and Enea, M., (2001). "Fuzzy Approach to the Robust Facility Layout in Uncertain Production Environments", International Journal of Production Research, v39(18), pp. 4089-4101.

Amaral, A.R.S., (2006). "Discrete Optimization on the Exact Solution of a Facility Layout Problem ", European Journal of Operational Research, v173, pp. 508-518.

Amaral, A.R.S., (2009). " A New Lower Bound for the Single Row Facility Layout Problem ", Discreet Applied Mathematics, v157, pp. 183-190.

Azadivar, F., and Wang, J., (2000). "Facility Layout Optimization Using Simulation and Genetic Algorithms", International Journal of Production Research, v38(17), pp. 4369-4383.

Balakrishnan, J., Cheng, C.H., and Wong, K.F., (2003). "FACOPT: A User Friendly Facility Layout Optimization System", Computers and Operations Research, v30(11), pp. 1625-1641.

Balakrishnan, J., Cheng, C.H., Conway, D.G., and Lau, C.M., (2003). "A Hybrid Genetic Algorithm for the Dynamic Plant Layout Problem", International Journal of Production Economics, v86(2), pp. 107-120.

Balakrishnan, J., Robert Jacobs, F., and Venkataramanan, M.A., (1992). "Solutions for the Constrained Dynamic Facility Layout Problem", European Journal of Operational Research, v57(2), pp. 280-286.

Baykasoglu, A., and Gindy, N.N.Z., (2001). "A Simulated Annealing Algorithm for Dynamic Layout Problem", Computers and Operations Research, v28(14), pp. 1403-1426.

Baykasoglu, A., Dereli, T., and Sabuncu, I., (2006). "An Ant Colony Algorithm for Solving Budget Constraint and Unconstraint Dynamic Facility Layout Problems", Omega, v34(4), pp. 385-396.

Bisschop, J., (2014). "AIMMS Optimization Modeling", pp.83-85.

Braglia, M., (1996). "Optimization of a Simulated-Annealing-Based Heuristic for Single Row Machine Layout Problem by Genetic Algorithm", International Transactions in Operational Research, v3(1), pp. 37-49.

Braglia, M., Zanoni, S., and Zavanella, L., (2003). "Layout Design in Dynamic Environments: Strategies and Quantitative Indices", International Journal of Production Research, v41(5), 995-1016.

Buffa, E.S., Armour, G.C., and Vollman, T.E., (1964). "Allocating Facilities with CRAFT", Harvard Business Review, v42, pp. 136-157.

Burkard, R.E., (2008). "Quadratic Assignment Problems", Handbook of Combinatorial Optimization, Second Edition, Springer Reference, pp. 2741-2814.

Burkard, R., Dell'Amico, M., Martello, S., (2009). "Assignment Problems", Society for Industrial and Applied Mathematics, pp. 8.

Chen, C.W., and Sha, D.Y., (2005). "Heuristic Approach for Solving the Multi-objective Facility Layout Problem", International Journal of Production Research, v43(21), pp. 4493-4507.

Cheng, R., and Gen, M., (1998). "Loop Layout Design Problem in Flexible Manufacturing Systems Using Genetic Algorithms", Computers and Industrial Engineering, v34(1), pp. 53-61.

Cheng, R., Gen, M., and Tosawa, T., (1996). "Genetic Algorithms for Designing Loop Layout Manufacturing Systems", Computers and Industrial Engineering, v31(3-4), pp. 587-591.

Chiang, W.C., and Kouvelis, P., (1996). "An Improved Tabu Search Heuristic For Solving Facility Layout Design Problems", International Journal of Production Research, v34(9), pp. 2565-2585.

Chung, Y.K. (1999). "A neuro-based expert system for facility layout construction", Journal of Intelligent Manufacturing, v10(5),pp. 359-385.

Chwif, L., Pereira Barretto, M.R., and Moscato, L.A., (1998). "A Solution to the Facility Layout Problem Using Simulated Annealing", Computers in Industry, v36(1–2), pp. 125-132.

Co, H.C., Wu, A., and Reisman, A., (1989). "A Throughput-Maximizing Facility Planning and Layout Model", International Journal of Production Research, v27(1), pp. 1-12.

Das, S.K., (1993). "A Facility Layout Method for Flexible Manufacturing Systems", International Journal of Production Research, v31(2), pp. 279-297.

Deb, S.K., and Bhattacharyya, B., (2005). "Fuzzy Decision Support Systems for Manufacturing Facilities Layout Planning", Decision Support Systems, v40, pp. 305-314.

Devise, O., and Pierreval, A., (2000). "Indicators for Measuring Performances of Morphology and Materials Handling Systems", International Journal of Production Economics, v64(1–3), pp. 209-218.

Dilworth, J.B., (1996). "Operation Management", McGraw Hill.

Drira, A., Pierreval, H., and Hajri-Gabouj, S., (2007). "Facility Layout Problems: A Survey", Annual Reviews in Control, v31, pp. 255-267.

Dweiri, F., and Meier, F.A., (1996). "Application of Fuzzy Decision-Making in Facilities Layout Planning", International Journal of Production Research, v34(11), pp. 3207-3225.

El-Ansary, A.M., and Shalaby, M.F., (2014). "Sustainable Cities and Society", v11, pp. 48-55.

El-Baz, M.A., (2004). "A Genetic Algorithm for Facility Layout Problems of Different Manufacturing Environments", Computers and Industrial Engineering, v47(2–3), pp. 233-246.

El-Rayes, K., and Khalafallah, A., (2005). "Trade-Off Between Safety and Cost in Planning Construction Site Layouts", Journal of Construction Engineering and Management, v131, pp. 1186-1195.

El-Rayes, K., and Said, H., (2009). "Dynamic Site Layout Planning Using Approximate Dynamic Programming", Journal of Computing in Civil Engineering, v23(2), pp. 119-127.

Elbeltagi, E., Hegazy, T., and Eldosouky, A., (2004). "Dynamic Layout of Construction Temporary Facilities Considering Safety", Journal of Construction Engineering and Management, v130, pp. 534-541.

Evans, G.W., Wilhlem, M.R., and Karwowsky, W., (1987). "A Layout Design Heuristic Employing the Theory of Fuzzy Sets", International Journal of Production Research, v25, pp. 1431-1450.

Ezell, B.C., and Davis, M.J., (2001). "Base Camp Design: Site Selection and Facility Layout", A Technical Report of the Operations Research Center, United States Military Academy.

Foulds, L.R., (1991). "Graph Theory and Applications", Springer, Berlin Heidelberg, New York.

Francis, R.L., and White J.A., (1974). "Facility Layout and Location: An Analytical Approach", Printice Hall, Englewood Cliffs, NJ.

Fruggiero, F., Lambiase, A., and Negri, F., (2006). "Design and Optimization of a Facility Layout Problem in Virtual Environment", In Proceeding of ICAD 2006, pp. 2206.

Garey, M.R., and Johnson, D.S., (1979). "Computers and Intractability: A Guide to the Theory of NP-Completeness", WH Freeman, New York.

Gen, M., Ida, K., and Cheng, C., (1995). "Multi Row Machine Layout Problem in Fuzzy Environment Using Genetic Algorithms", Computers and Industrial Engineering, v29(1–4), pp. 519-523.

Grobelny, J., (1987). "The Fuzzy Approach to Facility Layout Problems", Fuzzy Sets and Systems, v23, pp. 175-190.

Gupta, T., and Seifoddini, H., (1990). "Production Data Based Similarity Coefficient for Machine–Component Grouping Decisions in the Design of Cellular Manufacturing System", International Journal of Production Research, v28(4), pp. 1247-1269.

Hadi-Vencheh, A., and Mohamadghasemi, A., (2013). "An Integrated AHP-NLP Methodology for Facility Layout Design", Journal of Manufacturing Systems, v32, pp. 40-45.

Hamann, T., and Vernadat, F., (1992). "The Intra Cell Layout Problem in Automated Manufacturing System", 8th International Conference on CAD/CAM, Robotics and Factory of the Future (CARs and FOF 92).

Harmanani, H., Zouein, P., and Hajar, A., (2000). "An Evolutionary Algorithm for Solving the Geometrically Constrained Site Layout Problem", Computing in Civil and Building Engineering, pp. 1442-1449.

Hassan, M.M.D., (1994). "Machine Layout Problem in Modern Manufacturing Facilities", International Journal of Production Research, v32(11), pp. 2559-2584.

Hassan, M.M.D., and Hogg, G.L., (1989). "On Converting a Dual Graph into a Block Layout", International Journal of Production Research, v27, n7, pp. 1149-1160.

Hassan, M.M.D., and Hogg, G.L., (1991). "On Constructing a Block Layout by Graph Theory", International Journal of Production Research, v6, pp. 1263-1278.

Hegazy, H., and Elbeltagi, E., (1999). "EvoSite: Evolution Based Model for Site Layout Planning", Journal of Computing in Civil Engineering", v13, pp. 198-206.

Heragu, S.S., (2008). "Facilities Design", Third Edition, CRC Press, Taylor and Francis Group.

Heragu, S., and Kusiak, A., (1991). "Efficient Models for the Facility Layout Problems", European Jeurnal of Operational Research, v53, pp. 1-13.

http://afvdb.50megs.com/usa/m113.html, (Last accessed on 20.11.2014).

http://www.fnss.com.tr/urun/m113-modernizasyonu/teknik-ozellikler, (Last accessed on 20.11.2014).

http://www.mercedes-benz.com.tr, "Unimog U 4000" Broşür, Mercedes-Benz Türk A.Ş., Mart, 2010, (Last accessed on 20.11.2014).

http://www.otobilge.com/Arac/Ford-24/Tourneo-Connect-MPV-5-Kapi-617/2010-2011-145/TDCi-110-HP-Manuel-5310, (Last accessed on 20.11.2014).

http://www.tank-net.com/forums/index.php?showtopic=33715, (Last accessed on 20.11.2014).

Kettani, O., and Oral, M., (1993). "Reformulating Quadratic Assignment Problems for Efficient Optimization", IIE Transactions, v25, pp. 97-107.

Kim, C.B., Kim, S.S., and Bobbie, L.F., (1996). "Assignment Problems in Single-Row and Double-Row Machine Layouts During Slow and Peak Periods", Computers and Industrial Engineering, v30(3), pp. 411-422.

Kim, J.Y., and Kim, Y.D., (1995). "Graph Theoretic Heuristics for Unequal-Sized Facility Layout Problems", Omega, v23(4), pp. 391-401.

Kim, J.Y., and Kim, Y.D., (1999). "A Branch-and-Bound Algorithm for Locating Input and Output Points of Departments on the Block Lyout", J Oper Res Soc, 50, pp. 517-525.

Kim, J.G., and Kim, Y.D., (2000). "Layout Planning for Facilities with Fixed Shapes and Input and Output Points", International Journal of Production Research, v38(18), pp. 4635-4653.

Kochhar, J.S., and Heragu, S.S., (1998). "MULTI-HOPE: A Tool for Multiple Floor Layout Problems", International Journal of Production Research, v36(12), pp. 3421-3435.

Konak, A., Kulturel Konak, S., Norman, B.A., and Smith, A.E., (2006). "A New Mixed Integer Programming Formulation for Facility Layout Design Using Flexible Bays", Operations Research Letters, v34, pp. 660-672.

Koopmans, T.C., and Beckman, M., (1957). "Assignment Problems and the Location of Economic Activities", Econometrica, v25, pp. 53-76.

Kouvelis, P., and Kim, M.W., (1992). "Unidirectional Loop Network Layout Problem in Automated Manufacturing Systems", Operations Research, v40, pp. 533-550.

Kusiak, A., and Heragu, S.S., (1987). "The Facility Layout Problem", European Journal of Operational Research, v29, pp. 229-251.

Lacksonen, T.A., (1994). "Static and Dynamic Facility Layout Problems with Varying Areas", Journal of Operational Research Soc, v45, pp. 59-69.

Lacksonen, T.A., (1997). "Pre-processing for Static and Dynamic Facility Layout Problems", International Journal of Production Research, v35, pp. 1095-1106.

Lacksonen, T.A., and Enscore, E. E., (1993). "Quadratic Assignment Algorithms for the Dynamic Layout Problem", International Journal of Production Research, v31, pp. 503-517.

Lee, G.C., and Kim, Y. D., (2000). "Algorithms for Adjusting Shapes of Departments in Block Layouts on the Gird-Based Plane", Omega, v28(1), pp. 111-122.

Lee, K.Y., Roh, M.I., and Jeong, H.S., (2005). "An Improved Genetic Algorithm for Multi-Floor Facility Layout Problems Having Inner Structure Walls and Passages", Computers & Operations Research, v32(4), pp. 879-899.

Lee, Y.H., and Lee, M.H., (2002). "A Shape-Based Block Layout Approach to Facility Layout Problems Using Hybrid Genetic Algorithm", Computers and Industrial Engineering, v42, pp. 237-248.

Li, H., and Love, E.D., (1998). "Site-Level Facilities Layout Using Genetic Algorithms", Journal of Computing in Civil Engineering , v12, pp. 227-231.

Liang, L.Y., Chao, W.C., (2008). "The Strategies of Tabu Search Technique for Facility Layout Optimization", Automation in Construction, v17, pp. 657-669.

Loiola, E.M., Abreu, N.M.M., Boaventura-Netto, P.O., Hahn, P., and Querido, T., (2007). "A Survey for the Quadratic Assignment Problem", European Journal of Operational Research, v176, pp. 657-690.

Ma, Z., Shen, Q., and Zhang, J., (2005). "Application of 4D for Dynamic Site Layout and Management of Construction Projects", Automation in Construction, v14, pp. 369-381.

Mahdi, A.H., Amet, H., and Portman, M.C., (1998). "Physical Layout with Minimization of the Transport Cost", Research Internal Report, Nancy, France: LORIA.

Matsuzaki, K., Takashi, I., and Yoshimoto, K., (1999). "Heuristic Algorithm to Solve the Multi-Floor Layout Problem with the Consideration of Elevator Utilization", Computers & Industrial Engineering, v36(2), pp. 487-502.

Mawdesley, M.J., and Al-Jibouri, S.H., (2003). "Proposed Genetic Algorithms for Construction Site Layout", Engineering Applications of Artificial Intelligence, v16, pp. 501-509.

Mawdesley, M.J., Al-Jibouri, S.H., and Yang, H., (2002). "Genetic Algorithms for Construction Site Layout in Project Planning", Journal of Construction Engineering and Management, v128(5), pp. 418-426.

McKendall, A.R., Shang, J., and Kuppusamy, S., (2006). "Simulated Annealing Heuristics for the Dynamic Facility Layout Problem", Computers and Operations Research, v33(8), pp. 2431-2444.

Meller, R.D., and Bozer, Y. A., (1996). "A New Simulated Annealing Algorithm for the Facility Layout Problem", International Journal of Production Research, v34, pp. 1675-1692.

Meller, R.D., and Bozer, Y. A., (1997). "Alternative Approaches to Solve the Multi-Floor Facility Layout Problem", Journal of Manufacturing System, v16(3), pp. 192-203.

Meller, R.D., and Gau, K., (1996). "The Facility Layout Problem: Recent and Emerging Trends and Perspectives", Journal of Manufacturing Systems, v15(5), pp. 351-366.

Meller, R.D., Narayanan, V., and Vance, P.H., (1999). "Optimal Facility Layout Design", Operations Research Letters, v23(3-5), pp. 117-127.

Meng, G., Heragu, S.S., and Zijm, H., (2004). "Reconfigurable Layout Problem", International Journal of Production Research, v42(22), pp. 4709-4729.

Mir, M., and Imam, M.H., (2001). "A Hybrid Optimization Approach forLlayout Design of Unequal-Area Facilities", Computers & Industrial Engineering, v39(1-2), pp. 49-63.

Montreuil, B., (1990). "A Modeling Framework for Integrating Layout Design and Flow Network Design", Proceedings of the Material Handling Research Colloquium, Hebron, KY, pp. 43-58.

Ning, X., Lam, K., and Lam, M.C., (2011). "A Decision Making System for Construction Site Layout Planning", Automation in Construction, v20, pp. 459-473.

Osman, H.M., and Georgy, M.E., (2005). "Layout Planning of Construction Sites Considering Multiple Objectives: A Goal Programming Approach", Construction Research Congress.

Page, A.L., (1991). "New Product Development Survey: Performance, and Best Practices", PDMA Conference.

Patsiatzis, D.I., and Papageorgiou, L.G., (2002). "Optimal Multi-Floor Process Plant Layout", Computers and Chemical Engineering, v26(4-5), pp. 575-583.

Raoot, A.D., and Rakshit, A., (1991). "A Fuzzy Approach to Facilities Layout Planning", International Journal of Production Research, v29, pp. 835-857.

Razavialavi, S., Abourizk, S., and Alanjari, P., (2014). "Estimating the Size of Temporary Facilities in Construction Site Layout Plannning Using Simulation", Construction Research Congress, pp. 70-79.

Robertson, M.U., Ezell, B.C., and McGinnis, M.L., (2001). "Base Camp Facility Layout", Systems, Man, and Cybernetics, 2001 IEEE International Conference, v(3), pp. 2064-2070.

Rosenblatt, M.J., (1986). "The Dynamics of Plant Layout", Management Science, v32(1), pp. 76-86.

Sadeghpour, F., Moselhi, O, and Alkass, S.T., (2006). "Computer-Aided Site Layout Planning", Journal of Construction Engineering and Management, v132, pp. 143-151.

Said, H., and El-Rayes, K., (2013). "Performance of Global Optimization Models for Dynamic Site Layout Planning of Construction Projects", Automation in Construction, v36, pp. 71-78.

Scholz, D., Petrick, A, and Domschke, W., (2009). "STaTS: A Slicing Tree and Tabu Search Based Heuristic for the Unequal Area Facility Layout Problem", European Journal of Operational Research, v197, pp. 166-178.

Segal, R.S., (2000). "Some Quantitative Methods for Determining Capacities and Locations of Military Emergency Medical Facilities", Applied Mathematical Modelling, v24(5), pp. 365-389.

Shayan, E., and Chittilappilly, A., (2004). "Genetic Algorithm for Facilities Layout Problems Based on Slicing Tree Structure", International Journal of Production Research, v42(19), pp. 4055-4067.

Singh, S.P., and Sharma, R.R.K., (2006). "A Review of Different Approaches to the Facility Layout Problems", v30, International Journal of Advanced Manufacturing Technology, v30, pp. 425-433.

Sirinaovakul, B., and Thajchayapong, P., (1996). "An Analysis of Computer-Aided Facility Layout Techniques", International Journal of Computer Integrated Manufacturing, v9(4), pp. 260-264.

Solimanpur, M., and Jafari, A., (2008). "Optimal Solution for the Two Dimensional Facility Layout Problem Using a Branch and Bound Algorithm", Computers and Industrial Engineering, v55, pp. 606-619.

Solimanpur, M., Vrat, P., and Shankar, R., (2005). "An Ant Algorithm for the Single Row Layout Problem in Flexible Manufacturing Systems", Computers and Operations Research, v32(3), pp.583-598.

Stewart, C., (2015). "Optimization of Military Installation Siting Based on Explosive Safety Standards Using Genetic Algorithms", MS Thesis, Department of Civil and Environmental Engineering, Brigham Young University.

Sule, D.R., (2008). "Manufacturing Facilities: Location, Planning and Design", CRC Press, Taylor and Francis Group pp. xxi,279.

Tate, D.M., and Smith, A.E., (1995). "A Genetic Approach to the Quadratic Assignment Problem", Computers and Operations Research, v22, pp. 73-83.

Tavakkoli-Moghaddam, R., Javadian, N., Javadi, B., and Safaei, N., (2007). "Design of a Facility Layout Problem in Cellular Manufacturing Systems with Stochastic Demands", Applied Mathematics and Computation, v184, pp. 721-728.

Tommelein, I.D., Levitt, R.E., and Hayes-Roth, B., (1992). "Sight Plan Model for Site Layout", Journal of Construction Engineering and Management, v118(4), pp. 749-766.

Tompkins, J.A., and White, J.A., (1984). "Facilities Planning", Wiley, New York.

Tompkins, J.A., White, J. A., Bozer, Y. A., Frazelle, E. H., Tanchoco, J. M., and Trevino, J., (1996). "Facilities Planning", New York: Wiley.

Tompkins, J.A., White, J.A., Bozer, Y.A., and Tanchoco, M.A., (2010). ""Facilities Planning", Fourth Edition, John Wiley and Sons Inc.

Tsuchiya, K., Bharitkar, S., and Takefuji, Y., (1996). "A Neural Network Approach to Facility Layout Problems", European Journal of Operational Research, v89(3), pp.556-563.

Wang, H.J., Zhang, J.P., Chau, K.W., and Anson, M., (2004). "4D Dynamic Management for Consturction Planning and Resource Utilization", Automation in Construction, v13, pp. 575-589.

Wang, M.J., Hu, M.H., and Ku, M.H., (2005). "A Solution to the Unequal Area Facilities Layout Problem by Genetic Algorithm", Computers in Industry, v56(2), pp. 207-220.

Welgama, P.S., and Gibson, P.R., (1993). "A Construction Algorithm for the Machine Layout Problem with Fixed Pick-up and Drop-off Points", International Journal of Production Research, v31(11), pp. 2575-2590.

Wong, C.K., Fung, W.H., Tam, C.M., (2010). " Comparison of Using Mixed-Integer Programming and Genetic Algorithms for Construction Site Facility Layout Planning", Journal of Construction Engineering and Management, v136, pp. 1116-1128.

Xie, W., and SahinidisN.V., (2008). "A Branch and Bound Algorithm for the Continuous Facility Layout Problem", Computers and Chemical Engineering, v32, pp. 1016-1028.

Yahya, M., and Saka, M.P., (2014). "Construction Site Layout Planning Using Multi-Objective Artificial Bee Colony Algorithm with Levy Flights", Automation in Construction, v38, pp. 14-29.

Yang, T., and Kuo, C., (2003). "A Hierarchical AHP/DEA Methodology for the Facilities Layout Design Problem", European Journal of Operational Research, v147, pp. 128-136.

Yang, T., Peters, B.A., and Tu, M., (2005). "Layout Design for Flexible Manufacturing Systems Considering Single-Loop Directional Flow Patterns", European Journal of Operational Research, v164(2), pp. 440-455.

Yeh, I., (1995). "Construction-Site Layout Using Annealed Neural Network", Journal of Computing in Civil Engineering, v9, pp. 201-208.

Zhang, H., and Wang, J.Y., (2008). "Particle Swarm Optimization for Construction Site Unequal-Area Layout", Journal of Construction Engineering and Management, v134, pp. 739-748.

Zhou, F., AbouRizk, S.M., and AL-Battaineh, H., (2009). "Optimization of Construction Site Layout Using a Hybrid Simulation Based System", Simulation Modelling Practice and Theory, v17, pp. 348-363.

Zouein, P.P., and Tommelein, I.D., (1999). "Dynamic Layout Planning Using a Hybrid Incremental Solution Method", Journal of Construction Engineering and Management", v125, pp. 400-408.

Zouein, P.P., Harmanani, H., and Hajar, A., (2002). "Genetic Algorithm for Solving site Layout Problem with Unequal-Size and Constrained Facilities", Journal of Computing in Civil Engineering, v16(2), pp. 143-151.

APPENDIX A

PROBLEM TEXT OUTPUT

```
Model Military_Layout_Optimization {
    Set Facilities {
        Index: i, h;
        Definition: {
            data
                { 'Facility 1' , 'Facility 2' , 'Facility 3' , 'Facility 4' , 'Facility 5' , 'Facility 6' , 'Facility 7' , 'Facility 8' ,
                  'Facility 9' , 'Facility 10', 'Facility 11', 'Facility 12', 'Facility 13', 'Facility 14', 'Facility 15', 'Facility 16',
                  'Facility 17', 'Facility 18', 'Facility 19', 'Facility 20' }
        }
    }
    Set Fac_1234 {
        SubsetOf: Facilities;
        Index: t1;
        Definition: data { 'Facility 1', 'Facility 2', 'Facility 3', 'Facility 4' };
    }
    Set Fac_5678 {
        SubsetOf: Facilities;
        Index: t4;
        Definition: data { 'Facility 5', 'Facility 6', 'Facility 7', 'Facility 8' };
    }
    Set Fac_91011 {
        SubsetOf: Facilities;
        Index: t5;
        Definition: data { 'Facility 9', 'Facility 10', 'Facility 11' };
    }
    Set Fac_121314 {
        SubsetOf: Facilities;
        Index: t6;
        Definition: data { 'Facility 12', 'Facility 13', 'Facility 14' };
    }
    Set Fac_151617 {
        SubsetOf: Facilities;
        Index: t7;
        Definition: data { 'Facility 15', 'Facility 16', 'Facility 17' };
    }
    Set Locations {
        Index: j, l;
        Definition: {
            data
                { 'Location 1', 'Location 2', 'Location 3', 'Location 4', 'Location 5', 'Location 6', 'Location 7', 'Location
8', 'Location 9', Location10  , Location11  , Location12  , Location13  , Location14  , Location15  , Location16  ,
Location17  , Location18  , Location19  , Location20  }
        }
    }
    Set PerS_1 {
        Index: pers1;
```

```
    Definition: 'Facility 18';
}
Set PerS_2 {
    Index: pers2;
    Definition: 'Facility 20';
}
Set PerS_3 {
    Index: pers3;
    Definition: 'DH_D_C';
}
Set S1_ {
    Index: s1;
    Definition: data {ExerciseArea};
}
Set S2_ {
    Index: s2;
    Definition: data {Training-ShootingArea};
}
Set S3_ {
    Index: s3;
    Definition: data {MainGate};
}
Set S4_ {
    Index: s4;
    Definition: data {RefuellingArea};
}
Set P1_ {
    Index: p1;
    Definition: data { A01, A02, A03, A04, A05, A06, A07, A08 };
}
Set P2_ {
    Index: p2;
    Definition: {
        {'B01'..'B08'}
    }
}
Set P3_ {
    Index: p3;
    Definition: {
        {'C01'..'C08'}
    }
}
Set P4_ {
    Index: p4;
    Definition: {
        {'D01'..'D08'}
    }
}
Set P5_ {
    Index: p5;
    Definition: {
        {'E01'..'E08'}
    }
}
Set Vehicles {
    Index: k;
    InitialData: data { Tank, APC, Unimog, Landrover, Van };
}
Set Personnel {
    Index: r;
```

```
      Definition: 'Per Cap';
   }
   Parameter FacPersonnel {
      IndexDomain: (i,r);
      Definition: {
         data
         { ( 'Facility 1' , 'Per Cap' ) : 1200,  ( 'Facility 5' , 'Per Cap' ) : 1200,  ( 'Facility 9' , 'Per Cap' ) :  600,
           ( 'Facility 12', 'Per Cap' ) :  300,  ( 'Facility 15', 'Per Cap' ) :  500,  ( 'Facility 18', 'Per Cap' ) :   20,
           ( 'Facility 19', 'Per Cap' ) :    7,  ( 'Facility 20', 'Per Cap' ) :    5 }
      }
   }
   Parameter PerWeight {
      IndexDomain: r;
      Definition: data { 'Per Cap' : 0.00005 };
   }
   Parameter Per_Weight_PerFac {
      IndexDomain: (i,r);
      Definition: {
         data
         { ( 'Facility 1' , 'Per Cap' ) : 0.06000,  ( 'Facility 5' , 'Per Cap' ) : 0.06000,  ( 'Facility 9' , 'Per Cap' ) :
0.03000, ( 'Facility 12', 'Per Cap' ) : 0.01500,  ( 'Facility 15', 'Per Cap' ) : 0.02500,  ( 'Facility 18', 'Per Cap' ) :
0.00100,  ( 'Facility 19', 'Per Cap' ) : 0.00035,  ( 'Facility 20', 'Per Cap' ) : 0.00025 }
      }
      Comment: "FacPersonnel(i,r)*PerWeight(r)";
   }
   Parameter Freq_Per_PerS_1 {
      IndexDomain: (r,pers1);
      Definition: data { ( 'Per Cap', 'Facility 18' ) : 4 };
   }
   Parameter Freq_Per_PerS_2 {
      IndexDomain: (r,pers2);
      Definition: data { ( 'Per Cap', 'Facility 20' ) : 20 };
   }
   Parameter Freq_Per_PerS_3 {
      IndexDomain: (r,pers3);
      Definition: data { ( 'Per Cap', DH_D_C ) : 60 };
   }
   Parameter Distance_PerS3 {
      IndexDomain: (j,p5);
      Definition: {
         data
         { ( 'Location 1', E01 ) :  313,  ( 'Location 1', E02 ) :  650,  ( 'Location 1', E03 ) :  928,  ( 'Location 1', E04 )
: 1076, ( 'Location 1', E05 ) : 1067,  ( 'Location 1', E06 ) :  902,  ( 'Location 1', E07 ) :  611,  ( 'Location 1', E08 ) :
279, ('Location 2', E01 ) :  258,  ( 'Location 2', E02 ) :  526,  ( 'Location 2', E03 ) :  817,  ( 'Location 2', E04 ) :
1006, ('Location 2', E05 ) : 1052,  ( 'Location 2', E06 ) :  947,  ( 'Location 2', E07 ) :  711,  ( 'Location 2', E08 ) :
402, ('Location 3', E01 ) :  258,  ( 'Location 3', E02 ) :  402,  ( 'Location 3', E03 ) :  711,  ( 'Location 3', E04 ) :
947, ('Location 3', E05 ) : 1052,  ( 'Location 3', E06 ) : 1006,  ( 'Location 3', E07 ) :  817,  ( 'Location 3', E08 ) :
526, ('Location 4', E01 ) :  313,  ( 'Location 4', E02 ) :  279,  ( 'Location 4', E03 ) :  611,  ( 'Location 4', E04 ) :
902, ('Location 4', E05 ) : 1067,  ( 'Location 4', E06 ) : 1076,  ( 'Location 4', E07 ) :  928,  ( 'Location 4', E08 ) :
650, ('Location 5', E01 ) :  488,  ( 'Location 5', E02 ) :  697,  ( 'Location 5', E03 ) :  861,  ( 'Location 5', E04 ) :
924, ('Location 5', E05 ) :  870,  ( 'Location 5', E06 ) :  714,  ( 'Location 5', E07 ) :  504,  ( 'Location 5', E08 ) :
376, ('Location 6', E01 ) :  454,  ( 'Location 6', E02 ) :  583,  ( 'Location 6', E03 ) :  740,  ( 'Location 6', E04 ) :
841, ('Location 6', E05 ) :  852,  ( 'Location 6', E06 ) :  770,  ( 'Location 6', E07 ) :  621,  ( 'Location 6', E08 ) :
474, ('Location 7', E01 ) :  454,  ( 'Location 7', E02 ) :  474,  ( 'Location 7', E03 ) :  621,  ( 'Location 7', E04 ) :
770, ('Location 7', E05 ) :  852,  ( 'Location 7', E06 ) :  841,  ( 'Location 7', E07 ) :  740,  ( 'Location 7', E08 ) :
583, ('Location 8', E01 ) :  488,  ( 'Location 8', E02 ) :  376,  ( 'Location 8', E03 ) :  504,  ( 'Location 8', E04 ) :
714, ('Location 8', E05 ) :  870,  ( 'Location 8', E06 ) :  924,  ( 'Location 8', E07 ) :  861,  ( 'Location 8', E08 ) :
697, ('Location 9', E01 ) :  677,  ( 'Location 9', E02 ) :  794,  ( 'Location 9', E03 ) :  838,  ( 'Location 9', E04 ) :
794, ('Location 9', E05 ) :  677,  ( 'Location 9', E06 ) :  534,  ( 'Location 9', E07 ) :  463,  ( 'Location 9', E08 ) :
534,(Location10  , E01 ) :  653,  ( Location10  , E02 ) :  696,  ( Location10  , E03 ) :  713,  ( Location10  , E04 ) :
```

```
696,(Location10  , E05 ) :  653,  ( Location10  , E06 ) :  607,  ( Location10  , E07 ) :  588,  ( Location10  , E08 ) :
607,(Location11  , E01 ) :  653,  ( Location11  , E02 ) :  607,  ( Location11  , E03 ) :  588,  ( Location11  , E04 ) :
607,(Location11  , E05 ) :  653,  ( Location11  , E06 ) :  696,  ( Location11  , E07 ) :  713,  ( Location11  , E08 ) :
696,(Location12  , E01 ) :  677,  ( Location12  , E02 ) :  534,  ( Location12  , E03 ) :  463,  ( Location12  , E04 ) :
534,(Location12  , E05 ) :  677,  ( Location12  , E06 ) :  794,  ( Location12  , E07 ) :  838,  ( Location12  , E08 ) :
794,(Location13  , E01 ) :  870,  ( Location13  , E02 ) :  924,  ( Location13  , E03 ) :  861,  ( Location13  , E04 ) :
697,(Location13  , E05 ) :  488,  ( Location13  , E06 ) :  376,  ( Location13  , E07 ) :  504,  ( Location13  , E08 ) :
714,(Location14  , E01 ) :  852,  ( Location14  , E02 ) :  841,  ( Location14  , E03 ) :  740,  ( Location14  , E04 ) :
583,(Location14  , E05 ) :  454,  ( Location14  , E06 ) :  474,  ( Location14  , E07 ) :  621,  ( Location14  , E08 ) :
770,(Location15  , E01 ) :  852,  ( Location15  , E02 ) :  770,  ( Location15  , E03 ) :  621,  ( Location15  , E04 ) :
474,(Location15  , E05 ) :  454,  ( Location15  , E06 ) :  583,  ( Location15  , E07 ) :  740,  ( Location15  , E08 ) :
841,(Location16  , E01 ) :  870,  ( Location16  , E02 ) :  714,  ( Location16  , E03 ) :  504,  ( Location16  , E04 ) :
376,(Location16  , E05 ) :  488,  ( Location16  , E06 ) :  697,  ( Location16  , E07 ) :  861,  ( Location16  , E08 ) :
924,(Location17 , E01 ) : 1067,  ( Location17  , E02 ) : 1076,  ( Location17  , E03 ) :  928,  ( Location17  , E04 ) :
650,( Location17  , E05 ) :  313,  ( Location17  , E06 ) :  279,  ( Location17  , E07 ) :  611,  ( Location17  , E08 ) :
902,( Location18 , E01 ) : 1052,  ( Location18 , E02 ) : 1006,  ( Location18  , E03 ) :  817,  ( Location18  , E04 ) :
526,(Location18, E05 ) :  258,  (Location18  , E06 ) :  402,  ( Location18  , E07 ) :  711,  ( Location18  , E08 ) :
947,(Location19, E01 ) : 1052,  ( Location19 , E02 ) :  947,  ( Location19  , E03 ) :  711,  ( Location19  , E04 ) :
402,(Location19, E05 ) :  258,  ( Location19  , E06 ) :  526,  ( Location19  , E07 ) :  817,  ( Location19  , E08 ) :
1006,(Location20, E01 ) : 1067,  ( Location20  , E02 ) :  902,  ( Location20  , E03 ) :  611,  ( Location20  , E04 ) :
279,(Location20  , E05 ) :  313,  ( Location20  , E06 ) :  650,  ( Location20  , E07 ) :  928,  ( Location20  , E08 ) :
1076 }
      }
   }
   Parameter FacVehicles {
      IndexDomain: (i,k);
      Definition: {
         data
         { ( 'Facility 2' , APC       ) :  60,  ( 'Facility 2' , Unimog    ) :  53,  ( 'Facility 2' , Landrover ) :   6,
           ( 'Facility 3' , APC       ) :  60,  ( 'Facility 3' , Unimog    ) :  53,  ( 'Facility 3' , Landrover ) :   6,
           ( 'Facility 6' , Tank      ) :  40,  ( 'Facility 6' , APC       ) :  14,  ( 'Facility 6' , Unimog    ) :  49,
           ( 'Facility 6' , Landrover ) :   5,  ( 'Facility 7' , Tank      ) :  40,  ( 'Facility 7' , APC       ) :  14,
           ( 'Facility 7' , Unimog    ) :  49,  ( 'Facility 7' , Landrover ) :   5,  ( 'Facility 10', APC       ) :  28,
           ( 'Facility 10', Unimog    ) :  83,  ( 'Facility 10', Landrover ) :   7,  ( 'Facility 13', Tank      ) :   2,
           ( 'Facility 13', APC       ) :  51,  ( 'Facility 13', Unimog    ) :  94,  ( 'Facility 13', Landrover ) :   8,
           ( 'Facility 13', Van       ) :   1,  ( 'Facility 16', APC       ) :  11,  ( 'Facility 16', Unimog    ) : 170,
           ( 'Facility 16', Landrover ) :  17,  ( 'Facility 16', Van       ) :   1 }
      }
   }
   Parameter VehicleWeight {
      IndexDomain: k;
      Definition: data { Tank : 0.02106,  APC : 0.00351,  Unimog : 0.00081,  Landrover : 0.00053,  Van : 0.00025
};
   }
   Parameter Veh_Weights_PerFac {
      IndexDomain: (i,k);
      Definition: {
         data
         { ( 'Facility 2' , APC       ) : 0.21060,  ( 'Facility 2' , Unimog    ) : 0.04293,  ( 'Facility 2' , Landrover ) :
0.00318, ( 'Facility 3' , APC       ) : 0.21060,  ( 'Facility 3' , Unimog    ) : 0.04293,  ( 'Facility 3' , Landrover ) :
0.00318, ( 'Facility 6' , Tank      ) : 0.84240,  ( 'Facility 6' , APC       ) : 0.04914,  ( 'Facility 6' , Unimog    ) :
0.03969, ( 'Facility 6' , Landrover ) : 0.00265,  ( 'Facility 7' , Tank      ) : 0.84240,  ( 'Facility 7' , APC       ) :
0.04914, ( 'Facility 7' , Unimog    ) : 0.03969,  ( 'Facility 7' , Landrover ) : 0.00265,  ( 'Facility 10', APC       ) :
0.09828, ( 'Facility 10', Unimog    ) : 0.06723,  ( 'Facility 10', Landrover ) : 0.00371,  ( 'Facility 13', Tank      ) :
0.04212, ( 'Facility 13', APC       ) : 0.17901,  ( 'Facility 13', Unimog    ) : 0.07614,  ( 'Facility 13', Landrover ) :
0.00424, ( 'Facility 13', Van       ) : 0.00025,  ( 'Facility 16', APC       ) : 0.03861,  ( 'Facility 16', Unimog    ) :
0.13770, ( 'Facility 16', Landrover ) : 0.00901,  ( 'Facility 16', Van       ) : 0.00025 }
      }
      Comment: "FacVehicles(i,k)*VehicleWeight(k)";
   }
```

```
   Parameter Frequency_Veh_S1 {
      IndexDomain: (k,s1);
      Definition: data { ( Tank, ExerciseArea ) : 5,  ( APC, ExerciseArea ) : 5,  ( Unimog, ExerciseArea ) : 10,  (
Landrover, ExerciseArea ) : 20 };
   }
   Parameter Frequency_Veh_S2 {
      IndexDomain: (k,s2);
      Definition: {
         data
         { ( Tank     , Training-ShootingArea ) : 15,  ( APC      , Training-ShootingArea ) : 15,
           ( Unimog   , Training-ShootingArea ) : 40,  ( Landrover, Training-ShootingArea ) : 30 }
      }
   }
   Parameter Frequency_Veh_S3 {
      IndexDomain: (k,s3);
      Definition: data { ( Unimog, MainGate ) : 3,  ( Landrover, MainGate ) : 10,  ( Van, MainGate ) : 40 };
   }
   Parameter Frequency_Veh_S4 {
      IndexDomain: (k,s4);
      Definition: {
         data
         { ( Tank     , RefuellingArea ) : 1,  ( APC      , RefuellingArea ) : 1,  ( Unimog   , RefuellingArea ) : 1,
           ( Landrover, RefuellingArea ) : 1,  ( Van      , RefuellingArea ) : 1 }
      }
   }
   Parameter Distance_P1 {
      IndexDomain: (j,p1);
      Definition: {
         data
         { ( 'Location 1', A01 ) : 4604,  ( 'Location 1', A02 ) : 4867,  ( 'Location 1', A03 ) : 5203,  ( 'Location 1',
A04 ) : 5418, ( 'Location 1', A05 ) : 5403,  ( 'Location 1', A06 ) : 5167,  ( 'Location 1', A07 ) : 4829,  ( 'Location
1', A08 ) : 4587, ( 'Location 2', A01 ) : 4600,  ( 'Location 2', A02 ) : 4773,  ( 'Location 2', A03 ) : 5078,
('Location 2', A04 ) : 5332, ( 'Location 2', A05 ) : 5400,  ( 'Location 2', A06 ) : 5249,  ( 'Location 2', A07 ) : 4954,
( 'Location 2',A08) : 4679, ( 'Location 3', A01 ) : 4600,  ( 'Location 3', A02 ) : 4679,  ( 'Location 3', A03 ) : 4954,
( 'Location 3',A04) : 5249, ( 'Location 3', A05 ) : 5400,  ( 'Location 3', A06 ) : 5332,  ( 'Location 3', A07 ) : 5078,
( 'Location 3',A08) : 4773, ( 'Location 4', A01 ) : 4604,  ( 'Location 4', A02 ) : 4587,  ( 'Location 4', A03 ) : 4829,
( 'Location 4',A04) : 5167,  ( 'Location 4', A05 ) : 5403,  ( 'Location 4', A06 ) : 5418,  ( 'Location 4', A07 ) : 5203,
( 'Location 4',A08) : 4867, ( 'Location 5', A01 ) : 4804,  ( 'Location 5', A02 ) : 4999,  ( 'Location 5', A03 ) : 5191,
( 'Location 5',A04) : 5274, ( 'Location 5', A05 ) : 5203,  ( 'Location 5', A06 ) : 5016,  ( 'Location 5', A07 ) : 4817,
( 'Location 5',A08) : 4726,  ( 'Location 6', A01 ) : 4800,  ( 'Location 6', A02 ) : 4906,  ( 'Location 6', A03 ) : 5066,
( 'Location 6',A04) : 5187, ( 'Location 6', A05 ) : 5200,  ( 'Location 6', A06 ) : 5101,  ( 'Location 6', A07 ) : 4942,
( 'Location 6',A08) : 4815, ( 'Location 7', A01 ) : 4800,  ( 'Location 7', A02 ) : 4815,  ( 'Location 7', A03 ) : 4942,
( 'Location 7',A04) : 5101, ( 'Location 7', A05 ) : 5200,  ( 'Location 7', A06 ) : 5187,  ( 'Location 7', A07 ) : 5066,
( 'Location 7',A08) : 4906, ( 'Location 8', A01 ) : 4804,  ( 'Location 8', A02 ) : 4726,  ( 'Location 8', A03 ) : 4817,
( 'Location 8',A04) : 5016,  ( 'Location 8', A05 ) : 5203,  ( 'Location 8', A06 ) : 5274,  ( 'Location 8', A07 ) : 5191,
( 'Location 8',A08) : 4999,  ( 'Location 9', A01 ) : 5004,  ( 'Location 9', A02 ) : 5134,  ( 'Location 9', A03 ) : 5188,
( 'Location 9',A04) : 5134, ( 'Location 9', A05 ) : 5004,  ( 'Location 9', A06 ) : 4869,  ( 'Location 9', A07 ) : 4813,
( 'Location 9',A08) : 4869, ( Location10, A01) : 5000,  ( Location10  , A02 ) : 5044,  ( Location10  , A03 ) : 5063,
( Location10,A04) : 5044, ( Location10, A05 ) : 5000,  ( Location10  , A06 ) : 4956,  ( Location10  , A07 ) : 4938,
( Location10,A08) : 4956,  (Location11, A01 ) : 5000,  ( Location11  , A02 ) : 4956,  ( Location11  , A03 ) : 4938,
( Location11,A04): 4956,  ( Location11, A05 ) : 5000,  ( Location11  , A06 ) : 5044,  ( Location11  , A07 ) : 5063,
( Location11,A08): 5044,( Location12, A01 ) : 5004,  ( Location12  , A02 ) : 4869,  ( Location12  , A03 ) : 4813,
( Location12,A04): 4869,( Location12, A05 ) : 5004,  ( Location12  , A06 ) : 5134,  ( Location12  , A07 ) : 5188,
( Location12,A08): 5134,( Location13, A01 ) : 5203,  ( Location13  , A02 ) : 5274,  ( Location13  , A03 ) : 5191,
( Location13,A04): 4999,( Location13, A05 ) : 4804,  ( Location13  , A06 ) : 4726,  ( Location13  , A07 ) : 4817,
( Location13,A08): 5016,( Location14, A01 ) : 5200,  ( Location14  , A02 ) : 5187,  ( Location14  , A03 ) : 5066,
( Location14,A04): 4906,( Location14, A05 ) : 4800,  ( Location14  , A06 ) : 4815,  ( Location14  , A07 ) : 4942,
( Location14,A08): 5101,( Location15, A01 ) : 5200,  ( Location15  , A02 ) : 5101,  ( Location15  , A03 ) : 4942,
( Location15,A04): 4815,( Location15, A05 ) : 4800,  ( Location15  , A06 ) : 4906,  ( Location15  , A07 ) : 5066,
( Location15,A08): 5187,( Location16, A01 ) : 5203,  ( Location16  , A02 ) : 5016,  ( Location16  , A03 ) : 4817,
```

```
( Location16,A04): 4726,( Location16, A05 ) : 4804,  ( Location16  , A06 ) : 4999,  ( Location16  , A07 ) : 5191,
( Location16,A08): 5274,( Location17, A01 ) : 5403,  ( Location17  , A02 ) : 5418,  ( Location17  , A03 ) : 5203,
( Location17,A04): 4867,( Location17, A05 ) : 4604,  ( Location17  , A06 ) : 4587,  ( Location17  , A07 ) : 4829,
( Location17,A08): 5167,( Location18, A01 ) : 5400,  ( Location18  , A02 ) : 5332,  ( Location18  , A03 ) : 5078,
( Location18,A04): 4773,( Location18, A05 ) : 4600,  ( Location18  , A06 ) : 4679,  ( Location18  , A07 ) : 4954,
( Location18,A08): 5249,( Location19, A01 ) : 5400,  ( Location19  , A02 ) : 5249,  ( Location19  , A03 ) : 4954,
( Location19,A04): 4679,( Location19, A05 ) : 4600,  ( Location19  , A06 ) : 4773,  ( Location19  , A07 ) : 5078,
( Location19,A08): 5332,( Location20, A01 ) : 5403,  ( Location20  , A02 ) : 5167,  ( Location20  , A03 ) : 4829,
( Location20,A04): 4587,( Location20, A05 ) : 4604,  ( Location20  , A06 ) : 4867,  ( Location20  , A07 ) : 5203,
( Location20,A08): 5418 }
      }
   }
   Parameter Distance_P2 {
      IndexDomain: (j,p2);
      Definition: {
         data
         { ( 'Location 1', B01 ) : 2607,  ( 'Location 1', B02 ) : 2880,  ( 'Location 1', B03 ) : 3213,  ( 'Location 1',
B04 ) : 3419, ( 'Location 1', B05 ) : 3405,  ( 'Location 1', B06 ) : 3178,  ( 'Location 1', B07 ) : 2841,  ( 'Location 1',
B08 ) : 2589, ( 'Location 2', B01 ) : 2601,  ( 'Location 2', B02 ) : 2781,  ( 'Location 2', B03 ) : 3089,  ( 'Location 2',
B04 ) : 3336, ( 'Location 2', B05 ) : 3401,  ( 'Location 2', B06 ) : 3255,  ( 'Location 2', B07 ) : 2965,  ( 'Location 2',
B08 ) : 2684,  ( 'Location 3', B01 ) : 2601,  ( 'Location 3', B02 ) : 2684,  ( 'Location 3', B03 ) : 2965, ( 'Location 3',
B04 ) : 3255, ( 'Location 3', B05 ) : 3401,  ( 'Location 3', B06 ) : 3336,  ( 'Location 3', B07 ) : 3089,  ( 'Location 3',
B08 ) : 2781, ( 'Location 4', B01 ) : 2607,  ( 'Location 4', B02 ) : 2589,  ( 'Location 4', B03 ) : 2841,  ( 'Location 4',
B04 ) : 3178, ( 'Location 4', B05 ) : 3405,  ( 'Location 4', B06 ) : 3419,  ( 'Location 4', B07 ) : 3213,  ( 'Location 4',
B08 ) : 2880, ( 'Location 5', B01 ) : 2806,  ( 'Location 5', B02 ) : 3004,  ( 'Location 5', B03 ) : 3194,  ( 'Location 5',
B04 ) : 3274, ( 'Location 5', B05 ) : 3205,  ( 'Location 5', B06 ) : 3021,  ( 'Location 5', B07 ) : 2820,  ( 'Location 5',
B08 ) : 2726, ( 'Location 6', B01 ) : 2801,  ( 'Location 6', B02 ) : 2909,  ( 'Location 6', B03 ) : 3069,  ( 'Location 6',
B04 ) : 3187, ( 'Location 6', B05 ) : 3201,  ( 'Location 6', B06 ) : 3103,  ( 'Location 6', B07 ) : 2944,  ( 'Location 6',
B08 ) : 2816, ( 'Location 7', B01 ) : 2801,  ( 'Location 7', B02 ) : 2816,  ( 'Location 7', B03 ) : 2944,  ( 'Location 7',
B04 ) : 3103, ( 'Location 7', B05 ) : 3201,  ( 'Location 7', B06 ) : 3187,  ( 'Location 7', B07 ) : 3069,  ( 'Location 7',
B08 ) : 2909, ( 'Location 8', B01 ) : 2806,  ( 'Location 8', B02 ) : 2726,  ( 'Location 8', B03 ) : 2820,  ( 'Location 8',
B04 ) : 3021, ( 'Location 8', B05 ) : 3205,  ( 'Location 8', B06 ) : 3274,  ( 'Location 8', B07 ) : 3194,  ( 'Location 8',
B08 ) : 3004, ( 'Location 9', B01 ) : 3006,  ( 'Location 9', B02 ) : 3135,  ( 'Location 9', B03 ) : 3188,  ( 'Location 9',
B04 ) : 3135, ( 'Location 9', B05 ) : 3006,  ( 'Location 9', B06 ) : 2870,  ( 'Location 9', B07 ) : 2813,  ( 'Location 9',
B08): 2870, (Location10,B01) : 3001,  ( Location10  , B02 ) : 3045,  ( Location10  , B03 ) : 3063,  ( Location10 ,
B04 ) : 3045,(Location10, B05 ) : 3001,  ( Location10  , B06 ) : 2956,  ( Location10  , B07 ) : 2938,  ( Location10
, B08 ) : 2956, (Location11  , B01 ) : 3001,  ( Location11  , B02 ) : 2956,  ( Location11  , B03 ) : 2938,
(Location11  , B04 ) : 2956, ( Location11  , B05 ) : 3001,  ( Location11  , B06 ) : 3045,  (Location11, B07) : 3063,
( Location11 ,B08 ) : 3045, ( Location12  , B01 ) : 3006,  ( Location12  , B02 ) : 2870,  (Location12, B03 ) : 2813,
( Location12  , B04 ) : 2870, ( Location12  , B05 ) : 3006,  ( Location12  , B06 ) : 3135, (Location12, B07) : 3188,
( Location12  , B08 ) : 3135, ( Location13  , B01 ) : 3205,  ( Location13  , B02 ) : 3274, (Location13, B03) : 3194,
( Location13  , B04 ) : 3004, ( Location13  , B05 ) : 2806,  ( Location13  , B06 ) : 2726, (Location13, B07) : 2820,
( Location13  , B08 ) : 3021, ( Location14  , B01 ) : 3201,  ( Location14  , B02 ) : 3187, (Location14, B03) : 3069,
( Location14  , B04 ) : 2909, ( Location14  , B05 ) : 2801,  ( Location14  , B06 ) : 2816, (Location14, B07) : 2944,
( Location14  , B08 ) : 3103, ( Location15  , B01 ) : 3201,  ( Location15  , B02 ) : 3103, (Location15, B03) : 2944,
( Location15  , B04 ) : 2816, ( Location15  , B05 ) : 2801,  ( Location15  , B06 ) : 2909, (Location15, B07) : 3069,
( Location15  , B08 ) : 3187, ( Location16  , B01 ) : 3205,  ( Location16  , B02 ) : 3021, (Location16, B03) : 2820,
( Location16  , B04 ) : 2726, ( Location16  , B05 ) : 2806,  ( Location16  , B06 ) : 3004, (Location16, B07) : 3194,
( Location16  , B08 ) : 3274, ( Location17  , B01 ) : 3405,  ( Location17  , B02 ) : 3419, (Location17, B03) : 3213,
( Location17  , B04 ) : 2880, ( Location17  , B05 ) : 2607,  ( Location17  , B06 ) : 2589, (Location17, B07) : 2841,
( Location17  , B08 ) : 3178, ( Location18  , B01 ) : 3401,  ( Location18  , B02 ) : 3336, (Location18, B03) : 3089,
( Location18  , B04 ) : 2781,( Location18  , B05 ) : 2601,  ( Location18  , B06 ) : 2684, (Location18, B07 ) : 2965,
( Location18  , B08 ) : 3255, ( Location19  , B01 ) : 3401,  ( Location19  , B02 ) : 3255, (Location19, B03) : 2965,
( Location19  , B04 ) : 2684, ( Location19  , B05 ) : 2601,  ( Location19  , B06 ) : 2781, (Location19, B07) : 3089,
( Location19  , B08 ) : 3336, ( Location20  , B01 ) : 3405,  ( Location20  , B02 ) : 3178, (Location20, B03) : 2841,
( Location20  , B04 ) : 2589,( Location20  , B05 ) : 2607,  ( Location20  , B06 ) : 2880, (Location20, B07) : 3213,
( Location20  , B08 ) : 3419 }
      }
   }
   Parameter Distance_P3 {
```

```
      IndexDomain: (j,p3);
      Definition: {
         data
         { ( 'Location 1', C01 ) :  397,  ( 'Location 1', C02 ) :  730,  ( 'Location 1', C03 ) : 1019, ('Location 1', C04) :
1175, ( 'Location 1', C05 ) : 1165,  ( 'Location 1', C06 ) :  991,  ( 'Location 1', C07 ) :  690,  ( 'Location 1', C08 ) :
367, ( 'Location 2', C01 ) :  356,  ( 'Location 2', C02 ) :  607,  ( 'Location 2', C03 ) :  906,  ( 'Location 2', C04 ) :
1103, ( 'Location 2', C05 ) : 1152,  ( 'Location 2', C06 ) : 1041,  ( 'Location 2', C07 ) :  795,  ( 'Location 2', C08 ) :
486, ( 'Location 3', C01 ) :  356,  ( 'Location 3', C02 ) :  486,  ( 'Location 3', C03 ) :  795,  ( 'Location 3', C04 ) :
1041, ( 'Location 3', C05 ) : 1152,  ( 'Location 3', C06 ) : 1103,  ( 'Location 3', C07 ) :  906,  ( 'Location 3', C08 ) :
607, ( 'Location 4', C01 ) :  397,  ( 'Location 4', C02 ) :  367,  ( 'Location 4', C03 ) :  690,  ( 'Location 4', C04 ) :
991, ( 'Location 4', C05 ) : 1165,  ( 'Location 4', C06 ) : 1175,  ( 'Location 4', C07 ) : 1019,  ( 'Location 4', C08 ) :
730, ( 'Location 5', C01 ) :  581,  ( 'Location 5', C02 ) :  790,  ( 'Location 5', C03 ) :  959,  ( 'Location 5', C04 ) :
1024, ( 'Location 5', C05 ) :  968,  ( 'Location 5', C06 ) :  807,  ( 'Location 5', C07 ) :  597,  ( 'Location 5', C08 ) :
476, ( 'Location 6', C01 ) :  554,  ( 'Location 6', C02 ) :  679,  ( 'Location 6', C03 ) :  837,  ( 'Location 6', C04 ) :
941, ( 'Location 6', C05 ) :  952,  ( 'Location 6', C06 ) :  867,  ( 'Location 6', C07 ) :  716,  ( 'Location 6', C08 ) :
573, ( 'Location 7', C01 ) :  554,  ( 'Location 7', C02 ) :  573,  ( 'Location 7', C03 ) :  716,  ( 'Location 7', C04 ) :
867, ( 'Location 7', C05 ) :  952,  ( 'Location 7', C06 ) :  941,  ( 'Location 7', C07 ) :  837,  ( 'Location 7', C08 ) :
679, ( 'Location 8', C01 ) :  581,  ( 'Location 8', C02 ) :  476,  ( 'Location 8', C03 ) :  597,  ( 'Location 8', C04 ) :
807, ( 'Location 8', C05 ) :  968,  ( 'Location 8', C06 ) : 1024,  ( 'Location 8', C07 ) :  959,  ( 'Location 8', C08 ) :
790, ( 'Location 9', C01 ) :  773,  ( 'Location 9', C02 ) :  892,  ( 'Location 9', C03 ) :  938,  ( 'Location 9', C04 ) :
892, ( 'Location 9', C05 ) :  773,  ( 'Location 9', C06 ) :  631,  ( 'Location 9', C07 ) :  563,  ( 'Location 9', C08 ) :
631, ( Location10  , C01 ) :  753,  ( Location10  , C02 ) :  795,  ( Location10  , C03 ) :  813,  ( Location10, C04 ) :
795, ( Location10  , C05 ) :  753,  ( Location10  , C06 ) :  707,  ( Location10  , C07 ) :  688,  ( Location10, C08 ) :
707, ( Location11  , C01 ) :  753,  ( Location11  , C02 ) :  707,  ( Location11  , C03 ) :  688,  ( Location11, C04 ) :
707, ( Location11  , C05 ) :  753,  ( Location11  , C06 ) :  795,  ( Location11  , C07 ) :  813,  ( Location11, C08 ) :
795, ( Location12  , C01 ) :  773,  ( Location12  , C02 ) :  631,  ( Location12  , C03 ) :  563,  ( Location12 , C04 ) :
631, ( Location12  , C05 ) :  773,  ( Location12  , C06 ) :  892,  ( Location12  , C07 ) :  938,  ( Location12, C08 ) :
892, ( Location13  , C01 ) :  968,  ( Location13  , C02 ) : 1024,  ( Location13  , C03 ) :  959,  ( Location13, C04 ) :
790, ( Location13  , C05 ) :  581,  ( Location13  , C06 ) :  476,  ( Location13  , C07 ) :  597,  ( Location13, C08 ) :
807, ( Location14  , C01 ) :  952,  ( Location14  , C02 ) :  941,  ( Location14  , C03 ) :  837,  ( Location14, C04 ) :
679, ( Location14  , C05 ) :  554,  ( Location14  , C06 ) :  573,  ( Location14  , C07 ) :  716,  ( Location14, C08 ) :
867, ( Location15  , C01 ) :  952,  ( Location15  , C02 ) :  867,  ( Location15  , C03 ) :  716,  ( Location15, C04 ) :
573, ( Location15  , C05 ) :  554,  ( Location15  , C06 ) :  679,  ( Location15  , C07 ) :  837,  ( Location15, C08 ) :
941, ( Location16  , C01 ) :  968,  ( Location16  , C02 ) :  807,  ( Location16  , C03 ) :  597,  ( Location16, C04 ) :
476, ( Location16  , C05 ) :  581,  ( Location16  , C06 ) :  790,  ( Location16  , C07 ) :  959,  ( Location16, C08 ) :
1024, ( Location17 , C01 ) : 1165,  ( Location17  , C02 ) : 1175,  ( Location17  , C03 ) : 1019, (Location17,C04) :
730,  ( Location17 , C05 ) :  397,  ( Location17  , C06 ) :  367,  ( Location17  , C07 ) :  690,  (Location17,C08) :
991, ( Location18 , C01 ) : 1152,  ( Location18  , C02 ) : 1103,  ( Location18 , C03 ) :  906,  (Location18,C04) :
607, ( Location18 , C05 ) :  356,  ( Location18  , C06 ) :  486,  ( Location18  , C07 ) :  795,  (Location18,C08 ) :
1041, ( Location19 , C01 ) : 1152,  ( Location19  , C02 ) : 1041,  ( Location19, C03 ) : 795,(Location19, C04 ) :
486, ( Location19, C05 ) :  356,  ( Location19  , C06 ) :  607,  ( Location19 , C07 ) :  906, (Location19 , C08 ) :
1103, ( Location20, C01 ) : 1165,  ( Location20  , C02 ) :  991,  ( Location20 , C03 ) :  690,(Location20, C04 ) :
367, ( Location20, C05 ) :  397,  ( Location20  , C06 ) :  730,  ( Location20, C07 ) : 1019,  ( Location20, C08 ) :
1175 }
      }
   }
   Parameter Distance_P4 {
      IndexDomain: (j,p4);
      Definition: {
         data
         { ( 'Location 1', D01 ) :  274,  ( 'Location 1', D02 ) :  612,  ( 'Location 1', D03 ) :  883,( 'Location 1', D04) :
1026, ( 'Location 1', D05 ) : 1017,  ( 'Location 1', D06 ) :  858,  ( 'Location 1', D07 ) :  575,  ( 'Location 1', D08 ) :
238, ( 'Location 2', D01 ) :  210,  ( 'Location 2', D02 ) :  487,  ( 'Location 2', D03 ) :  774,  ( 'Location 2', D04 ) :
957, ( 'Location 2', D05 ) : 1002,  ( 'Location 2', D06 ) :  900,  ( 'Location 2', D07 ) :  670,  ( 'Location 2', D08 ) :
363, ( 'Location 3', D01 ) :  210,  ( 'Location 3', D02 ) :  363,  ( 'Location 3', D03 ) :  670,  ( 'Location 3', D04 ) :
900, ( 'Location 3', D05 ) : 1002,  ( 'Location 3', D06 ) :  957,  ( 'Location 3', D07 ) :  774,  ( 'Location 3', D08 ) :
487, ( 'Location 4', D01 ) :  274,  ( 'Location 4', D02 ) :  238,  ( 'Location 4', D03 ) :  575,  ( 'Location 4', D04 ) :
858, ( 'Location 4', D05 ) : 1017,  ( 'Location 4', D06 ) : 1026,  ( 'Location 4', D07 ) :  883,  ( 'Location 4', D08 ) :
612, ( 'Location 5', D01 ) :  442,  ( 'Location 5', D02 ) :  652,  ( 'Location 5', D03 ) :  813,  ( 'Location 5', D04 ) :
874, ( 'Location 5', D05 ) :  822,  ( 'Location 5', D06 ) :  668,  ( 'Location 5', D07 ) :  458,  ( 'Location 5', D08 ) :
```

```
326, ( 'Location 6', D01 ) :  405,  ( 'Location 6', D02 ) :  536,  ( 'Location 6', D03 ) :  692,  ( 'Location 6', D04 ) :
792, ( 'Location 6', D05 ) :  802,  ( 'Location 6', D06 ) :  722,  ( 'Location 6', D07 ) :  574,  ( 'Location 6', D08 ) :
426, ( 'Location 7', D01 ) :  405,  ( 'Location 7', D02 ) :  426,  ( 'Location 7', D03 ) :  574,  ( 'Location 7', D04 ) :
722, ( 'Location 7', D05 ) :  802,  ( 'Location 7', D06 ) :  792,  ( 'Location 7', D07 ) :  692,  ( 'Location 7', D08 ) :
536, ( 'Location 8', D01 ) :  442,  ( 'Location 8', D02 ) :  326,  ( 'Location 8', D03 ) :  458,  ( 'Location 8', D04 ) :
668, ( 'Location 8', D05 ) :  822,  ( 'Location 8', D06 ) :  874,  ( 'Location 8', D07 ) :  813,  ( 'Location 8', D08 ) :
652, ( 'Location 9', D01 ) :  629,  ( 'Location 9', D02 ) :  744,  ( 'Location 9', D03 ) :  788,  ( 'Location 9', D04 ) :
744, ( 'Location 9', D05 ) :  629,  ( 'Location 9', D06 ) :  486,  ( 'Location 9', D07 ) :  413,  ( 'Location 9', D08 ) :
486, ( Location10  , D01 ) :  603,  ( Location10  , D02 ) :  646,  ( Location10  , D03 ) :  663,  ( Location10, D04) :
646, ( Location10  , D05 ) :  603,  ( Location10  , D06 ) :  558,  ( Location10  , D07 ) :  538,  ( Location10, D08 ) :
558, ( Location11  , D01 ) :  603,  ( Location11  , D02 ) :  558,  ( Location11  , D03 ) :  538,  ( Location11, D04 ) :
558, ( Location11  , D05 ) :  603,  ( Location11  , D06 ) :  646,  ( Location11  , D07 ) :  663,  ( Location11, D08 ) :
646, ( Location12  , D01 ) :  629,  ( Location12  , D02 ) :  486,  ( Location12  , D03 ) :  413,  ( Location12, D04 ) :
486, ( Location12  , D05 ) :  629,  ( Location12  , D06 ) :  744,  ( Location12  , D07 ) :  788,  ( Location12, D08 ) :
744, ( Location13  , D01 ) :  822,  ( Location13  , D02 ) :  874,  ( Location13  , D03 ) :  813,  ( Location13, D04 ) :
652, ( Location13  , D05 ) :  442,  ( Location13  , D06 ) :  326,  ( Location13  , D07 ) :  458,  ( Location13, D08 ) :
668, ( Location14  , D01 ) :  802,  ( Location14  , D02 ) :  792,  ( Location14  , D03 ) :  692,  ( Location14, D04 ) :
536, ( Location14  , D05 ) :  405,  ( Location14  , D06 ) :  426,  ( Location14  , D07 ) :  574,  ( Location14, D08 ) :
722, ( Location15  , D01 ) :  802,  ( Location15  , D02 ) :  722,  ( Location15  , D03 ) :  574,  ( Location15, D04 ) :
426, ( Location15  , D05 ) :  405,  ( Location15  , D06 ) :  536,  ( Location15  , D07 ) :  692,  ( Location15, D08 ) :
792, ( Location16  , D01 ) :  822,  ( Location16  , D02 ) :  668,  ( Location16  , D03 ) :  458,  ( Location16, D04 ) :
326, ( Location16  , D05 ) :  442,  ( Location16  , D06 ) :  652,  ( Location16  , D07 ) :  813,  ( Location16, D08 ) :
874, ( Location17  , D01 ) : 1017,  ( Location17  , D02 ) : 1026,  ( Location17  , D03 ) :  883, (Location17, D04 ) :
612, ( Location17  , D05 ) :  274,  ( Location17  , D06 ) :  238,  ( Location17  , D07 ) :  575,  (Location17, D08 ) :
858, ( Location18  , D01 ) : 1002,  ( Location18  , D02 ) :  957,  ( Location18  , D03 ) :  774, (Location18, D04 ) :
487, ( Location18  , D05 ) :  210,  ( Location18  , D06 ) :  363,  ( Location18  , D07 ) :  670,  ( Location18, D08 ) :
900, ( Location19  , D01 ) : 1002,  ( Location19  , D02 ) :  900,  ( Location19  , D03 ) :  670,  (Location19, D04 ) :
363, ( Location19  , D05 ) :  210,  ( Location19  , D06 ) :  487,  ( Location19  , D07 ) :  774,  ( Location19, D08 ) :
957, ( Location20  , D01 ) : 1017,  ( Location20  , D02 ) :  858,  ( Location20  , D03 ) :  575,  ( Location20,D04 ) :
238,( Location20  , D05 ) :  274,  ( Location20  , D06 ) :  612,  ( Location20  , D07 ) :  883,  ( Location20, D08 ) :
1026 }
        }
    }
    Parameter Distance_Locs {
        IndexDomain: (j,l);
        Definition: {
            data
            { ( 'Location 1', 'Location 2' ) : 125,  ( 'Location 1', 'Location 3' ) : 250,  ( 'Location 1', 'Location 4' ) : 375,
 ('Location 1', 'Location 5' ) : 200,  ( 'Location 1', 'Location 6' ) : 236,  ( 'Location 1', 'Location 7' ) : 320,
 ( 'Location 1', 'Location 8' ) : 425,  ( 'Location 1', 'Location 9' ) : 400,  ( 'Location 1', Location10) : 419,
 ( 'Location 1', Location11   ) : 472,  ( 'Location 1', Location12   ) : 548,  ( 'Location 1', Location13) : 600,
('Location 1', Location14   ) : 613,  ( 'Location 1', Location15   ) : 650,  ( 'Location 1', Location16) : 708,
 ( 'Location 1', Location17   ) : 800,  ( 'Location 1', Location18   ) : 810,  ( 'Location 1', Location19) : 838,
('Location 1', Location20   ) : 884,  ( 'Location 2', 'Location 1' ) : 125,  ( 'Location 2', 'Location 3' ) : 125,
 ( 'Location 2', 'Location 4' ) : 250,  ( 'Location 2', 'Location 5' ) : 236,  ( 'Location 2', 'Location 6 ) : 200,
 ( 'Location 2', 'Location 7' ) : 236,  ( 'Location 2', 'Location 8' ) : 320,  ( 'Location 2', 'Location 9') : 419,
 ( 'Location 2', Location10   ) : 400,  ( 'Location 2', Location11   ) : 419,  ( 'Location 2', Location12) : 472,
('Location 2', Location13   ) : 613,  ( 'Location 2', Location14   ) : 600,  ( 'Location 2', Location15) : 613,
 ( 'Location 2', Location16   ) : 650,  ( 'Location 2', Location17   ) : 810,  ( 'Location 2', Location18) : 800,
('Location 2', Location19   ) : 810,  ( 'Location 2', Location20   ) : 838,  ( 'Location 3', 'Location 1' ) : 250,
 ( 'Location 3', 'Location 2' ) : 125,  ( 'Location 3', 'Location 4' ) : 125,  ( 'Location 3', 'Location 5' ) : 320,
 ( 'Location 3', 'Location 6' ) : 236,  ( 'Location 3', 'Location 7' ) : 200,  ( 'Location 3', 'Location 8' ) : 236,
 ( 'Location 3', 'Location 9' ) : 472,  ( 'Location 3', Location10   ) : 419,  ( 'Location 3', Location11   ) : 400,
('Location 3', Location12   ) : 419,  ( 'Location 3', Location13   ) : 650,  ( 'Location 3', Location14   ) : 613,
 ( 'Location 3', Location15   ) : 600,  ( 'Location 3', Location16   ) : 613,  ( 'Location 3', Location17   ) : 838,
('Location 3', Location18   ) : 810,  ( 'Location 3', Location19   ) : 800,  ( 'Location 3', Location20   ) : 810,
 ( 'Location 4', 'Location 1' ) : 375,  ( 'Location 4', 'Location 2' ) : 250,  ( 'Location 4', 'Location 3' ) : 125,
 ( 'Location 4', 'Location 5' ) : 425,  ( 'Location 4', 'Location 6' ) : 320,  ( 'Location 4', 'Location 7' ) : 236,
 ( 'Location 4', 'Location 8' ) : 200,  ( 'Location 4', 'Location 9' ) : 548,  ( 'Location 4', Location10   ) : 472,
```

('Location 4', Location11) : 419, ('Location 4', Location12) : 400, ('Location 4', Location13) : 708,
('Location 4', Location14) : 650, ('Location 4', Location15) : 613, ('Location 4', Location16) : 600,
('Location 4', Location17) : 884, ('Location 4', Location18) : 838, ('Location 4', Location19) : 810,
('Location 4', Location20) : 800, ('Location 5', 'Location 1') : 200, ('Location 5', 'Location 2') : 236,
('Location 5', 'Location 3') : 320, ('Location 5', 'Location 4') : 425, ('Location 5', 'Location 6') : 125,
('Location 5', 'Location 7') : 250, ('Location 5', 'Location 8') : 375, ('Location 5', 'Location 9') : 200,
('Location 5', Location10) : 236, ('Location 5', Location11) : 320, ('Location 5', Location12) : 425,
('Location 5', Location13) : 400, ('Location 5', Location14) : 419, ('Location 5', Location15) : 472,
('Location 5', Location16) : 548, ('Location 5', Location17) : 600, ('Location 5', Location18) : 613,
('Location 5', Location19) : 650, ('Location 5', Location20) : 708, ('Location 6', 'Location 1') : 236,
('Location 6', 'Location 2') : 200, ('Location 6', 'Location 3') : 236, ('Location 6', 'Location 4') : 320,
('Location 6', 'Location 5') : 125, ('Location 6', 'Location 7') : 125, ('Location 6', 'Location 8') : 250,
('Location 6', 'Location 9') : 236, ('Location 6', Location10) : 200, ('Location 6', Location11) : 236,
('Location 6', Location12) : 320, ('Location 6', Location13) : 419, ('Location 6', Location14) : 400,
('Location 6', Location15) : 419, ('Location 6', Location16) : 472, ('Location 6', Location17) : 613,
('Location 6', Location18) : 600, ('Location 6', Location19) : 613, ('Location 6', Location20) : 650,
('Location 7', 'Location 1') : 320, ('Location 7', 'Location 2') : 236, ('Location 7', 'Location 3') : 200,
('Location 7', 'Location 4') : 236, ('Location 7', 'Location 5') : 250, ('Location 7', 'Location 6') : 125,
('Location 7', 'Location 8') : 125, ('Location 7', 'Location 9') : 320, ('Location 7', Location10) : 236,
('Location 7', Location11) : 200, ('Location 7', Location12) : 236, ('Location 7', Location13) : 472,
('Location 7', Location14) : 419, ('Location 7', Location15) : 400, ('Location 7', Location16) : 419,
('Location 7', Location17) : 650, ('Location 7', Location18) : 613, ('Location 7', Location19) : 600,
('Location 7', Location20) : 613, ('Location 8', 'Location 1') : 425, ('Location 8', 'Location 2') : 320,
('Location 8', 'Location 3') : 236, ('Location 8', 'Location 4') : 200, ('Location 8', 'Location 5') : 375,
('Location 8', 'Location 6') : 250, ('Location 8', 'Location 7') : 125, ('Location 8', 'Location 9') : 425,
('Location 8', Location10) : 320, ('Location 8', Location11) : 236, ('Location 8', Location12) : 200,
('Location 8', Location13) : 548, ('Location 8', Location14) : 472, ('Location 8', Location15) : 419,
('Location 8', Location16) : 400, ('Location 8', Location17) : 708, ('Location 8', Location18) : 650,
('Location 8', Location19) : 613, ('Location 8', Location20) : 600, ('Location 9', 'Location 1') : 400,
('Location 9', 'Location 2') : 419, ('Location 9', 'Location 3') : 472, ('Location 9', 'Location 4') : 548,
('Location 9', 'Location 5') : 200, ('Location 9', 'Location 6') : 236, ('Location 9', 'Location 7') : 320,
('Location 9', 'Location 8') : 425, ('Location 9', Location10) : 125, ('Location 9', Location11) : 250,
('Location 9', Location12) : 375, ('Location 9', Location13) : 200, ('Location 9', Location14) : 236,
('Location 9', Location15) : 320, ('Location 9', Location16) : 425, ('Location 9', Location17) : 400,
('Location 9', Location18) : 419, ('Location 9', Location19) : 472, ('Location 9', Location20) : 548,
(Location10 , 'Location 1') : 419, (Location10 , 'Location 2') : 400, (Location10 , 'Location 3') : 419,
(Location10 , 'Location 4') : 472, (Location10 , 'Location 5') : 236, (Location10 , 'Location 6') : 200,
(Location10 , 'Location 7') : 236, (Location10 , 'Location 8') : 320, (Location10 , 'Location 9') : 125,
(Location10 , Location11) : 125, (Location10 , Location12) : 250, (Location10 , Location13) : 236,
(Location10 , Location14) : 200, (Location10 , Location15) : 236, (Location10 , Location16) : 320,
(Location10 , Location17) : 419, (Location10 , Location18) : 400, (Location10 , Location19) : 419,
(Location10 , Location20) : 472, (Location11 , 'Location 1') : 472, (Location11 , 'Location 2') : 419,
(Location11 , 'Location 3') : 400, (Location11 , 'Location 4') : 419, (Location11 , 'Location 5') : 320,
(Location11 , 'Location 6') : 236, (Location11 , 'Location 7') : 200, (Location11 , 'Location 8') : 236,
(Location11 , 'Location 9') : 250, (Location11 , Location10) : 125, (Location11 , Location12) : 125,
(Location11 , Location13) : 320, (Location11 , Location14) : 236, (Location11 , Location15) : 200,
(Location11 , Location16) : 236, (Location11 , Location17) : 472, (Location11 , Location18) : 419,
(Location11 , Location19) : 400, (Location11 , Location20) : 419, (Location12 , 'Location 1') : 548,
(Location12 , 'Location 2') : 472, (Location12 , 'Location 3') : 419, (Location12 , 'Location 4') : 400,
(Location12 , 'Location 5') : 425, (Location12 , 'Location 6') : 320, (Location12 , 'Location 7') : 236,
(Location12 , 'Location 8') : 200, (Location12 , 'Location 9') : 375, (Location12 , Location10) : 250,
(Location12 , Location11) : 125, (Location12 , Location13) : 425, (Location12 , Location14) : 320,
(Location12 , Location15) : 236, (Location12 , Location16) : 200, (Location12 , Location17) : 548,
(Location12 , Location18) : 472, (Location12 , Location19) : 419, (Location12 , Location20) : 400,
(Location13 , 'Location 1') : 600, (Location13 , 'Location 2') : 613, (Location13 , 'Location 3') : 650,
(Location13 , 'Location 4') : 708, (Location13 , 'Location 5') : 400, (Location13 , 'Location 6') : 419,
(Location13 , 'Location 7') : 472, (Location13 , 'Location 8') : 548, (Location13 , 'Location 9') : 200,
(Location13 , Location10) : 236, (Location13 , Location11) : 320, (Location13 , Location12) : 425,
(Location13 , Location14) : 125, (Location13 , Location15) : 250, (Location13 , Location16) : 375,

```
(Location13  , Location17   ) : 200,  ( Location13  , Location18   ) : 236,  ( Location13  , Location19   ) : 320,
(Location13  , Location20   ) : 425,  ( Location14  , 'Location 1' ) : 613,  ( Location14  , 'Location 2' ) : 600,
( Location14  , 'Location 3' ) : 613,  ( Location14  , 'Location 4' ) : 650,  ( Location14  , 'Location 5' ) : 419,
(Location14  , 'Location 6' ) : 400,  ( Location14  , 'Location 7' ) : 419,  ( Location14  , 'Location 8' ) : 472,
( Location14  , 'Location 9' ) : 236,  ( Location14  , Location10   ) : 200,  ( Location14  , Location11   ) : 236,
(Location14  , Location12   ) : 320,  ( Location14  , Location13   ) : 125,  ( Location14  , Location15   ) : 125,
(Location14  , Location16   ) : 250,  ( Location14  , Location17   ) : 236,  ( Location14  , Location18   ) : 200,
(Location14  , Location19   ) : 236,  ( Location14  , Location20   ) : 320,  ( Location15  , 'Location 1' ) : 650,
( Location15  , 'Location 2' ) : 613,  ( Location15  , 'Location 3' ) : 600,  ( Location15  , 'Location 4' ) : 613,
(Location15  , 'Location 5' ) : 472,  ( Location15  , 'Location 6' ) : 419,  ( Location15  , 'Location 7' ) : 400,
( Location15  , 'Location 8' ) : 419,  ( Location15  , 'Location 9' ) : 320,  ( Location15  , Location10   ) : 236,
(Location15  , Location11   ) : 200,  ( Location15  , Location12   ) : 236,  ( Location15  , Location13   ) : 250,
(Location15  , Location14   ) : 125,  ( Location15  , Location16   ) : 125,  ( Location15  , Location17   ) : 320,
(Location15  , Location18   ) : 236,  ( Location15  , Location19   ) : 200,  ( Location15  , Location20   ) : 236,
(Location16  , 'Location 1' ) : 708,  ( Location16  , 'Location 2' ) : 650,  ( Location16  , 'Location 3' ) : 613,
 ( Location16  , 'Location 4' ) : 600,  ( Location16  , 'Location 5' ) : 548,  ( Location16  , 'Location 6' ) : 472,
(Location16  , 'Location 7' ) : 419,  ( Location16  , 'Location 8' ) : 400,  ( Location16  , 'Location 9' ) : 425,
( Location16  , Location10   ) : 320,  ( Location16  , Location11   ) : 236,  ( Location16  , Location12   ) : 200,
(Location16  , Location13   ) : 375,  ( Location16  , Location14   ) : 250,  ( Location16  , Location15   ) : 125,
(Location16  , Location17   ) : 425,  ( Location16  , Location18   ) : 320,  ( Location16  , Location19   ) : 236,
(Location16  , Location20   ) : 200,  ( Location17  , 'Location 1' ) : 800,  ( Location17  , 'Location 2' ) : 810,
( Location17  , 'Location 3' ) : 838,  ( Location17  , 'Location 4' ) : 884,  ( Location17  , 'Location 5' ) : 600,
(Location17  , 'Location 6' ) : 613,  ( Location17  , 'Location 7' ) : 650,  ( Location17  , 'Location 8' ) : 708,
( Location17  , 'Location 9' ) : 400,  ( Location17  , Location10   ) : 419,  ( Location17  , Location11   ) : 472,
(Location17  , Location12   ) : 548,  ( Location17  , Location13   ) : 200,  ( Location17  , Location14   ) : 236,
(Location17  , Location15   ) : 320,  ( Location17  , Location16   ) : 425,  ( Location17  , Location18   ) : 125,
(Location17  , Location19   ) : 250,  ( Location17  , Location20   ) : 375,  ( Location18  , 'Location 1' ) : 810,
( Location18  , 'Location 2' ) : 800,  ( Location18  , 'Location 3' ) : 810,  ( Location18  , 'Location 4' ) : 838,
(Location18  , 'Location 5' ) : 613,  ( Location18  , 'Location 6' ) : 600,  ( Location18  , 'Location 7' ) : 613,
( Location18  , 'Location 8' ) : 650,  ( Location18  , 'Location 9' ) : 419,  ( Location18  , Location10   ) : 400,
(Location18  , Location11   ) : 419,  ( Location18  , Location12   ) : 472,  ( Location18  , Location13   ) : 236,
(Location18  , Location14   ) : 200,  ( Location18  , Location15   ) : 236,  ( Location18  , Location16   ) : 320,
(Location18  , Location17   ) : 125,  ( Location18  , Location19   ) : 125,  ( Location18  , Location20   ) : 250,
(Location19  , 'Location 1' ) : 838,  ( Location19  , 'Location 2' ) : 810,  ( Location19  , 'Location 3' ) : 800,
( Location19  , 'Location 4' ) : 810,  ( Location19  , 'Location 5' ) : 650,  ( Location19  , 'Location 6' ) : 613,
(Location19  , 'Location 7' ) : 600,  ( Location19  , 'Location 8' ) : 613,  ( Location19  , 'Location 9' ) : 472,
( Location19  , Location10   ) : 419,  ( Location19  , Location11   ) : 400,  ( Location19  , Location12   ) : 419,
(Location19  , Location13   ) : 320,  ( Location19  , Location14   ) : 236,  ( Location19  , Location15   ) : 200,
(Location19  , Location16   ) : 236,  ( Location19  , Location17   ) : 250,  ( Location19  , Location18   ) : 125,
(Location19  , Location20   ) : 125,  ( Location20  , 'Location 1' ) : 884,  ( Location20  , 'Location 2' ) : 838,
( Location20  , 'Location 3' ) : 810,  ( Location20  , 'Location 4' ) : 800,  ( Location20  , 'Location 5' ) : 708,
(Location20  , 'Location 6' ) : 650,  ( Location20  , 'Location 7' ) : 613,  ( Location20  , 'Location 8' ) : 600,
( Location20  , 'Location 9' ) : 548,  ( Location20  , Location10   ) : 472,  ( Location20  , Location11   ) : 419,
(Location20  , Location12   ) : 400,  ( Location20  , Location13   ) : 425,  ( Location20  , Location14   ) : 320,
(Location20  , Location15   ) : 236,  ( Location20  , Location16   ) : 200,  ( Location20  , Location17   ) : 375,
(Location20  , Location18   ) : 250,  ( Location20  , Location19   ) : 125 }
        }
    }
    Variable Assignment {
        IndexDomain: (i,j);
        Range: binary;
    }
    Constraint Loc_Constraint {
        IndexDomain: i;
        Definition: sum(j, Assignment(i,j))=1;
    }
    Constraint Fac_Constraint {
        IndexDomain: j;
        Definition: sum(i, Assignment(i,j))=1;
    }
```

```
Constraint Distance_F2_F3 {
   IndexDomain: (j,l) | (Distance_Locs(j,l) < 125) or (Distance_Locs(j,l) > 200);
   Definition: Assignment('facility 2',j) + Assignment('facility 3',l) <= 1;
}
Constraint Distance_F6_F7 {
   IndexDomain: (j,l) | (Distance_Locs(j,l) < 125) or (Distance_Locs(j,l) > 200);
   Definition: Assignment('facility 6',j) + Assignment('facility 7',l) <= 1;
}
Constraint Fac_18 {
   Definition: Assignment('Facility 18','Location13')=1;
}
Constraint Fac_20 {
   Definition: Assignment('Facility 20','Location20')=1;
}
Variable Adj_1 {
   IndexDomain: (i,h)|i<>h;
   Range: binary;
}
Variable Adj_2 {
   IndexDomain: (i,h)|i<>h;
   Range: binary;
}
Variable Adj_3 {
   IndexDomain: (i,h)|i<>h;
   Range: binary;
}
Variable Adj_4 {
   IndexDomain: (i,h)|i<>h;
   Range: binary;
}
Variable Adj_5 {
   IndexDomain: (i,h)|i<>h;
   Range: binary;
}
Variable Adj_6 {
   IndexDomain: (i,h)|i<>h;
   Range: binary;
}
Variable Adj_7 {
   IndexDomain: (i,h)|i<>h;
   Range: binary;
}
Variable Adj_8 {
   IndexDomain: (i,h)|i<>h;
   Range: binary;
}
Variable Adj_9 {
   IndexDomain: (i,h)|i<>h;
   Range: binary;
}
Variable Adj_10 {
   IndexDomain: (i,h)|i<>h;
   Range: binary;
}
Variable Adj_11 {
   IndexDomain: (i,h)|i<>h;
   Range: binary;
}
Variable Adj_12 {
   IndexDomain: (i,h)|i<>h;
```

```
    Range: binary;
  }
  Variable Adj_13 {
    IndexDomain: (i,h)|i<>h;
    Range: binary;
  }
  Variable Adj_14 {
    IndexDomain: (i,h)|i<>h;
    Range: binary;
  }
  Variable Adj_15 {
    IndexDomain: (i,h)|i<>h;
    Range: binary;
  }
  Variable Adj_16 {
    IndexDomain: (i,h)|i<>h;
    Range: binary;
  }
  Variable Adj_17 {
    IndexDomain: (i,h)|i<>h;
    Range: binary;
  }
  Variable Adj_18 {
    IndexDomain: (i,h)|i<>h;
    Range: binary;
  }
  Variable Adj_19 {
    IndexDomain: (i,h)|i<>h;
    Range: binary;
  }
  Variable Adj_20 {
    IndexDomain: (i,h)|i<>h;
    Range: binary;
  }
  Variable Adj_21 {
    IndexDomain: (i,h)|i<>h;
    Range: binary;
  }
  Variable Adj_22 {
    IndexDomain: (i,h)|i<>h;
    Range: binary;
  }
  Variable Adj_23 {
    IndexDomain: (i,h)|i<>h;
    Range: binary;
  }
  Variable Adj_24 {
    IndexDomain: (i,h)|i<>h;
    Range: binary;
  }
  Variable Adj_25 {
    IndexDomain: (i,h)|i<>h;
    Range: binary;
  }
  Variable Adj_26 {
    IndexDomain: (i,h)|i<>h;
    Range: binary;
  }
  Variable Adj_27 {
    IndexDomain: (i,h)|i<>h;
```

```
   Range: binary;
}
Variable Adj_28 {
   IndexDomain: (i,h)|i<>h;
   Range: binary;
}
Variable Adj_29 {
   IndexDomain: (i,h)|i<>h;
   Range: binary;
}
Variable Adj_30 {
   IndexDomain: (i,h)|i<>h;
   Range: binary;
}
Variable Adj_31 {
   IndexDomain: (i,h)|i<>h;
   Range: binary;
}
   Constraint Adj_1_1 {
   IndexDomain: (i,h)|i<>h;
   Definition: Adj_1(i,h)<=Assignment(i,'Location 1');
}
Constraint Adj_1_2 {
   IndexDomain: (i,h)|i<>h;
   Definition: Adj_1(i,h)<=Assignment(h,'Location 2');
}
Constraint Adj_1_3 {
   IndexDomain: (i,h)|i<>h;
   Definition: Adj_1(i,h)>=Assignment(i,'Location 1')+Assignment(h,'Location 2')-1;
}
Constraint Adj_2_1 {
   IndexDomain: (i,h)|i<>h;
   Definition: Adj_2(i,h)<=Assignment(i,'Location 1');
}
Constraint Adj_2_2 {
   IndexDomain: (i,h)|i<>h;
   Definition: Adj_2(i,h)<=Assignment(h,'Location 5');
}
Constraint Adj_2_3 {
   IndexDomain: (i,h)|i<>h;
   Definition: Adj_2(i,h)>=Assignment(i,'Location 1')+Assignment(h,'Location 5')-1;
}
Constraint Adj_3_1 {
   IndexDomain: (i,h)|i<>h;
   Definition: Adj_3(i,h)<=Assignment(i,'Location 2');
}
Constraint Adj_3_2 {
   IndexDomain: (i,h)|i<>h;
   Definition: Adj_3(i,h)<=Assignment(h,'Location 3');
}
Constraint Adj_3_3 {
   IndexDomain: (i,h)|i<>h;
   Definition: Adj_3(i,h)>=Assignment(i,'Location 2')+Assignment(h,'Location 3')-1;
}
Constraint Adj_4_1 {
   IndexDomain: (i,h)|i<>h;
   Definition: Adj_4(i,h)<=Assignment(i,'Location 2');
}
Constraint Adj_4_2 {
   IndexDomain: (i,h)|i<>h;
```

```
    Definition: Adj_4(i,h)<=Assignment(h,'Location 6');
  }
  Constraint Adj_4_3 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_4(i,h)>=Assignment(i,'Location 2')+Assignment(h,'Location 6')-1;
  }
  Constraint Adj_5_1 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_5(i,h)<=Assignment(i,'Location 3');
  }
  Constraint Adj_5_2 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_5(i,h)<=Assignment(h,'Location 4');
  }
  Constraint Adj_5_3 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_5(i,h)>=Assignment(i,'Location 3')+Assignment(h,'Location 4')-1;
  }
  Constraint Adj_6_1 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_6(i,h)<=Assignment(i,'Location 3');
  }
  Constraint Adj_6_2 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_6(i,h)<=Assignment(h,'Location 7');
  }
  Constraint Adj_6_3 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_6(i,h)>=Assignment(i,'Location 3')+Assignment(h,'Location 7')-1;
  }
  Constraint Adj_7_1 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_7(i,h)<=Assignment(i,'Location 4');
  }
  Constraint Adj_7_2 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_7(i,h)<=Assignment(h,'Location 8');
  }
  Constraint Adj_7_3 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_7(i,h)>=Assignment(i,'Location 4')+Assignment(h,'Location 8')-1;
  }
  Constraint Adj_8_1 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_8(i,h)<=Assignment(i,'Location 5');
  }
  Constraint Adj_8_2 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_8(i,h)<=Assignment(h,'Location 6');
  }
  Constraint Adj_8_3 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_8(i,h)>=Assignment(i,'Location 5')+Assignment(h,'Location 6')-1;
  }
  Constraint Adj_9_1 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_9(i,h)<=Assignment(i,'Location 5');
  }
  Constraint Adj_9_2 {
    IndexDomain: (i,h)|i<>h;
```

```
    Definition: Adj_9(i,h)<=Assignment(h,'Location 9');
}
Constraint Adj_9_3 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_9(i,h)>=Assignment(i,'Location 5')+Assignment(h,'Location 9')-1;
}
Constraint Adj_10_1 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_10(i,h)<=Assignment(i,'Location 6');
}
Constraint Adj_10_2 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_10(i,h)<=Assignment(h,'Location 7');
}
Constraint Adj_10_3 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_10(i,h)>=Assignment(i,'Location 6')+Assignment(h,'Location 7')-1;
}
Constraint Adj_11_1 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_11(i,h)<=Assignment(i,'Location 6');
}
Constraint Adj_11_2 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_11(i,h)<=Assignment(h,'Location10');
}
Constraint Adj_11_3 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_11(i,h)>=Assignment(i,'Location 6')+Assignment(h,'Location10')-1;
}
Constraint Adj_12_1 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_12(i,h)<=Assignment(i,'Location 7');
}
Constraint Adj_12_2 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_12(i,h)<=Assignment(h,'Location 8');
}
Constraint Adj_12_3 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_12(i,h)>=Assignment(i,'Location 7')+Assignment(h,'Location 8')-1;
}
Constraint Adj_13_1 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_13(i,h)<=Assignment(i,'Location 7');
}
Constraint Adj_13_2 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_13(i,h)<=Assignment(h,'Location11');
}
Constraint Adj_13_3 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_13(i,h)>=Assignment(i,'Location 7')+Assignment(h,'Location11')-1;
}
Constraint Adj_14_1 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_14(i,h)<=Assignment(i,'Location 8');
}
Constraint Adj_14_2 {
    IndexDomain: (i,h)|i<>h;
```

```
    Definition: Adj_14(i,h)<=Assignment(h,'Location12');
  }
  Constraint Adj_14_3 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_14(i,h)>=Assignment(i,'Location 8')+Assignment(h,'Location12')-1;
  }
  Constraint Adj_15_1 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_15(i,h)<=Assignment(i,'Location 9');
  }
  Constraint Adj_15_2 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_15(i,h)<=Assignment(h,'Location10');
  }
  Constraint Adj_15_3 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_15(i,h)>=Assignment(i,'Location 9')+Assignment(h,'Location10')-1;
  }
  Constraint Adj_16_1 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_16(i,h)<=Assignment(i,'Location 9');
  }
  Constraint Adj_16_2 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_16(i,h)<=Assignment(h,'Location13');
  }
  Constraint Adj_16_3 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_16(i,h)>=Assignment(i,'Location 9')+Assignment(h,'Location13')-1;
  }
  Constraint Adj_17_1 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_17(i,h)<=Assignment(i,'Location10');
  }
  Constraint Adj_17_2 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_17(i,h)<=Assignment(h,'Location11');
  }
  Constraint Adj_17_3 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_17(i,h)>=Assignment(i,'Location10')+Assignment(h,'Location11')-1;
  }
  Constraint Adj_18_1 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_18(i,h)<=Assignment(i,'Location10');
  }
  Constraint Adj_18_2 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_18(i,h)<=Assignment(h,'Location14');
  }
  Constraint Adj_18_3 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_18(i,h)>=Assignment(i,'Location10')+Assignment(h,'Location14')-1;
  }
  Constraint Adj_19_1 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_19(i,h)<=Assignment(i,'Location11');
  }
  Constraint Adj_19_2 {
    IndexDomain: (i,h)|i<>h;
```

```
   Definition: Adj_19(i,h)<=Assignment(h,'Location12');
}
Constraint Adj_19_3 {
   IndexDomain: (i,h)|i<>h;
   Definition: Adj_19(i,h)>=Assignment(i,'Location11')+Assignment(h,'Location12')-1;
}
Constraint Adj_20_1 {
   IndexDomain: (i,h)|i<>h;
   Definition: Adj_20(i,h)<=Assignment(i,'Location11');
}
Constraint Adj_20_2 {
   IndexDomain: (i,h)|i<>h;
   Definition: Adj_20(i,h)<=Assignment(h,'Location15');
}
Constraint Adj_20_3 {
   IndexDomain: (i,h)|i<>h;
   Definition: Adj_20(i,h)>=Assignment(i,'Location11')+Assignment(h,'Location15')-1;
}
Constraint Adj_21_1 {
   IndexDomain: (i,h)|i<>h;
   Definition: Adj_21(i,h)<=Assignment(i,'Location12');
}
Constraint Adj_21_2 {
   IndexDomain: (i,h)|i<>h;
   Definition: Adj_21(i,h)<=Assignment(h,'Location16');
}
Constraint Adj_21_3 {
   IndexDomain: (i,h)|i<>h;
   Definition: Adj_21(i,h)>=Assignment(i,'Location12')+Assignment(h,'Location16')-1;
}
Constraint Adj_22_1 {
   IndexDomain: (i,h)|i<>h;
   Definition: Adj_22(i,h)<=Assignment(i,'Location13');
}
Constraint Adj_22_2 {
   IndexDomain: (i,h)|i<>h;
   Definition: Adj_22(i,h)<=Assignment(h,'Location14');
}
Constraint Adj_22_3 {
   IndexDomain: (i,h)|i<>h;
   Definition: Adj_22(i,h)>=Assignment(i,'Location13')+Assignment(h,'Location14')-1;
}
Constraint Adj_23_1 {
   IndexDomain: (i,h)|i<>h;
   Definition: Adj_23(i,h)<=Assignment(i,'Location13');
}
Constraint Adj_23_2 {
   IndexDomain: (i,h)|i<>h;
   Definition: Adj_23(i,h)<=Assignment(h,'Location17');
}
Constraint Adj_23_3 {
   IndexDomain: (i,h)|i<>h;
   Definition: Adj_23(i,h)>=Assignment(i,'Location13')+Assignment(h,'Location17')-1;
}
Constraint Adj_24_1 {
   IndexDomain: (i,h)|i<>h;
   Definition: Adj_24(i,h)<=Assignment(i,'Location14');
}
Constraint Adj_24_2 {
   IndexDomain: (i,h)|i<>h;
```

```
    Definition: Adj_24(i,h)<=Assignment(h,'Location15');
  }
  Constraint Adj_24_3 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_24(i,h)>=Assignment(i,'Location14')+Assignment(h,'Location15')-1;
  }
  Constraint Adj_25_1 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_25(i,h)<=Assignment(i,'Location14');
  }
  Constraint Adj_25_2 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_25(i,h)<=Assignment(h,'Location18');
  }
  Constraint Adj_25_3 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_25(i,h)>=Assignment(i,'Location14')+Assignment(h,'Location18')-1;
  }
  Constraint Adj_26_1 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_26(i,h)<=Assignment(i,'Location15');
  }
  Constraint Adj_26_2 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_26(i,h)<=Assignment(h,'Location16');
  }
  Constraint Adj_26_3 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_26(i,h)>=Assignment(i,'Location15')+Assignment(h,'Location16')-1;
  }
  Constraint Adj_27_1 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_27(i,h)<=Assignment(i,'Location15');
  }
  Constraint Adj_27_2 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_27(i,h)<=Assignment(h,'Location19');
  }
  Constraint Adj_27_3 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_27(i,h)>=Assignment(i,'Location15')+Assignment(h,'Location19')-1;
  }
  Constraint Adj_28_1 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_28(i,h)<=Assignment(i,'Location16');
  }
  Constraint Adj_28_2 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_28(i,h)<=Assignment(h,'Location20');
  }
  Constraint Adj_28_3 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_28(i,h)>=Assignment(i,'Location16')+Assignment(h,'Location20')-1;
  }
  Constraint Adj_29_1 {
    IndexDomain: (i,h)|i<>h;
    Definition: Adj_29(i,h)<=Assignment(i,'Location17');
  }
  Constraint Adj_29_2 {
    IndexDomain: (i,h)|i<>h;
```

```
        Definition: Adj_29(i,h)<=Assignment(h,'Location18');
    }
    Constraint Adj_29_3 {
        IndexDomain: (i,h)|i<>h;
        Definition: Adj_29(i,h)>=Assignment(i,'Location17')+Assignment(h,'Location18')-1;
    }
    Constraint Adj_30_1 {
        IndexDomain: (i,h)|i<>h;
        Definition: Adj_30(i,h)<=Assignment(i,'Location18');
    }
    Constraint Adj_30_2 {
        IndexDomain: (i,h)|i<>h;
        Definition: Adj_30(i,h)<=Assignment(h,'Location19');
    }
    Constraint Adj_30_3 {
        IndexDomain: (i,h)|i<>h;
        Definition: Adj_30(i,h)>=Assignment(i,'Location18')+Assignment(h,'Location19')-1;
    }
    Constraint Adj_31_1 {
        IndexDomain: (i,h)|i<>h;
        Definition: Adj_31(i,h)<=Assignment(i,'Location19');
    }
    Constraint Adj_31_2 {
        IndexDomain: (i,h)|i<>h;
        Definition: Adj_31(i,h)<=Assignment(h,'Location20');
    }
    Constraint Adj_31_3 {
        IndexDomain: (i,h)|i<>h;
        Definition: Adj_31(i,h)>=Assignment(i,'Location19')+Assignment(h,'Location20')-1;
    }
    Constraint Gen_Adj_1 {
        Definition: {
            sum(t1|t1<>'Facility 1',Adj_1('Facility 1',t1))+sum(t1|t1<>'Facility 1',Adj_2('Facility 1',t1))+
sum(t1|t1<>'Facility 1',Adj_3('Facility 1',t1))+ sum(t1|t1<>'Facility 1',Adj_4('Facility 1',t1))+
sum(t1|t1<>'Facility 1',Adj_5('Facility 1',t1))+sum(t1|t1<>'Facility 1',Adj_6('Facility 1',t1))+
sum(t1|t1<>'Facility 1',Adj_7('Facility 1',t1))+sum(t1|t1<>'Facility 1',Adj_8('Facility 1',t1))+
sum(t1|t1<>'Facility 1',Adj_9('Facility 1',t1))+ sum(t1|t1<>'Facility 1',Adj_10('Facility 1',t1))+
sum(t1|t1<>'Facility 1',Adj_11('Facility 1',t1))+sum(t1|t1<>'Facility 1',Adj_12('Facility 1',t1))+
sum(t1|t1<>'Facility 1',Adj_13('Facility 1',t1))+sum(t1|t1<>'Facility 1',Adj_14('Facility 1',t1))+
sum(t1|t1<>'Facility 1',Adj_15('Facility 1',t1))+ sum(t1|t1<>'Facility 1',Adj_16('Facility 1',t1))+
sum(t1|t1<>'Facility 1',Adj_17('Facility 1',t1))+sum(t1|t1<>'Facility 1',Adj_18('Facility 1',t1))+
sum(t1|t1<>'Facility 1',Adj_19('Facility 1',t1))+sum(t1|t1<>'Facility 1',Adj_20('Facility 1',t1))+
sum(t1|t1<>'Facility 1',Adj_21('Facility 1',t1))+ sum(t1|t1<>'Facility 1',Adj_22('Facility 1',t1))+
sum(t1|t1<>'Facility 1',Adj_23('Facility 1',t1))+sum(t1|t1<>'Facility 1',Adj_24('Facility 1',t1))+
sum(t1|t1<>'Facility 1',Adj_25('Facility 1',t1))+sum(t1|t1<>'Facility 1',Adj_26('Facility 1',t1))+
sum(t1|t1<>'Facility 1',Adj_27('Facility 1',t1))+ sum(t1|t1<>'Facility 1',Adj_28('Facility 1',t1))+
sum(t1|t1<>'Facility 1',Adj_29('Facility 1',t1))+sum(t1|t1<>'Facility 1',Adj_30('Facility 1',t1))+
sum(t1|t1<>'Facility 1',Adj_31('Facility 1',t1))+ sum(t1|t1<>'Facility 1',Adj_1(t1,'Facility 1'))+
sum(t1|t1<>'Facility 1',Adj_2(t1,'Facility 1'))+sum(t1|t1<>'Facility 1',Adj_3(t1,'Facility 1'))+
sum(t1|t1<>'Facility 1',Adj_4(t1,'Facility 1'))+sum(t1|t1<>'Facility 1',Adj_5(t1,'Facility 1'))+
sum(t1|t1<>'Facility 1',Adj_6(t1,'Facility 1'))+ sum(t1|t1<>'Facility 1',Adj_7(t1,'Facility 1'))+
sum(t1|t1<>'Facility 1',Adj_8(t1,'Facility 1'))+ sum(t1|t1<>'Facility 1',Adj_9(t1,'Facility 1'))+
sum(t1|t1<>'Facility 1',Adj_10(t1,'Facility 1'))+ sum(t1|t1<>'Facility 1',Adj_11(t1,'Facility 1'))+
sum(t1|t1<>'Facility 1',Adj_12(t1,'Facility 1'))+ sum(t1|t1<>'Facility 1',Adj_13(t1,'Facility 1'))+
sum(t1|t1<>'Facility 1',Adj_14(t1,'Facility 1'))+sum(t1|t1<>'Facility 1',Adj_15(t1,'Facility 1'))+
sum(t1|t1<>'Facility 1',Adj_16(t1,'Facility 1'))+sum(t1|t1<>'Facility 1',Adj_17(t1,'Facility 1'))+
sum(t1|t1<>'Facility 1',Adj_18(t1,'Facility 1'))+ sum(t1|t1<>'Facility 1',Adj_19(t1,'Facility 1'))+
sum(t1|t1<>'Facility 1',Adj_20(t1,'Facility 1'))+sum(t1|t1<>'Facility 1',Adj_21(t1,'Facility 1'))+
sum(t1|t1<>'Facility 1',Adj_22(t1,'Facility 1'))+sum(t1|t1<>'Facility 1',Adj_23(t1,'Facility 1'))+
sum(t1|t1<>'Facility 1',Adj_24(t1,'Facility 1'))+ sum(t1|t1<>'Facility 1',Adj_25(t1,'Facility 1'))+
```

```
sum(t1|t1<>'Facility 1',Adj_26(t1,'Facility 1'))+sum(t1|t1<>'Facility 1',Adj_27(t1,'Facility 1'))+
sum(t1|t1<>'Facility 1',Adj_28(t1,'Facility 1'))+sum(t1|t1<>'Facility 1',Adj_29(t1,'Facility 1'))+
sum(t1|t1<>'Facility 1',Adj_30(t1,'Facility 1'))+ sum(t1|t1<>'Facility 1',Adj_31(t1,'Facility 1')) >= 1
        }
    }
    Constraint Gen_Adj_2 {
        Definition: {
            sum(t1|t1<>'Facility 4',Adj_1('Facility 4',t1))+sum(t1|t1<>'Facility 4',Adj_2('Facility 4',t1))+
sum(t1|t1<>'Facility 4',Adj_3('Facility 4',t1))+ sum(t1|t1<>'Facility 4',Adj_4('Facility 4',t1))+
sum(t1|t1<>'Facility 4',Adj_5('Facility 4',t1))+sum(t1|t1<>'Facility 4',Adj_6('Facility 4',t1))+
sum(t1|t1<>'Facility 4',Adj_7('Facility 4',t1))+sum(t1|t1<>'Facility 4',Adj_8('Facility 4',t1))+
sum(t1|t1<>'Facility 4',Adj_9('Facility 4',t1))+sum(t1|t1<>'Facility 4',Adj_10('Facility 4',t1))+
sum(t1|t1<>'Facility 4',Adj_11('Facility 4',t1))+sum(t1|t1<>'Facility 4',Adj_12('Facility 4',t1))+
sum(t1|t1<>'Facility 4',Adj_13('Facility 4',t1))+sum(t1|t1<>'Facility 4',Adj_14('Facility 4',t1))+
sum(t1|t1<>'Facility 4',Adj_15('Facility 4',t1))+ sum(t1|t1<>'Facility 4',Adj_16('Facility 4',t1))+
sum(t1|t1<>'Facility 4',Adj_17('Facility 4',t1))+sum(t1|t1<>'Facility 4',Adj_18('Facility 4',t1))+
sum(t1|t1<>'Facility 4',Adj_19('Facility 4',t1))+sum(t1|t1<>'Facility 4',Adj_20('Facility 4',t1))+
sum(t1|t1<>'Facility 4',Adj_21('Facility 4',t1))+ sum(t1|t1<>'Facility 4',Adj_22('Facility 4',t1))+
sum(t1|t1<>'Facility 4',Adj_23('Facility 4',t1))+sum(t1|t1<>'Facility 4',Adj_24('Facility 4',t1))+
sum(t1|t1<>'Facility 4',Adj_25('Facility 4',t1))+sum(t1|t1<>'Facility 4',Adj_26('Facility 4',t1))+
sum(t1|t1<>'Facility 4',Adj_27('Facility 4',t1))+ sum(t1|t1<>'Facility 4',Adj_28('Facility 4',t1))+
sum(t1|t1<>'Facility 4',Adj_29('Facility 4',t1))+sum(t1|t1<>'Facility 4',Adj_30('Facility 4',t1))+
sum(t1|t1<>'Facility 4',Adj_31('Facility 4',t1))+sum(t1|t1<>'Facility 4',Adj_1(t1,'Facility 4'))+
sum(t1|t1<>'Facility 4',Adj_2(t1,'Facility 4'))+sum(t1|t1<>'Facility 4',Adj_3(t1,'Facility 4'))+
sum(t1|t1<>'Facility 4',Adj_4(t1,'Facility 4'))+sum(t1|t1<>'Facility 4',Adj_5(t1,'Facility 4'))+
sum(t1|t1<>'Facility 4',Adj_6(t1,'Facility 4'))+ sum(t1|t1<>'Facility 4',Adj_7(t1,'Facility 4'))+
sum(t1|t1<>'Facility 4',Adj_8(t1,'Facility 4'))+sum(t1|t1<>'Facility 4',Adj_9(t1,'Facility 4'))+
sum(t1|t1<>'Facility 4',Adj_10(t1,'Facility 4'))+sum(t1|t1<>'Facility 4',Adj_11(t1,'Facility 4'))+
sum(t1|t1<>'Facility 4',Adj_12(t1,'Facility 4'))+ sum(t1|t1<>'Facility 4',Adj_13(t1,'Facility 4'))+
sum(t1|t1<>'Facility 4',Adj_14(t1,'Facility 4'))+sum(t1|t1<>'Facility 4',Adj_15(t1,'Facility 4'))+
sum(t1|t1<>'Facility 4',Adj_16(t1,'Facility 4'))+sum(t1|t1<>'Facility 4',Adj_17(t1,'Facility 4'))+
sum(t1|t1<>'Facility 4',Adj_18(t1,'Facility 4'))+ sum(t1|t1<>'Facility 4',Adj_19(t1,'Facility 4'))+
sum(t1|t1<>'Facility 4',Adj_20(t1,'Facility 4'))+sum(t1|t1<>'Facility 4',Adj_21(t1,'Facility 4'))+
sum(t1|t1<>'Facility 4',Adj_22(t1,'Facility 4'))+sum(t1|t1<>'Facility 4',Adj_23(t1,'Facility 4'))+
sum(t1|t1<>'Facility 4',Adj_24(t1,'Facility 4'))+ sum(t1|t1<>'Facility 4',Adj_25(t1,'Facility 4'))+
sum(t1|t1<>'Facility 4',Adj_26(t1,'Facility 4'))+sum(t1|t1<>'Facility 4',Adj_27(t1,'Facility 4'))+
sum(t1|t1<>'Facility 4',Adj_28(t1,'Facility 4'))+sum(t1|t1<>'Facility 4',Adj_29(t1,'Facility 4'))+
sum(t1|t1<>'Facility 4',Adj_30(t1,'Facility 4'))+ sum(t1|t1<>'Facility 4',Adj_31(t1,'Facility 4')) >= 1
        }
    }
    Constraint Gen_Adj_3 {
        Definition: {
            Adj_1('Facility 1','Facility 2')+Adj_2('Facility 1','Facility 2')+Adj_3('Facility 1','Facility 2')+
                Adj_4('Facility 1','Facility 2')+Adj_5('Facility 1','Facility 2')+Adj_6('Facility 1','Facility 2')+
                Adj_7('Facility 1','Facility 2')+Adj_8('Facility 1','Facility 2')+Adj_9('Facility 1','Facility 2')+
                Adj_10('Facility 1','Facility 2')+Adj_11('Facility 1','Facility 2')+Adj_12('Facility 1','Facility 2')+
                Adj_13('Facility 1','Facility 2')+Adj_14('Facility 1','Facility 2')+Adj_15('Facility 1','Facility 2')+
                Adj_16('Facility 1','Facility 2')+Adj_17('Facility 1','Facility 2')+Adj_18('Facility 1','Facility 2')+
                Adj_19('Facility 1','Facility 2')+Adj_20('Facility 1','Facility 2')+Adj_21('Facility 1','Facility 2')+
                Adj_22('Facility 1','Facility 2')+Adj_23('Facility 1','Facility 2')+Adj_24('Facility 1','Facility 2')+
                Adj_25('Facility 1','Facility 2')+Adj_26('Facility 1','Facility 2')+Adj_27('Facility 1','Facility 2')+
                Adj_28('Facility 1','Facility 2')+Adj_29('Facility 1','Facility 2')+Adj_30('Facility 1','Facility 2')+
                Adj_31('Facility 1','Facility 2')+
                Adj_1('Facility 2','Facility 1')+Adj_2('Facility 2','Facility 1')+Adj_3('Facility 2','Facility 1')+
                Adj_4('Facility 2','Facility 1')+Adj_5('Facility 2','Facility 1')+Adj_6('Facility 2','Facility 1')+
                Adj_7('Facility 2','Facility 1')+Adj_8('Facility 2','Facility 1')+Adj_9('Facility 2','Facility 1')+
                Adj_10('Facility 2','Facility 1')+Adj_11('Facility 2','Facility 1')+Adj_12('Facility 2','Facility 1')+
                Adj_13('Facility 2','Facility 1')+Adj_14('Facility 2','Facility 1')+Adj_15('Facility 2','Facility 1')+
                Adj_16('Facility 2','Facility 1')+Adj_17('Facility 2','Facility 1')+Adj_18('Facility 2','Facility 1')+
                Adj_19('Facility 2','Facility 1')+Adj_20('Facility 2','Facility 1')+Adj_21('Facility 2','Facility 1')+
```

Adj_22('Facility 2','Facility 1')+Adj_23('Facility 2','Facility 1')+Adj_24('Facility 2','Facility 1')+
Adj_25('Facility 2','Facility 1')+Adj_26('Facility 2','Facility 1')+Adj_27('Facility 2','Facility 1')+
Adj_28('Facility 2','Facility 1')+Adj_29('Facility 2','Facility 1')+Adj_30('Facility 2','Facility 1')+
Adj_31('Facility 2','Facility 1')+
Adj_1('Facility 4','Facility 2')+Adj_2('Facility 4','Facility 2')+Adj_3('Facility 4','Facility 2')+
Adj_4('Facility 4','Facility 2')+Adj_5('Facility 4','Facility 2')+Adj_6('Facility 4','Facility 2')+
Adj_7('Facility 4','Facility 2')+Adj_8('Facility 4','Facility 2')+Adj_9('Facility 4','Facility 2')+
Adj_10('Facility 4','Facility 2')+Adj_11('Facility 4','Facility 2')+Adj_12('Facility 4','Facility 2')+
Adj_13('Facility 4','Facility 2')+Adj_14('Facility 4','Facility 2')+Adj_15('Facility 4','Facility 2')+
Adj_16('Facility 4','Facility 2')+Adj_17('Facility 4','Facility 2')+Adj_18('Facility 4','Facility 2')+
Adj_19('Facility 4','Facility 2')+Adj_20('Facility 4','Facility 2')+Adj_21('Facility 4','Facility 2')+
Adj_22('Facility 4','Facility 2')+Adj_23('Facility 4','Facility 2')+Adj_24('Facility 4','Facility 2')+
Adj_25('Facility 4','Facility 2')+Adj_26('Facility 4','Facility 2')+Adj_27('Facility 4','Facility 2')+
Adj_28('Facility 4','Facility 2')+Adj_29('Facility 4','Facility 2')+Adj_30('Facility 4','Facility 2')+
Adj_31('Facility 4','Facility 2')+
Adj_1('Facility 2','Facility 4')+Adj_2('Facility 2','Facility 4')+Adj_3('Facility 2','Facility 4')+
Adj_4('Facility 2','Facility 4')+Adj_5('Facility 2','Facility 4')+Adj_6('Facility 2','Facility 4')+
Adj_7('Facility 2','Facility 4')+Adj_8('Facility 2','Facility 4')+Adj_9('Facility 2','Facility 4')+
Adj_10('Facility 2','Facility 4')+Adj_11('Facility 2','Facility 4')+Adj_12('Facility 2','Facility 4')+
Adj_13('Facility 2','Facility 4')+Adj_14('Facility 2','Facility 4')+Adj_15('Facility 2','Facility 4')+
Adj_16('Facility 2','Facility 4')+Adj_17('Facility 2','Facility 4')+Adj_18('Facility 2','Facility 4')+
Adj_19('Facility 2','Facility 4')+Adj_20('Facility 2','Facility 4')+Adj_21('Facility 2','Facility 4')+
Adj_22('Facility 2','Facility 4')+Adj_23('Facility 2','Facility 4')+Adj_24('Facility 2','Facility 4')+
Adj_25('Facility 2','Facility 4')+Adj_26('Facility 2','Facility 4')+Adj_27('Facility 2','Facility 4')+
Adj_28('Facility 2','Facility 4')+Adj_29('Facility 2','Facility 4')+Adj_30('Facility 2','Facility 4')+
Adj_31('Facility 2','Facility 4')+
Adj_1('Facility 1','Facility 3')+Adj_2('Facility 1','Facility 3')+Adj_3('Facility 1','Facility 3')+
Adj_4('Facility 1','Facility 3')+Adj_5('Facility 1','Facility 3')+Adj_6('Facility 1','Facility 3')+
Adj_7('Facility 1','Facility 3')+Adj_8('Facility 1','Facility 3')+Adj_9('Facility 1','Facility 3')+
Adj_10('Facility 1','Facility 3')+Adj_11('Facility 1','Facility 3')+Adj_12('Facility 1','Facility 3')+
Adj_13('Facility 1','Facility 3')+Adj_14('Facility 1','Facility 3')+Adj_15('Facility 1','Facility 3')+
Adj_16('Facility 1','Facility 3')+Adj_17('Facility 1','Facility 3')+Adj_18('Facility 1','Facility 3')+
Adj_19('Facility 1','Facility 3')+Adj_20('Facility 1','Facility 3')+Adj_21('Facility 1','Facility 3')+
Adj_22('Facility 1','Facility 3')+Adj_23('Facility 1','Facility 3')+Adj_24('Facility 1','Facility 3')+
Adj_25('Facility 1','Facility 3')+Adj_26('Facility 1','Facility 3')+Adj_27('Facility 1','Facility 3')+
Adj_28('Facility 1','Facility 3')+Adj_29('Facility 1','Facility 3')+Adj_30('Facility 1','Facility 3')+
Adj_31('Facility 1','Facility 3')+
Adj_1('Facility 3','Facility 1')+Adj_2('Facility 3','Facility 1')+Adj_3('Facility 3','Facility 1')+
Adj_4('Facility 3','Facility 1')+Adj_5('Facility 3','Facility 1')+Adj_6('Facility 3','Facility 1')+
Adj_7('Facility 3','Facility 1')+Adj_8('Facility 3','Facility 1')+Adj_9('Facility 3','Facility 1')+
Adj_10('Facility 3','Facility 1')+Adj_11('Facility 3','Facility 1')+Adj_12('Facility 3','Facility 1')+
Adj_13('Facility 3','Facility 1')+Adj_14('Facility 3','Facility 1')+Adj_15('Facility 3','Facility 1')+
Adj_16('Facility 3','Facility 1')+Adj_17('Facility 3','Facility 1')+Adj_18('Facility 3','Facility 1')+
Adj_19('Facility 3','Facility 1')+Adj_20('Facility 3','Facility 1')+Adj_21('Facility 3','Facility 1')+
Adj_22('Facility 3','Facility 1')+Adj_23('Facility 3','Facility 1')+Adj_24('Facility 3','Facility 1')+
Adj_25('Facility 3','Facility 1')+Adj_26('Facility 3','Facility 1')+Adj_27('Facility 3','Facility 1')+
Adj_28('Facility 3','Facility 1')+Adj_29('Facility 3','Facility 1')+Adj_30('Facility 3','Facility 1')+
Adj_31('Facility 3','Facility 1')+
Adj_1('Facility 4','Facility 3')+Adj_2('Facility 4','Facility 3')+Adj_3('Facility 4','Facility 3')+
Adj_4('Facility 4','Facility 3')+Adj_5('Facility 4','Facility 3')+Adj_6('Facility 4','Facility 3')+
Adj_7('Facility 4','Facility 3')+Adj_8('Facility 4','Facility 3')+Adj_9('Facility 4','Facility 3')+
Adj_10('Facility 4','Facility 3')+Adj_11('Facility 4','Facility 3')+Adj_12('Facility 4','Facility 3')+
Adj_13('Facility 4','Facility 3')+Adj_14('Facility 4','Facility 3')+Adj_15('Facility 4','Facility 3')+
Adj_16('Facility 4','Facility 3')+Adj_17('Facility 4','Facility 3')+Adj_18('Facility 4','Facility 3')+
Adj_19('Facility 4','Facility 3')+Adj_20('Facility 4','Facility 3')+Adj_21('Facility 4','Facility 3')+
Adj_22('Facility 4','Facility 3')+Adj_23('Facility 4','Facility 3')+Adj_24('Facility 4','Facility 3')+
Adj_25('Facility 4','Facility 3')+Adj_26('Facility 4','Facility 3')+Adj_27('Facility 4','Facility 3')+
Adj_28('Facility 4','Facility 3')+Adj_29('Facility 4','Facility 3')+Adj_30('Facility 4','Facility 3')+
Adj_31('Facility 4','Facility 3')+
Adj_1('Facility 3','Facility 4')+Adj_2('Facility 3','Facility 4')+Adj_3('Facility 3','Facility 4')+

```
                Adj_4('Facility 3','Facility 4')+Adj_5('Facility 3','Facility 4')+Adj_6('Facility 3','Facility 4')+
                Adj_7('Facility 3','Facility 4')+Adj_8('Facility 3','Facility 4')+Adj_9('Facility 3','Facility 4')+
                Adj_10('Facility 3','Facility 4')+Adj_11('Facility 3','Facility 4')+Adj_12('Facility 3','Facility 4')+
                Adj_13('Facility 3','Facility 4')+Adj_14('Facility 3','Facility 4')+Adj_15('Facility 3','Facility 4')+
                Adj_16('Facility 3','Facility 4')+Adj_17('Facility 3','Facility 4')+Adj_18('Facility 3','Facility 4')+
                Adj_19('Facility 3','Facility 4')+Adj_20('Facility 3','Facility 4')+Adj_21('Facility 3','Facility 4')+
                Adj_22('Facility 3','Facility 4')+Adj_23('Facility 3','Facility 4')+Adj_24('Facility 3','Facility 4')+
                Adj_25('Facility 3','Facility 4')+Adj_26('Facility 3','Facility 4')+Adj_27('Facility 3','Facility 4')+
                Adj_28('Facility 3','Facility 4')+Adj_29('Facility 3','Facility 4')+Adj_30('Facility 3','Facility 4')+
                Adj_31('Facility 3','Facility 4') >= 1
        }
    }
    Constraint Gen_Adj_4 {
        Definition: {
            sum(t4|t4<>'Facility 5',Adj_1('Facility 5',t4))+sum(t4|t4<>'Facility 5',Adj_2('Facility 5',t4))+
sum(t4|t4<>'Facility 5',Adj_3('Facility 5',t4))+sum(t4|t4<>'Facility 5',Adj_4('Facility 5',t4))+
sum(t4|t4<>'Facility 5',Adj_5('Facility 5',t4))+sum(t4|t4<>'Facility 5',Adj_6('Facility 5',t4))+
sum(t4|t4<>'Facility 5',Adj_7('Facility 5',t4))+sum(t4|t4<>'Facility 5',Adj_8('Facility 5',t4))+
sum(t4|t4<>'Facility 5',Adj_9('Facility 5',t4))+sum(t4|t4<>'Facility 5',Adj_10('Facility 5',t4))+
sum(t4|t4<>'Facility 5',Adj_11('Facility 5',t4))+sum(t4|t4<>'Facility 5',Adj_12('Facility 5',t4))+
sum(t4|t4<>'Facility 5',Adj_13('Facility 5',t4))+sum(t4|t4<>'Facility 5',Adj_14('Facility 5',t4))+
sum(t4|t4<>'Facility 5',Adj_15('Facility 5',t4))+sum(t4|t4<>'Facility 5',Adj_16('Facility 5',t4))+
sum(t4|t4<>'Facility 5',Adj_17('Facility 5',t4))+sum(t4|t4<>'Facility 5',Adj_18('Facility 5',t4))+
sum(t4|t4<>'Facility 5',Adj_19('Facility 5',t4))+sum(t4|t4<>'Facility 5',Adj_20('Facility 5',t4))+
sum(t4|t4<>'Facility 5',Adj_21('Facility 5',t4))+ sum(t4|t4<>'Facility 5',Adj_22('Facility 5',t4))+
sum(t4|t4<>'Facility 5',Adj_23('Facility 5',t4))+sum(t4|t4<>'Facility 5',Adj_24('Facility 5',t4))+
sum(t4|t4<>'Facility 5',Adj_25('Facility 5',t4))+sum(t4|t4<>'Facility 5',Adj_26('Facility 5',t4))+
sum(t4|t4<>'Facility 5',Adj_27('Facility 5',t4))+ sum(t4|t4<>'Facility 5',Adj_28('Facility 5',t4))+
sum(t4|t4<>'Facility 5',Adj_29('Facility 5',t4))+sum(t4|t4<>'Facility 5',Adj_30('Facility 5',t4))+
sum(t4|t4<>'Facility 5',Adj_31('Facility 5',t4))+sum(t4|t4<>'Facility 5',Adj_1(t4,'Facility 5'))+
sum(t4|t4<>'Facility 5',Adj_2(t4,'Facility 5'))+sum(t4|t4<>'Facility 5',Adj_3(t4,'Facility 5'))+
sum(t4|t4<>'Facility 5',Adj_4(t4,'Facility 5'))+sum(t4|t4<>'Facility 5',Adj_5(t4,'Facility 5'))+
sum(t4|t4<>'Facility 5',Adj_6(t4,'Facility 5'))+ sum(t4|t4<>'Facility 5',Adj_7(t4,'Facility 5'))+
sum(t4|t4<>'Facility 5',Adj_8(t4,'Facility 5'))+sum(t4|t4<>'Facility 5',Adj_9(t4,'Facility 5'))+
sum(t4|t4<>'Facility 5',Adj_10(t4,'Facility 5'))+sum(t4|t4<>'Facility 5',Adj_11(t4,'Facility 5'))+
sum(t4|t4<>'Facility 5',Adj_12(t4,'Facility 5'))+sum(t4|t4<>'Facility 5',Adj_13(t4,'Facility 5'))+
sum(t4|t4<>'Facility 5',Adj_14(t4,'Facility 5'))+sum(t4|t4<>'Facility 5',Adj_15(t4,'Facility 5'))+
sum(t4|t4<>'Facility 5',Adj_16(t4,'Facility 5'))+sum(t4|t4<>'Facility 5',Adj_17(t4,'Facility 5'))+
sum(t4|t4<>'Facility 5',Adj_18(t4,'Facility 5'))+ sum(t4|t4<>'Facility 5',Adj_19(t4,'Facility 5'))+
sum(t4|t4<>'Facility 5',Adj_20(t4,'Facility 5'))+sum(t4|t4<>'Facility 5',Adj_21(t4,'Facility 5'))+
sum(t4|t4<>'Facility 5',Adj_22(t4,'Facility 5'))+sum(t4|t4<>'Facility 5',Adj_23(t4,'Facility 5'))+
sum(t4|t4<>'Facility 5',Adj_24(t4,'Facility 5'))+ sum(t4|t4<>'Facility 5',Adj_25(t4,'Facility 5'))+
sum(t4|t4<>'Facility 5',Adj_26(t4,'Facility 5'))+sum(t4|t4<>'Facility 5',Adj_27(t4,'Facility 5'))+
sum(t4|t4<>'Facility 5',Adj_28(t4,'Facility 5'))+sum(t4|t4<>'Facility 5',Adj_29(t4,'Facility 5'))+
sum(t4|t4<>'Facility 5',Adj_30(t4,'Facility 5'))+ sum(t4|t4<>'Facility 5',Adj_31(t4,'Facility 5')) >= 1
        }
    }
    Constraint Gen_Adj_5 {
        Definition: {
            sum(t4|t4<>'Facility 8',Adj_1('Facility 8',t4))+sum(t4|t4<>'Facility 8',Adj_2('Facility 8',t4))+
sum(t4|t4<>'Facility 8',Adj_3('Facility 8',t4))+ sum(t4|t4<>'Facility 8',Adj_4('Facility 8',t4))+
sum(t4|t4<>'Facility 8',Adj_5('Facility 8',t4))+sum(t4|t4<>'Facility 8',Adj_6('Facility 8',t4))+
sum(t4|t4<>'Facility 8',Adj_7('Facility 8',t4))+sum(t4|t4<>'Facility 8',Adj_8('Facility 8',t4))+
sum(t4|t4<>'Facility 8',Adj_9('Facility 8',t4))+ sum(t4|t4<>'Facility 8',Adj_10('Facility 8',t4))+
sum(t4|t4<>'Facility 8',Adj_11('Facility 8',t4))+ sum(t4|t4<>'Facility 8',Adj_12('Facility 8',t4))+
sum(t4|t4<>'Facility 8',Adj_13('Facility 8',t4))+ sum(t4|t4<>'Facility 8',Adj_14('Facility 8',t4))+
sum(t4|t4<>'Facility 8',Adj_15('Facility 8',t4))+ sum(t4|t4<>'Facility 8',Adj_16('Facility 8',t4))+
sum(t4|t4<>'Facility 8',Adj_17('Facility 8',t4))+ sum(t4|t4<>'Facility 8',Adj_18('Facility 8',t4))+
sum(t4|t4<>'Facility 8',Adj_19('Facility 8',t4))+ sum(t4|t4<>'Facility 8',Adj_20('Facility 8',t4))+
sum(t4|t4<>'Facility 8',Adj_21('Facility 8',t4))+  sum(t4|t4<>'Facility 8',Adj_22('Facility 8',t4))+
```

```
sum(t4|t4<>'Facility 8',Adj_23('Facility 8',t4))+ sum(t4|t4<>'Facility 8',Adj_24('Facility 8',t4))+
sum(t4|t4<>'Facility 8',Adj_25('Facility 8',t4))+sum(t4|t4<>'Facility 8',Adj_26('Facility 8',t4))+
sum(t4|t4<>'Facility 8',Adj_27('Facility 8',t4))+ sum(t4|t4<>'Facility 8',Adj_28('Facility 8',t4))+
sum(t4|t4<>'Facility 8',Adj_29('Facility 8',t4))+sum(t4|t4<>'Facility 8',Adj_30('Facility 8',t4))+
sum(t4|t4<>'Facility 8',Adj_31('Facility 8',t4))+ sum(t4|t4<>'Facility 8',Adj_1(t4,'Facility 8'))+
sum(t4|t4<>'Facility 8',Adj_2(t4,'Facility 8'))+sum(t4|t4<>'Facility 8',Adj_3(t4,'Facility 8'))+
sum(t4|t4<>'Facility 8',Adj_4(t4,'Facility 8'))+sum(t4|t4<>'Facility 8',Adj_5(t4,'Facility 8'))+
sum(t4|t4<>'Facility 8',Adj_6(t4,'Facility 8'))+ sum(t4|t4<>'Facility 8',Adj_7(t4,'Facility 8'))+
sum(t4|t4<>'Facility 8',Adj_8(t4,'Facility 8'))+sum(t4|t4<>'Facility 8',Adj_9(t4,'Facility 8'))+
sum(t4|t4<>'Facility 8',Adj_10(t4,'Facility 8'))+sum(t4|t4<>'Facility 8',Adj_11(t4,'Facility 8'))+
sum(t4|t4<>'Facility 8',Adj_12(t4,'Facility 8'))+ sum(t4|t4<>'Facility 8',Adj_13(t4,'Facility 8'))+
sum(t4|t4<>'Facility 8',Adj_14(t4,'Facility 8'))+sum(t4|t4<>'Facility 8',Adj_15(t4,'Facility 8'))+
sum(t4|t4<>'Facility 8',Adj_16(t4,'Facility 8'))+sum(t4|t4<>'Facility 8',Adj_17(t4,'Facility 8'))+
sum(t4|t4<>'Facility 8',Adj_18(t4,'Facility 8'))+ sum(t4|t4<>'Facility 8',Adj_19(t4,'Facility 8'))+
sum(t4|t4<>'Facility 8',Adj_20(t4,'Facility 8'))+sum(t4|t4<>'Facility 8',Adj_21(t4,'Facility 8'))+
sum(t4|t4<>'Facility 8',Adj_22(t4,'Facility 8'))+sum(t4|t4<>'Facility 8',Adj_23(t4,'Facility 8'))+
sum(t4|t4<>'Facility 8',Adj_24(t4,'Facility 8'))+ sum(t4|t4<>'Facility 8',Adj_25(t4,'Facility 8'))+
sum(t4|t4<>'Facility 8',Adj_26(t4,'Facility 8'))+sum(t4|t4<>'Facility 8',Adj_27(t4,'Facility 8'))+
sum(t4|t4<>'Facility 8',Adj_28(t4,'Facility 8'))+sum(t4|t4<>'Facility 8',Adj_29(t4,'Facility 8'))+
sum(t4|t4<>'Facility 8',Adj_30(t4,'Facility 8'))+ sum(t4|t4<>'Facility 8',Adj_31(t4,'Facility 8')) >= 1
    }
  }
  Constraint Gen_Adj_6 {
    Definition: {
      Adj_1('Facility 5','Facility 6')+Adj_2('Facility 5','Facility 6')+Adj_3('Facility 5','Facility 6')+
            Adj_4('Facility 5','Facility 6')+Adj_5('Facility 5','Facility 6')+Adj_6('Facility 5','Facility 6')+
            Adj_7('Facility 5','Facility 6')+Adj_8('Facility 5','Facility 6')+Adj_9('Facility 5','Facility 6')+
            Adj_10('Facility 5','Facility 6')+Adj_11('Facility 5','Facility 6')+Adj_12('Facility 5','Facility 6')+
            Adj_13('Facility 5','Facility 6')+Adj_14('Facility 5','Facility 6')+Adj_15('Facility 5','Facility 6')+
            Adj_16('Facility 5','Facility 6')+Adj_17('Facility 5','Facility 6')+Adj_18('Facility 5','Facility 6')+
            Adj_19('Facility 5','Facility 6')+Adj_20('Facility 5','Facility 6')+Adj_21('Facility 5','Facility 6')+
            Adj_22('Facility 5','Facility 6')+Adj_23('Facility 5','Facility 6')+Adj_24('Facility 5','Facility 6')+
            Adj_25('Facility 5','Facility 6')+Adj_26('Facility 5','Facility 6')+Adj_27('Facility 5','Facility 6')+
            Adj_28('Facility 5','Facility 6')+Adj_29('Facility 5','Facility 6')+Adj_30('Facility 5','Facility 6')+
            Adj_31('Facility 5','Facility 6')+
            Adj_1('Facility 6','Facility 5')+Adj_2('Facility 6','Facility 5')+Adj_3('Facility 6','Facility 5')+
            Adj_4('Facility 6','Facility 5')+Adj_5('Facility 6','Facility 5')+Adj_6('Facility 6','Facility 5')+
            Adj_7('Facility 6','Facility 5')+Adj_8('Facility 6','Facility 5')+Adj_9('Facility 6','Facility 5')+
            Adj_10('Facility 6','Facility 5')+Adj_11('Facility 6','Facility 5')+Adj_12('Facility 6','Facility 5')+
            Adj_13('Facility 6','Facility 5')+Adj_14('Facility 6','Facility 5')+Adj_15('Facility 6','Facility 5')+
            Adj_16('Facility 6','Facility 5')+Adj_17('Facility 6','Facility 5')+Adj_18('Facility 6','Facility 5')+
            Adj_19('Facility 6','Facility 5')+Adj_20('Facility 6','Facility 5')+Adj_21('Facility 6','Facility 5')+
            Adj_22('Facility 6','Facility 5')+Adj_23('Facility 6','Facility 5')+Adj_24('Facility 6','Facility 5')+
            Adj_25('Facility 6','Facility 5')+Adj_26('Facility 6','Facility 5')+Adj_27('Facility 6','Facility 5')+
            Adj_28('Facility 6','Facility 5')+Adj_29('Facility 6','Facility 5')+Adj_30('Facility 6','Facility 5')+
            Adj_31('Facility 6','Facility 5')+
            Adj_1('Facility 8','Facility 6')+Adj_2('Facility 8','Facility 6')+Adj_3('Facility 8','Facility 6')+
            Adj_4('Facility 8','Facility 6')+Adj_5('Facility 8','Facility 6')+Adj_6('Facility 8','Facility 6')+
            Adj_7('Facility 8','Facility 6')+Adj_8('Facility 8','Facility 6')+Adj_9('Facility 8','Facility 6')+
            Adj_10('Facility 8','Facility 6')+Adj_11('Facility 8','Facility 6')+Adj_12('Facility 8','Facility 6')+
            Adj_13('Facility 8','Facility 6')+Adj_14('Facility 8','Facility 6')+Adj_15('Facility 8','Facility 6')+
            Adj_16('Facility 8','Facility 6')+Adj_17('Facility 8','Facility 6')+Adj_18('Facility 8','Facility 6')+
            Adj_19('Facility 8','Facility 6')+Adj_20('Facility 8','Facility 6')+Adj_21('Facility 8','Facility 6')+
            Adj_22('Facility 8','Facility 6')+Adj_23('Facility 8','Facility 6')+Adj_24('Facility 8','Facility 6')+
            Adj_25('Facility 8','Facility 6')+Adj_26('Facility 8','Facility 6')+Adj_27('Facility 8','Facility 6')+
            Adj_28('Facility 8','Facility 6')+Adj_29('Facility 8','Facility 6')+Adj_30('Facility 8','Facility 6')+
            Adj_31('Facility 8','Facility 6')+
            Adj_1('Facility 6','Facility 8')+Adj_2('Facility 6','Facility 8')+Adj_3('Facility 6','Facility 8')+
            Adj_4('Facility 6','Facility 8')+Adj_5('Facility 6','Facility 8')+Adj_6('Facility 6','Facility 8')+
            Adj_7('Facility 6','Facility 8')+Adj_8('Facility 6','Facility 8')+Adj_9('Facility 6','Facility 8')+
```

```
                Adj_10('Facility 6','Facility 8')+Adj_11('Facility 6','Facility 8')+Adj_12('Facility 6','Facility 8')+
                Adj_13('Facility 6','Facility 8')+Adj_14('Facility 6','Facility 8')+Adj_15('Facility 6','Facility 8')+
                Adj_16('Facility 6','Facility 8')+Adj_17('Facility 6','Facility 8')+Adj_18('Facility 6','Facility 8')+
                Adj_19('Facility 6','Facility 8')+Adj_20('Facility 6','Facility 8')+Adj_21('Facility 6','Facility 8')+
                Adj_22('Facility 6','Facility 8')+Adj_23('Facility 6','Facility 8')+Adj_24('Facility 6','Facility 8')+
                Adj_25('Facility 6','Facility 8')+Adj_26('Facility 6','Facility 8')+Adj_27('Facility 6','Facility 8')+
                Adj_28('Facility 6','Facility 8')+Adj_29('Facility 6','Facility 8')+Adj_30('Facility 6','Facility 8')+
                Adj_31('Facility 6','Facility 8')+
                Adj_1('Facility 5','Facility 7')+Adj_2('Facility 5','Facility 7')+Adj_3('Facility 5','Facility 7')+
                Adj_4('Facility 5','Facility 7')+Adj_5('Facility 5','Facility 7')+Adj_6('Facility 5','Facility 7')+
                Adj_7('Facility 5','Facility 7')+Adj_8('Facility 5','Facility 7')+Adj_9('Facility 5','Facility 7')+
                Adj_10('Facility 5','Facility 7')+Adj_11('Facility 5','Facility 7')+Adj_12('Facility 5','Facility 7')+
                Adj_13('Facility 5','Facility 7')+Adj_14('Facility 5','Facility 7')+Adj_15('Facility 5','Facility 7')+
                Adj_16('Facility 5','Facility 7')+Adj_17('Facility 5','Facility 7')+Adj_18('Facility 5','Facility 7')+
                Adj_19('Facility 5','Facility 7')+Adj_20('Facility 5','Facility 7')+Adj_21('Facility 5','Facility 7')+
                Adj_22('Facility 5','Facility 7')+Adj_23('Facility 5','Facility 7')+Adj_24('Facility 5','Facility 7')+
                Adj_25('Facility 5','Facility 7')+Adj_26('Facility 5','Facility 7')+Adj_27('Facility 5','Facility 7')+
                Adj_28('Facility 5','Facility 7')+Adj_29('Facility 5','Facility 7')+Adj_30('Facility 5','Facility 7')+
                Adj_31('Facility 5','Facility 7')+
                Adj_1('Facility 7','Facility 5')+Adj_2('Facility 7','Facility 5')+Adj_3('Facility 7','Facility 5')+
                Adj_4('Facility 7','Facility 5')+Adj_5('Facility 7','Facility 5')+Adj_6('Facility 7','Facility 5')+
                Adj_7('Facility 7','Facility 5')+Adj_8('Facility 7','Facility 5')+Adj_9('Facility 7','Facility 5')+
                Adj_10('Facility 7','Facility 5')+Adj_11('Facility 7','Facility 5')+Adj_12('Facility 7','Facility 5')+
                Adj_13('Facility 7','Facility 5')+Adj_14('Facility 7','Facility 5')+Adj_15('Facility 7','Facility 5')+
                Adj_16('Facility 7','Facility 5')+Adj_17('Facility 7','Facility 5')+Adj_18('Facility 7','Facility 5')+
                Adj_19('Facility 7','Facility 5')+Adj_20('Facility 7','Facility 5')+Adj_21('Facility 7','Facility 5')+
                Adj_22('Facility 7','Facility 5')+Adj_23('Facility 7','Facility 5')+Adj_24('Facility 7','Facility 5')+
                Adj_25('Facility 7','Facility 5')+Adj_26('Facility 7','Facility 5')+Adj_27('Facility 7','Facility 5')+
                Adj_28('Facility 7','Facility 5')+Adj_29('Facility 7','Facility 5')+Adj_30('Facility 7','Facility 5')+
                Adj_31('Facility 7','Facility 5')+
                Adj_1('Facility 8','Facility 7')+Adj_2('Facility 8','Facility 7')+Adj_3('Facility 8','Facility 7')+
                Adj_4('Facility 8','Facility 7')+Adj_5('Facility 8','Facility 7')+Adj_6('Facility 8','Facility 7')+
                Adj_7('Facility 8','Facility 7')+Adj_8('Facility 8','Facility 7')+Adj_9('Facility 8','Facility 7')+
                Adj_10('Facility 8','Facility 7')+Adj_11('Facility 8','Facility 7')+Adj_12('Facility 8','Facility 7')+
                Adj_13('Facility 8','Facility 7')+Adj_14('Facility 8','Facility 7')+Adj_15('Facility 8','Facility 7')+
                Adj_16('Facility 8','Facility 7')+Adj_17('Facility 8','Facility 7')+Adj_18('Facility 8','Facility 7')+
                Adj_19('Facility 8','Facility 7')+Adj_20('Facility 8','Facility 7')+Adj_21('Facility 8','Facility 7')+
                Adj_22('Facility 8','Facility 7')+Adj_23('Facility 8','Facility 7')+Adj_24('Facility 8','Facility 7')+
                Adj_25('Facility 8','Facility 7')+Adj_26('Facility 8','Facility 7')+Adj_27('Facility 8','Facility 7')+
                Adj_28('Facility 8','Facility 7')+Adj_29('Facility 8','Facility 7')+Adj_30('Facility 8','Facility 7')+
                Adj_31('Facility 8','Facility 7')+
                Adj_1('Facility 7','Facility 8')+Adj_2('Facility 7','Facility 8')+Adj_3('Facility 7','Facility 8')+
                Adj_4('Facility 7','Facility 8')+Adj_5('Facility 7','Facility 8')+Adj_6('Facility 7','Facility 8')+
                Adj_7('Facility 7','Facility 8')+Adj_8('Facility 7','Facility 8')+Adj_9('Facility 7','Facility 8')+
                Adj_10('Facility 7','Facility 8')+Adj_11('Facility 7','Facility 8')+Adj_12('Facility 7','Facility 8')+
                Adj_13('Facility 7','Facility 8')+Adj_14('Facility 7','Facility 8')+Adj_15('Facility 7','Facility 8')+
                Adj_16('Facility 7','Facility 8')+Adj_17('Facility 7','Facility 8')+Adj_18('Facility 7','Facility 8')+
                Adj_19('Facility 7','Facility 8')+Adj_20('Facility 7','Facility 8')+Adj_21('Facility 7','Facility 8')+
                Adj_22('Facility 7','Facility 8')+Adj_23('Facility 7','Facility 8')+Adj_24('Facility 7','Facility 8')+
                Adj_25('Facility 7','Facility 8')+Adj_26('Facility 7','Facility 8')+Adj_27('Facility 7','Facility 8')+
                Adj_28('Facility 7','Facility 8')+Adj_29('Facility 7','Facility 8')+Adj_30('Facility 7','Facility 8')+
                Adj_31('Facility 7','Facility 8') >= 1
        }
    }
    Constraint Gen_Adj_7 {
        Definition: {
            Adj_1('Facility 9','Facility 10')+Adj_2('Facility 9','Facility 10')+Adj_3('Facility 9','Facility 10')+
Adj_4('Facility 9','Facility 10')+Adj_5('Facility 9','Facility 10')+Adj_6('Facility 9','Facility 10')+
Adj_7('Facility 9','Facility 10')+Adj_8('Facility 9','Facility 10')+Adj_9('Facility 9','Facility 10')+
Adj_10('Facility 9','Facility 10')+Adj_11('Facility 9','Facility 10')+Adj_12('Facility 9','Facility 10')+
```

```
Adj_13('Facility 9','Facility 10')+Adj_14('Facility 9','Facility 10')+Adj_15('Facility 9','Facility 10')+
Adj_16('Facility 9','Facility 10')+Adj_17('Facility 9','Facility 10')+Adj_18('Facility 9','Facility 10')+
Adj_19('Facility 9','Facility 10')+Adj_20('Facility 9','Facility 10')+Adj_21('Facility 9','Facility 10')+
Adj_22('Facility 9','Facility 10')+Adj_23('Facility 9','Facility 10')+Adj_24('Facility 9','Facility 10')+
Adj_25('Facility 9','Facility 10')+Adj_26('Facility 9','Facility 10')+Adj_27('Facility 9','Facility 10')+
Adj_28('Facility 9','Facility 10')+Adj_29('Facility 9','Facility 10')+Adj_30('Facility 9','Facility 10')+
Adj_31('Facility 9','Facility 10')+ Adj_1('Facility 10','Facility 9')+Adj_2('Facility 10','Facility 9')+
Adj_3('Facility 10','Facility 9')+ Adj_4('Facility 10','Facility 9')+Adj_5('Facility 10','Facility 9')+
Adj_6('Facility 10','Facility 9')+ Adj_7('Facility 10','Facility 9')+Adj_8('Facility 10','Facility 9')+
Adj_9('Facility 10','Facility 9')+ Adj_10('Facility 10','Facility 9')+Adj_11('Facility 10','Facility 9')+
Adj_12('Facility 10','Facility 9')+ Adj_13('Facility 10','Facility 9')+Adj_14('Facility 10','Facility 9')+
Adj_15('Facility 10','Facility 9')+ Adj_16('Facility 10','Facility 9')+Adj_17('Facility 10','Facility 9')+
Adj_18('Facility 10','Facility 9')+ Adj_19('Facility 10','Facility 9')+Adj_20('Facility 10','Facility 9')+
Adj_21('Facility 10','Facility 9')+ Adj_22('Facility 10','Facility 9')+Adj_23('Facility 10','Facility 9')+
Adj_24('Facility 10','Facility 9')+ Adj_25('Facility 10','Facility 9')+Adj_26('Facility 10','Facility 9')+
Adj_27('Facility 10','Facility 9')+ Adj_28('Facility 10','Facility 9')+Adj_29('Facility 10','Facility 9')+
Adj_30('Facility 10','Facility 9')+ Adj_31('Facility 10','Facility 9')+ Adj_1('Facility 9','Facility 11')+
Adj_2('Facility 9','Facility 11')+Adj_3('Facility 9','Facility 11')+ Adj_4('Facility 9','Facility 11')+Adj_5('Facility
9','Facility 11')+Adj_6('Facility 9','Facility 11')+ Adj_7('Facility 9','Facility 11')+Adj_8('Facility 9','Facility
11')+Adj_9('Facility 9','Facility 11')+ Adj_10('Facility 9','Facility 11')+Adj_11('Facility 9','Facility
11')+Adj_12('Facility 9','Facility 11')+ Adj_13('Facility 9','Facility 11')+Adj_14('Facility 9','Facility
11')+Adj_15('Facility 9','Facility 11')+ Adj_16('Facility 9','Facility 11')+Adj_17('Facility 9','Facility
11')+Adj_18('Facility 9','Facility 11')+ Adj_19('Facility 9','Facility 11')+Adj_20('Facility 9','Facility
11')+Adj_21('Facility 9','Facility 11')+ Adj_22('Facility 9','Facility 11')+Adj_23('Facility 9','Facility
11')+Adj_24('Facility 9','Facility 11')+ Adj_25('Facility 9','Facility 11')+Adj_26('Facility 9','Facility
11')+Adj_27('Facility 9','Facility 11')+ Adj_28('Facility 9','Facility 11')+Adj_29('Facility 9','Facility
11')+Adj_30('Facility 9','Facility 11')+ Adj_31('Facility 9','Facility 11')+ Adj_1('Facility 11','Facility
9')+Adj_2('Facility 11','Facility 9')+Adj_3('Facility 11','Facility 9')+ Adj_4('Facility 11','Facility
9')+Adj_5('Facility 11','Facility 9')+Adj_6('Facility 11','Facility 9')+ Adj_7('Facility 11','Facility
9')+Adj_8('Facility 11','Facility 9')+Adj_9('Facility 11','Facility 9')+ Adj_10('Facility 11','Facility
9')+Adj_11('Facility 11','Facility 9')+Adj_12('Facility 11','Facility 9')+ Adj_13('Facility 11','Facility
9')+Adj_14('Facility 11','Facility 9')+Adj_15('Facility 11','Facility 9')+ Adj_16('Facility 11','Facility
9')+Adj_17('Facility 11','Facility 9')+Adj_18('Facility 11','Facility 9')+ Adj_19('Facility 11','Facility
9')+Adj_20('Facility 11','Facility 9')+Adj_21('Facility 11','Facility 9')+ Adj_22('Facility 11','Facility
9')+Adj_23('Facility 11','Facility 9')+Adj_24('Facility 11','Facility 9')+ Adj_25('Facility 11','Facility
9')+Adj_26('Facility 11','Facility 9')+Adj_27('Facility 11','Facility 9')+ Adj_28('Facility 11','Facility
9')+Adj_29('Facility 11','Facility 9')+Adj_30('Facility 11','Facility 9')+ Adj_31('Facility 11','Facility 9') >= 1
        }
    }
    Constraint Gen_Adj_8 {
        Definition: {
            Adj_1('Facility 10','Facility 9')+Adj_2('Facility 10','Facility 9')+Adj_3('Facility 10','Facility 9')+
Adj_4('Facility 10','Facility 9')+Adj_5('Facility 10','Facility 9')+Adj_6('Facility 10','Facility 9')+
Adj_7('Facility 10','Facility 9')+Adj_8('Facility 10','Facility 9')+Adj_9('Facility 10','Facility 9')+
Adj_10('Facility 10','Facility 9')+Adj_11('Facility 10','Facility 9')+Adj_12('Facility 10','Facility 9')+
Adj_13('Facility 10','Facility 9')+Adj_14('Facility 10','Facility 9')+Adj_15('Facility 10','Facility 9')+
Adj_16('Facility 10','Facility 9')+Adj_17('Facility 10','Facility 9')+Adj_18('Facility 10','Facility 9')+
Adj_19('Facility 10','Facility 9')+Adj_20('Facility 10','Facility 9')+Adj_21('Facility 10','Facility 9')+
Adj_22('Facility 10','Facility 9')+Adj_23('Facility 10','Facility 9')+Adj_24('Facility 10','Facility 9')+
Adj_25('Facility 10','Facility 9')+Adj_26('Facility 10','Facility 9')+Adj_27('Facility 10','Facility 9')+
Adj_28('Facility 10','Facility 9')+Adj_29('Facility 10','Facility 9')+Adj_30('Facility 10','Facility 9')+
Adj_31('Facility 10','Facility 9')+ Adj_1('Facility 9','Facility 10')+Adj_2('Facility 9','Facility 10')+
Adj_3('Facility 9','Facility 10')+ Adj_4('Facility 9','Facility 10')+Adj_5('Facility 9','Facility 10')+
Adj_6('Facility 9','Facility 10')+ Adj_7('Facility 9','Facility 10')+Adj_8('Facility 9','Facility 10')+
Adj_9('Facility 9','Facility 10')+ Adj_10('Facility 9','Facility 10')+Adj_11('Facility 9','Facility
10')+Adj_12('Facility 9','Facility 10')+ Adj_13('Facility 9','Facility 10')+Adj_14('Facility 9','Facility
10')+Adj_15('Facility 9','Facility 10')+ Adj_16('Facility 9','Facility 10')+Adj_17('Facility 9','Facility
10')+Adj_18('Facility 9','Facility 10')+ Adj_19('Facility 9','Facility 10')+Adj_20('Facility 9','Facility
10')+Adj_21('Facility 9','Facility 10')+ Adj_22('Facility 9','Facility 10')+Adj_23('Facility 9','Facility
10')+Adj_24('Facility 9','Facility 10')+ Adj_25('Facility 9','Facility 10')+Adj_26('Facility 9','Facility
```

10')+Adj_27('Facility 9','Facility 10')+ Adj_28('Facility 9','Facility 10')+Adj_29('Facility 9','Facility 10')+Adj_30('Facility 9','Facility 10')+ Adj_31('Facility 9','Facility 10')+ Adj_1('Facility 10','Facility 11')+Adj_2('Facility 10','Facility 11')+Adj_3('Facility 10','Facility 11')+ Adj_4('Facility 10','Facility 11')+Adj_5('Facility 10','Facility 11')+Adj_6('Facility 10','Facility 11')+ Adj_7('Facility 10','Facility 11')+Adj_8('Facility 10','Facility 11')+Adj_9('Facility 10','Facility 11')+ Adj_10('Facility 10','Facility 11')+Adj_11('Facility 10','Facility 11')+Adj_12('Facility 10','Facility 11')+ Adj_13('Facility 10','Facility 11')+Adj_14('Facility 10','Facility 11')+Adj_15('Facility 10','Facility 11')+ Adj_16('Facility 10','Facility 11')+Adj_17('Facility 10','Facility 11')+Adj_18('Facility 10','Facility 11')+ Adj_19('Facility 10','Facility 11')+Adj_20('Facility 10','Facility 11')+Adj_21('Facility 10','Facility 11')+ Adj_22('Facility 10','Facility 11')+Adj_23('Facility 10','Facility 11')+Adj_24('Facility 10','Facility 11')+ Adj_25('Facility 10','Facility 11')+Adj_26('Facility 10','Facility 11')+Adj_27('Facility 10','Facility 11')+ Adj_28('Facility 10','Facility 11')+Adj_29('Facility 10','Facility 11')+Adj_30('Facility 10','Facility 11')+ Adj_31('Facility 10','Facility 11')+
Adj_1('Facility 11','Facility 10')+Adj_2('Facility 11','Facility 10')+Adj_3('Facility 11','Facility 10')+
Adj_4('Facility 11','Facility 10')+Adj_5('Facility 11','Facility 10')+Adj_6('Facility 11','Facility 10')+
Adj_7('Facility 11','Facility 10')+Adj_8('Facility 11','Facility 10')+Adj_9('Facility 11','Facility 10')+
Adj_10('Facility 11','Facility 10')+Adj_11('Facility 11','Facility 10')+Adj_12('Facility 11','Facility 10')+
Adj_13('Facility 11','Facility 10')+Adj_14('Facility 11','Facility 10')+Adj_15('Facility 11','Facility 10')+
Adj_16('Facility 11','Facility 10')+Adj_17('Facility 11','Facility 10')+Adj_18('Facility 11','Facility 10')+
Adj_19('Facility 11','Facility 10')+Adj_20('Facility 11','Facility 10')+Adj_21('Facility 11','Facility 10')+
Adj_22('Facility 11','Facility 10')+Adj_23('Facility 11','Facility 10')+Adj_24('Facility 11','Facility 10')+
Adj_25('Facility 11','Facility 10')+Adj_26('Facility 11','Facility 10')+Adj_27('Facility 11','Facility 10')+
Adj_28('Facility 11','Facility 10')+Adj_29('Facility 11','Facility 10')+Adj_30('Facility 11','Facility 10')+
Adj_31('Facility 11','Facility 10') >= 1
}
}
Constraint Gen_Adj_9 {
Definition: {
Adj_1('Facility 11','Facility 10')+Adj_2('Facility 11','Facility 10')+Adj_3('Facility 11','Facility 10')+
Adj_4('Facility 11','Facility 10')+Adj_5('Facility 11','Facility 10')+Adj_6('Facility 11','Facility 10')+
Adj_7('Facility 11','Facility 10')+Adj_8('Facility 11','Facility 10')+Adj_9('Facility 11','Facility 10')+
Adj_10('Facility 11','Facility 10')+Adj_11('Facility 11','Facility 10')+Adj_12('Facility 11','Facility 10')+
Adj_13('Facility 11','Facility 10')+Adj_14('Facility 11','Facility 10')+Adj_15('Facility 11','Facility 10')+
Adj_16('Facility 11','Facility 10')+Adj_17('Facility 11','Facility 10')+Adj_18('Facility 11','Facility 10')+
Adj_19('Facility 11','Facility 10')+Adj_20('Facility 11','Facility 10')+Adj_21('Facility 11','Facility 10')+
Adj_22('Facility 11','Facility 10')+Adj_23('Facility 11','Facility 10')+Adj_24('Facility 11','Facility 10')+
Adj_25('Facility 11','Facility 10')+Adj_26('Facility 11','Facility 10')+Adj_27('Facility 11','Facility 10')+
Adj_28('Facility 11','Facility 10')+Adj_29('Facility 11','Facility 10')+Adj_30('Facility 11','Facility 10')+
Adj_31('Facility 11','Facility 10')+ Adj_1('Facility 10','Facility 11')+Adj_2('Facility 10','Facility 11')+Adj_3('Facility 10','Facility 11')+ Adj_4('Facility 10','Facility 11')+Adj_5('Facility 10','Facility 11')+Adj_6('Facility 10','Facility 11')+ Adj_7('Facility 10','Facility 11')+Adj_8('Facility 10','Facility 11')+Adj_9('Facility 10','Facility 11')+ Adj_10('Facility 10','Facility 11')+Adj_11('Facility 10','Facility 11')+Adj_12('Facility 10','Facility 11')+ Adj_13('Facility 10','Facility 11')+Adj_14('Facility 10','Facility 11')+Adj_15('Facility 10','Facility 11')+ Adj_16('Facility 10','Facility 11')+Adj_17('Facility 10','Facility 11')+Adj_18('Facility 10','Facility 11')+ Adj_19('Facility 10','Facility 11')+Adj_20('Facility 10','Facility 11')+Adj_21('Facility 10','Facility 11')+ Adj_22('Facility 10','Facility 11')+Adj_23('Facility 10','Facility 11')+Adj_24('Facility 10','Facility 11')+ Adj_25('Facility 10','Facility 11')+Adj_26('Facility 10','Facility 11')+Adj_27('Facility 10','Facility 11')+ Adj_28('Facility 10','Facility 11')+Adj_29('Facility 10','Facility 11')+Adj_30('Facility 10','Facility 11')+ Adj_31('Facility 10','Facility 11')+ Adj_1('Facility 9','Facility 11')+Adj_2('Facility 9','Facility 11')+Adj_3('Facility 9','Facility 11')+ Adj_4('Facility 9','Facility 11')+Adj_5('Facility 9','Facility 11')+Adj_6('Facility 9','Facility 11')+ Adj_7('Facility 9','Facility 11')+Adj_8('Facility 9','Facility 11')+Adj_9('Facility 9','Facility 11')+ Adj_10('Facility 9','Facility 11')+Adj_11('Facility 9','Facility 11')+Adj_12('Facility 9','Facility 11')+ Adj_13('Facility 9','Facility 11')+Adj_14('Facility 9','Facility 11')+Adj_15('Facility 9','Facility 11')+ Adj_16('Facility 9','Facility 11')+Adj_17('Facility 9','Facility 11')+Adj_18('Facility 9','Facility 11')+ Adj_19('Facility 9','Facility 11')+Adj_20('Facility 9','Facility 11')+Adj_21('Facility 9','Facility 11')+ Adj_22('Facility 9','Facility 11')+Adj_23('Facility 9','Facility 11')+Adj_24('Facility 9','Facility 11')+ Adj_25('Facility 9','Facility 11')+Adj_26('Facility 9','Facility 11')+Adj_27('Facility 9','Facility 11')+ Adj_28('Facility 9','Facility 11')+Adj_29('Facility 9','Facility 11')+Adj_30('Facility 9','Facility 11')+ Adj_31('Facility 9','Facility 11')+
Adj_1('Facility 11','Facility 9')+Adj_2('Facility 11','Facility 9')+Adj_3('Facility 11','Facility 9')+
Adj_4('Facility 11','Facility 9')+Adj_5('Facility 11','Facility 9')+Adj_6('Facility 11','Facility 9')+

```
Adj_7('Facility 11','Facility 9')+Adj_8('Facility 11','Facility 9')+Adj_9('Facility 11','Facility 9')+
Adj_10('Facility 11','Facility 9')+Adj_11('Facility 11','Facility 9')+Adj_12('Facility 11','Facility 9')+
Adj_13('Facility 11','Facility 9')+Adj_14('Facility 11','Facility 9')+Adj_15('Facility 11','Facility 9')+
Adj_16('Facility 11','Facility 9')+Adj_17('Facility 11','Facility 9')+Adj_18('Facility 11','Facility 9')+
Adj_19('Facility 11','Facility 9')+Adj_20('Facility 11','Facility 9')+Adj_21('Facility 11','Facility 9')+
Adj_22('Facility 11','Facility 9')+Adj_23('Facility 11','Facility 9')+Adj_24('Facility 11','Facility 9')+
Adj_25('Facility 11','Facility 9')+Adj_26('Facility 11','Facility 9')+Adj_27('Facility 11','Facility 9')+
Adj_28('Facility 11','Facility 9')+Adj_29('Facility 11','Facility 9')+Adj_30('Facility 11','Facility 9')+
Adj_31('Facility 11','Facility 9') >= 1
    }
  }
  Constraint Gen_Adj_10 {
    Definition: {
      Adj_1('Facility 12','Facility 13')+Adj_2('Facility 12','Facility 13')+Adj_3('Facility 12','Facility 13')+
Adj_4('Facility 12','Facility 13')+Adj_5('Facility 12','Facility 13')+Adj_6('Facility 12','Facility 13')+
Adj_7('Facility 12','Facility 13')+Adj_8('Facility 12','Facility 13')+Adj_9('Facility 12','Facility 13')+
Adj_10('Facility 12','Facility 13')+Adj_11('Facility 12','Facility 13')+Adj_12('Facility 12','Facility 13')+
Adj_13('Facility 12','Facility 13')+Adj_14('Facility 12','Facility 13')+Adj_15('Facility 12','Facility 13')+
Adj_16('Facility 12','Facility 13')+Adj_17('Facility 12','Facility 13')+Adj_18('Facility 12','Facility 13')+
Adj_19('Facility 12','Facility 13')+Adj_20('Facility 12','Facility 13')+Adj_21('Facility 12','Facility 13')+
Adj_22('Facility 12','Facility 13')+Adj_23('Facility 12','Facility 13')+Adj_24('Facility 12','Facility 13')+
Adj_25('Facility 12','Facility 13')+Adj_26('Facility 12','Facility 13')+Adj_27('Facility 12','Facility 13')+
Adj_28('Facility 12','Facility 13')+Adj_29('Facility 12','Facility 13')+Adj_30('Facility 12','Facility 13')+
Adj_31('Facility 12','Facility 13')+ Adj_1('Facility 13','Facility 12')+Adj_2('Facility 13','Facility
12')+Adj_3('Facility 13','Facility 12')+ Adj_4('Facility 13','Facility 12')+Adj_5('Facility 13','Facility
12')+Adj_6('Facility 13','Facility 12')+ Adj_7('Facility 13','Facility 12')+Adj_8('Facility 13','Facility
12')+Adj_9('Facility 13','Facility 12')+ Adj_10('Facility 13','Facility 12')+Adj_11('Facility 13','Facility
12')+Adj_12('Facility 13','Facility 12')+ Adj_13('Facility 13','Facility 12')+Adj_14('Facility 13','Facility
12')+Adj_15('Facility 13','Facility 12')+ Adj_16('Facility 13','Facility 12')+Adj_17('Facility 13','Facility
12')+Adj_18('Facility 13','Facility 12')+ Adj_19('Facility 13','Facility 12')+Adj_20('Facility 13','Facility
12')+Adj_21('Facility 13','Facility 12')+ Adj_22('Facility 13','Facility 12')+Adj_23('Facility 13','Facility
12')+Adj_24('Facility 13','Facility 12')+ Adj_25('Facility 13','Facility 12')+Adj_26('Facility 13','Facility
12')+Adj_27('Facility 13','Facility 12')+ Adj_28('Facility 13','Facility 12')+Adj_29('Facility 13','Facility
12')+Adj_30('Facility 13','Facility 12')+ Adj_31('Facility 13','Facility 12')+ Adj_1('Facility 12','Facility
14')+Adj_2('Facility 12','Facility 14')+Adj_3('Facility 12','Facility 14')+ Adj_4('Facility 12','Facility
14')+Adj_5('Facility 12','Facility 14')+Adj_6('Facility 12','Facility 14')+ Adj_7('Facility 12','Facility
14')+Adj_8('Facility 12','Facility 14')+Adj_9('Facility 12','Facility 14')+ Adj_10('Facility 12','Facility
14')+Adj_11('Facility 12','Facility 14')+Adj_12('Facility 12','Facility 14')+ Adj_13('Facility 12','Facility
14')+Adj_14('Facility 12','Facility 14')+Adj_15('Facility 12','Facility 14')+ Adj_16('Facility 12','Facility
14')+Adj_17('Facility 12','Facility 14')+Adj_18('Facility 12','Facility 14')+ Adj_19('Facility 12','Facility
14')+Adj_20('Facility 12','Facility 14')+Adj_21('Facility 12','Facility 14')+ Adj_22('Facility 12','Facility
14')+Adj_23('Facility 12','Facility 14')+Adj_24('Facility 12','Facility 14')+ Adj_25('Facility 12','Facility
14')+Adj_26('Facility 12','Facility 14')+Adj_27('Facility 12','Facility 14')+ Adj_28('Facility 12','Facility
14')+Adj_29('Facility 12','Facility 14')+Adj_30('Facility 12','Facility 14')+ Adj_31('Facility 12','Facility 14')+
Adj_1('Facility 14','Facility 12')+Adj_2('Facility 14','Facility 12')+Adj_3('Facility 14','Facility 12')+
Adj_4('Facility 14','Facility 12')+Adj_5('Facility 14','Facility 12')+Adj_6('Facility 14','Facility 12')+
Adj_7('Facility 14','Facility 12')+Adj_8('Facility 14','Facility 12')+Adj_9('Facility 14','Facility 12')+
Adj_10('Facility 14','Facility 12')+Adj_11('Facility 14','Facility 12')+Adj_12('Facility 14','Facility 12')+
Adj_13('Facility 14','Facility 12')+Adj_14('Facility 14','Facility 12')+Adj_15('Facility 14','Facility 12')+
Adj_16('Facility 14','Facility 12')+Adj_17('Facility 14','Facility 12')+Adj_18('Facility 14','Facility 12')+
Adj_19('Facility 14','Facility 12')+Adj_20('Facility 14','Facility 12')+Adj_21('Facility 14','Facility 12')+
Adj_22('Facility 14','Facility 12')+Adj_23('Facility 14','Facility 12')+Adj_24('Facility 14','Facility 12')+
Adj_25('Facility 14','Facility 12')+Adj_26('Facility 14','Facility 12')+Adj_27('Facility 14','Facility 12')+
Adj_28('Facility 14','Facility 12')+Adj_29('Facility 14','Facility 12')+Adj_30('Facility 14','Facility 12')+
Adj_31('Facility 14','Facility 12') >= 1
    }
  }
  Constraint Gen_Adj_11 {
    Definition: {
```

Adj_1('Facility 13','Facility 12')+Adj_2('Facility 13','Facility 12')+Adj_3('Facility 13','Facility 12')+
Adj_4('Facility 13','Facility 12')+Adj_5('Facility 13','Facility 12')+Adj_6('Facility 13','Facility 12')+
Adj_7('Facility 13','Facility 12')+Adj_8('Facility 13','Facility 12')+Adj_9('Facility 13','Facility 12')+
Adj_10('Facility 13','Facility 12')+Adj_11('Facility 13','Facility 12')+Adj_12('Facility 13','Facility 12')+
Adj_13('Facility 13','Facility 12')+Adj_14('Facility 13','Facility 12')+Adj_15('Facility 13','Facility 12')+
Adj_16('Facility 13','Facility 12')+Adj_17('Facility 13','Facility 12')+Adj_18('Facility 13','Facility 12')+
Adj_19('Facility 13','Facility 12')+Adj_20('Facility 13','Facility 12')+Adj_21('Facility 13','Facility 12')+
Adj_22('Facility 13','Facility 12')+Adj_23('Facility 13','Facility 12')+Adj_24('Facility 13','Facility 12')+
Adj_25('Facility 13','Facility 12')+Adj_26('Facility 13','Facility 12')+Adj_27('Facility 13','Facility 12')+
Adj_28('Facility 13','Facility 12')+Adj_29('Facility 13','Facility 12')+Adj_30('Facility 13','Facility 12')+
Adj_31('Facility 13','Facility 12')+ Adj_1('Facility 12','Facility 13')+Adj_2('Facility 12','Facility
13')+Adj_3('Facility 12','Facility 13')+ Adj_4('Facility 12','Facility 13')+Adj_5('Facility 12','Facility
13')+Adj_6('Facility 12','Facility 13')+ Adj_7('Facility 12','Facility 13')+Adj_8('Facility 12','Facility
13')+Adj_9('Facility 12','Facility 13')+ Adj_10('Facility 12','Facility 13')+Adj_11('Facility 12','Facility
13')+Adj_12('Facility 12','Facility 13')+ Adj_13('Facility 12','Facility 13')+Adj_14('Facility 12','Facility
13')+Adj_15('Facility 12','Facility 13')+ Adj_16('Facility 12','Facility 13')+Adj_17('Facility 12','Facility
13')+Adj_18('Facility 12','Facility 13')+ Adj_19('Facility 12','Facility 13')+Adj_20('Facility 12','Facility
13')+Adj_21('Facility 12','Facility 13')+ Adj_22('Facility 12','Facility 13')+Adj_23('Facility 12','Facility
13')+Adj_24('Facility 12','Facility 13')+ Adj_25('Facility 12','Facility 13')+Adj_26('Facility 12','Facility
13')+Adj_27('Facility 12','Facility 13')+ Adj_28('Facility 12','Facility 13')+Adj_29('Facility 12','Facility
13')+Adj_30('Facility 12','Facility 13')+ Adj_31('Facility 12','Facility 13')+ Adj_1('Facility 13','Facility
14')+Adj_2('Facility 13','Facility 14')+Adj_3('Facility 13','Facility 14')+ Adj_4('Facility 13','Facility
14')+Adj_5('Facility 13','Facility 14')+Adj_6('Facility 13','Facility 14')+ Adj_7('Facility 13','Facility
14')+Adj_8('Facility 13','Facility 14')+Adj_9('Facility 13','Facility 14')+ Adj_10('Facility 13','Facility
14')+Adj_11('Facility 13','Facility 14')+Adj_12('Facility 13','Facility 14')+ Adj_13('Facility 13','Facility
14')+Adj_14('Facility 13','Facility 14')+Adj_15('Facility 13','Facility 14')+ Adj_16('Facility 13','Facility
14')+Adj_17('Facility 13','Facility 14')+Adj_18('Facility 13','Facility 14')+ Adj_19('Facility 13','Facility
14')+Adj_20('Facility 13','Facility 14')+Adj_21('Facility 13','Facility 14')+ Adj_22('Facility 13','Facility
14')+Adj_23('Facility 13','Facility 14')+Adj_24('Facility 13','Facility 14')+ Adj_25('Facility 13','Facility
14')+Adj_26('Facility 13','Facility 14')+Adj_27('Facility 13','Facility 14')+ Adj_28('Facility 13','Facility
14')+Adj_29('Facility 13','Facility 14')+Adj_30('Facility 13','Facility 14')+ Adj_31('Facility 13','Facility 14')+
Adj_1('Facility 14','Facility 13')+Adj_2('Facility 14','Facility 13')+Adj_3('Facility 14','Facility 13')+
Adj_4('Facility 14','Facility 13')+Adj_5('Facility 14','Facility 13')+Adj_6('Facility 14','Facility 13')+
Adj_7('Facility 14','Facility 13')+Adj_8('Facility 14','Facility 13')+Adj_9('Facility 14','Facility 13')+
Adj_10('Facility 14','Facility 13')+Adj_11('Facility 14','Facility 13')+Adj_12('Facility 14','Facility 13')+
Adj_13('Facility 14','Facility 13')+Adj_14('Facility 14','Facility 13')+Adj_15('Facility 14','Facility 13')+
Adj_16('Facility 14','Facility 13')+Adj_17('Facility 14','Facility 13')+Adj_18('Facility 14','Facility 13')+
Adj_19('Facility 14','Facility 13')+Adj_20('Facility 14','Facility 13')+Adj_21('Facility 14','Facility 13')+
Adj_22('Facility 14','Facility 13')+Adj_23('Facility 14','Facility 13')+Adj_24('Facility 14','Facility 13')+
Adj_25('Facility 14','Facility 13')+Adj_26('Facility 14','Facility 13')+Adj_27('Facility 14','Facility 13')+
Adj_28('Facility 14','Facility 13')+Adj_29('Facility 14','Facility 13')+Adj_30('Facility 14','Facility 13')+
Adj_31('Facility 14','Facility 13') >= 1
}
}
Constraint Gen_Adj_12 {
Definition: {
Adj_1('Facility 14','Facility 12')+Adj_2('Facility 14','Facility 12')+Adj_3('Facility 14','Facility 12')+
Adj_4('Facility 14','Facility 12')+Adj_5('Facility 14','Facility 12')+Adj_6('Facility 14','Facility 12')+
Adj_7('Facility 14','Facility 12')+Adj_8('Facility 14','Facility 12')+Adj_9('Facility 14','Facility 12')+
Adj_10('Facility 14','Facility 12')+Adj_11('Facility 14','Facility 12')+Adj_12('Facility 14','Facility 12')+
Adj_13('Facility 14','Facility 12')+Adj_14('Facility 14','Facility 12')+Adj_15('Facility 14','Facility 12')+
Adj_16('Facility 14','Facility 12')+Adj_17('Facility 14','Facility 12')+Adj_18('Facility 14','Facility 12')+
Adj_19('Facility 14','Facility 12')+Adj_20('Facility 14','Facility 12')+Adj_21('Facility 14','Facility 12')+
Adj_22('Facility 14','Facility 12')+Adj_23('Facility 14','Facility 12')+Adj_24('Facility 14','Facility 12')+
Adj_25('Facility 14','Facility 12')+Adj_26('Facility 14','Facility 12')+Adj_27('Facility 14','Facility 12')+
Adj_28('Facility 14','Facility 12')+Adj_29('Facility 14','Facility 12')+Adj_30('Facility 14','Facility 12')+
Adj_31('Facility 14','Facility 12')+ Adj_1('Facility 12','Facility 14')+Adj_2('Facility 12','Facility
14')+Adj_3('Facility 12','Facility 14')+ Adj_4('Facility 12','Facility 14')+Adj_5('Facility 12','Facility
14')+Adj_6('Facility 12','Facility 14')+ Adj_7('Facility 12','Facility 14')+Adj_8('Facility 12','Facility
14')+Adj_9('Facility 12','Facility 14')+ Adj_10('Facility 12','Facility 14')+Adj_11('Facility 12','Facility

```
14')+Adj_12('Facility 12','Facility 14')+ Adj_13('Facility 12','Facility 14')+Adj_14('Facility 12','Facility
14')+Adj_15('Facility 12','Facility 14')+ Adj_16('Facility 12','Facility 14')+Adj_17('Facility 12','Facility
14')+Adj_18('Facility 12','Facility 14')+ Adj_19('Facility 12','Facility 14')+Adj_20('Facility 12','Facility
14')+Adj_21('Facility 12','Facility 14')+ Adj_22('Facility 12','Facility 14')+Adj_23('Facility 12','Facility
14')+Adj_24('Facility 12','Facility 14')+ Adj_25('Facility 12','Facility 14')+Adj_26('Facility 12','Facility
14')+Adj_27('Facility 12','Facility 14')+ Adj_28('Facility 12','Facility 14')+Adj_29('Facility 12','Facility
14')+Adj_30('Facility 12','Facility 14')+ Adj_31('Facility 12','Facility 14')+ Adj_1('Facility 14','Facility
13')+Adj_2('Facility 14','Facility 13')+Adj_3('Facility 14','Facility 13')+ Adj_4('Facility 14','Facility
13')+Adj_5('Facility 14','Facility 13')+Adj_6('Facility 14','Facility 13')+ Adj_7('Facility 14','Facility
13')+Adj_8('Facility 14','Facility 13')+Adj_9('Facility 14','Facility 13')+ Adj_10('Facility 14','Facility
13')+Adj_11('Facility 14','Facility 13')+Adj_12('Facility 14','Facility 13')+ Adj_13('Facility 14','Facility
13')+Adj_14('Facility 14','Facility 13')+Adj_15('Facility 14','Facility 13')+ Adj_16('Facility 14','Facility
13')+Adj_17('Facility 14','Facility 13')+Adj_18('Facility 14','Facility 13')+ Adj_19('Facility 14','Facility
13')+Adj_20('Facility 14','Facility 13')+Adj_21('Facility 14','Facility 13')+ Adj_22('Facility 14','Facility
13')+Adj_23('Facility 14','Facility 13')+Adj_24('Facility 14','Facility 13')+ Adj_25('Facility 14','Facility
13')+Adj_26('Facility 14','Facility 13')+Adj_27('Facility 14','Facility 13')+ Adj_28('Facility 14','Facility
13')+Adj_29('Facility 14','Facility 13')+Adj_30('Facility 14','Facility 13')+ Adj_31('Facility 14','Facility 13')+
Adj_1('Facility 13','Facility 14')+Adj_2('Facility 13','Facility 14')+Adj_3('Facility 13','Facility 14')+
Adj_4('Facility 13','Facility 14')+Adj_5('Facility 13','Facility 14')+Adj_6('Facility 13','Facility 14')+
Adj_7('Facility 13','Facility 14')+Adj_8('Facility 13','Facility 14')+Adj_9('Facility 13','Facility 14')+
Adj_10('Facility 13','Facility 14')+Adj_11('Facility 13','Facility 14')+Adj_12('Facility 13','Facility 14')+
Adj_13('Facility 13','Facility 14')+Adj_14('Facility 13','Facility 14')+Adj_15('Facility 13','Facility 14')+
Adj_16('Facility 13','Facility 14')+Adj_17('Facility 13','Facility 14')+Adj_18('Facility 13','Facility 14')+
Adj_19('Facility 13','Facility 14')+Adj_20('Facility 13','Facility 14')+Adj_21('Facility 13','Facility 14')+
Adj_22('Facility 13','Facility 14')+Adj_23('Facility 13','Facility 14')+Adj_24('Facility 13','Facility 14')+
Adj_25('Facility 13','Facility 14')+Adj_26('Facility 13','Facility 14')+Adj_27('Facility 13','Facility 14')+
Adj_28('Facility 13','Facility 14')+Adj_29('Facility 13','Facility 14')+Adj_30('Facility 13','Facility 14')+
Adj_31('Facility 13','Facility 14') >= 1
      }
   }
   Constraint Gen_Adj_13 {
      Definition: {
         Adj_1('Facility 15','Facility 16')+Adj_2('Facility 15','Facility 16')+Adj_3('Facility 15','Facility 16')+
Adj_4('Facility 15','Facility 16')+Adj_5('Facility 15','Facility 16')+Adj_6('Facility 15','Facility 16')+
Adj_7('Facility 15','Facility 16')+Adj_8('Facility 15','Facility 16')+Adj_9('Facility 15','Facility 16')+
Adj_10('Facility 15','Facility 16')+Adj_11('Facility 15','Facility 16')+Adj_12('Facility 15','Facility 16')+
Adj_13('Facility 15','Facility 16')+Adj_14('Facility 15','Facility 16')+Adj_15('Facility 15','Facility 16')+
Adj_16('Facility 15','Facility 16')+Adj_17('Facility 15','Facility 16')+Adj_18('Facility 15','Facility 16')+
Adj_19('Facility 15','Facility 16')+Adj_20('Facility 15','Facility 16')+Adj_21('Facility 15','Facility 16')+
Adj_22('Facility 15','Facility 16')+Adj_23('Facility 15','Facility 16')+Adj_24('Facility 15','Facility 16')+
Adj_25('Facility 15','Facility 16')+Adj_26('Facility 15','Facility 16')+Adj_27('Facility 15','Facility 16')+
Adj_28('Facility 15','Facility 16')+Adj_29('Facility 15','Facility 16')+Adj_30('Facility 15','Facility 16')+
Adj_31('Facility 15','Facility 16')+ Adj_1('Facility 16','Facility 15')+Adj_2('Facility 16','Facility
15')+Adj_3('Facility 16','Facility 15')+  Adj_4('Facility 16','Facility 15')+Adj_5('Facility 16','Facility
15')+Adj_6('Facility 16','Facility 15')+ Adj_7('Facility 16','Facility 15')+Adj_8('Facility 16','Facility
15')+Adj_9('Facility 16','Facility 15')+ Adj_10('Facility 16','Facility 15')+Adj_11('Facility 16','Facility
15')+Adj_12('Facility 16','Facility 15')+ Adj_13('Facility 16','Facility 15')+Adj_14('Facility 16','Facility
15')+Adj_15('Facility 16','Facility 15')+ Adj_16('Facility 16','Facility 15')+Adj_17('Facility 16','Facility
15')+Adj_18('Facility 16','Facility 15')+ Adj_19('Facility 16','Facility 15')+Adj_20('Facility 16','Facility
15')+Adj_21('Facility 16','Facility 15')+ Adj_22('Facility 16','Facility 15')+Adj_23('Facility 16','Facility
15')+Adj_24('Facility 16','Facility 15')+ Adj_25('Facility 16','Facility 15')+Adj_26('Facility 16','Facility
15')+Adj_27('Facility 16','Facility 15')+ Adj_28('Facility 16','Facility 15')+Adj_29('Facility 16','Facility
15')+Adj_30('Facility 16','Facility 15')+ Adj_31('Facility 16','Facility 15')+ Adj_1('Facility 15','Facility
17')+Adj_2('Facility 15','Facility 17')+Adj_3('Facility 15','Facility 17')+ Adj_4('Facility 15','Facility
17')+Adj_5('Facility 15','Facility 17')+Adj_6('Facility 15','Facility 17')+ Adj_7('Facility 15','Facility
17')+Adj_8('Facility 15','Facility 17')+Adj_9('Facility 15','Facility 17')+ Adj_10('Facility 15','Facility
17')+Adj_11('Facility 15','Facility 17')+Adj_12('Facility 15','Facility 17')+ Adj_13('Facility 15','Facility
17')+Adj_14('Facility 15','Facility 17')+Adj_15('Facility 15','Facility 17')+ Adj_16('Facility 15','Facility
17')+Adj_17('Facility 15','Facility 17')+Adj_18('Facility 15','Facility 17')+ Adj_19('Facility 15','Facility
17')+Adj_20('Facility 15','Facility 17')+Adj_21('Facility 15','Facility 17')+ Adj_22('Facility 15','Facility
```

```
17')+Adj_23('Facility 15','Facility 17')+Adj_24('Facility 15','Facility 17')+ Adj_25('Facility 15','Facility
17')+Adj_26('Facility 15','Facility 17')+Adj_27('Facility 15','Facility 17')+ Adj_28('Facility 15','Facility
17')+Adj_29('Facility 15','Facility 17')+Adj_30('Facility 15','Facility 17')+ Adj_31('Facility 15','Facility 17')+
Adj_1('Facility 17','Facility 15')+Adj_2('Facility 17','Facility 15')+Adj_3('Facility 17','Facility 15')+
Adj_4('Facility 17','Facility 15')+Adj_5('Facility 17','Facility 15')+Adj_6('Facility 17','Facility 15')+
Adj_7('Facility 17','Facility 15')+Adj_8('Facility 17','Facility 15')+Adj_9('Facility 17','Facility 15')+
Adj_10('Facility 17','Facility 15')+Adj_11('Facility 17','Facility 15')+Adj_12('Facility 17','Facility 15')+
Adj_13('Facility 17','Facility 15')+Adj_14('Facility 17','Facility 15')+Adj_15('Facility 17','Facility 15')+
Adj_16('Facility 17','Facility 15')+Adj_17('Facility 17','Facility 15')+Adj_18('Facility 17','Facility 15')+
Adj_19('Facility 17','Facility 15')+Adj_20('Facility 17','Facility 15')+Adj_21('Facility 17','Facility 15')+
Adj_22('Facility 17','Facility 15')+Adj_23('Facility 17','Facility 15')+Adj_24('Facility 17','Facility 15')+
Adj_25('Facility 17','Facility 15')+Adj_26('Facility 17','Facility 15')+Adj_27('Facility 17','Facility 15')+
Adj_28('Facility 17','Facility 15')+Adj_29('Facility 17','Facility 15')+Adj_30('Facility 17','Facility 15')+
Adj_31('Facility 17','Facility 15') >= 1
    }
  }
  Constraint Gen_Adj_14 {
    Definition: {
      Adj_1('Facility 16','Facility 15')+Adj_2('Facility 16','Facility 15')+Adj_3('Facility 16','Facility 15')+
Adj_4('Facility 16','Facility 15')+Adj_5('Facility 16','Facility 15')+Adj_6('Facility 16','Facility 15')+
Adj_7('Facility 16','Facility 15')+Adj_8('Facility 16','Facility 15')+Adj_9('Facility 16','Facility 15')+
Adj_10('Facility 16','Facility 15')+Adj_11('Facility 16','Facility 15')+Adj_12('Facility 16','Facility 15')+
Adj_13('Facility 16','Facility 15')+Adj_14('Facility 16','Facility 15')+Adj_15('Facility 16','Facility 15')+
Adj_16('Facility 16','Facility 15')+Adj_17('Facility 16','Facility 15')+Adj_18('Facility 16','Facility 15')+
Adj_19('Facility 16','Facility 15')+Adj_20('Facility 16','Facility 15')+Adj_21('Facility 16','Facility 15')+
Adj_22('Facility 16','Facility 15')+Adj_23('Facility 16','Facility 15')+Adj_24('Facility 16','Facility 15')+
Adj_25('Facility 16','Facility 15')+Adj_26('Facility 16','Facility 15')+Adj_27('Facility 16','Facility 15')+
Adj_28('Facility 16','Facility 15')+Adj_29('Facility 16','Facility 15')+Adj_30('Facility 16','Facility 15')+
Adj_31('Facility 16','Facility 15')+ Adj_1('Facility 15','Facility 16')+Adj_2('Facility 15','Facility
16')+Adj_3('Facility 15','Facility 16')+ Adj_4('Facility 15','Facility 16')+Adj_5('Facility 15','Facility
16')+Adj_6('Facility 15','Facility 16')+ Adj_7('Facility 15','Facility 16')+Adj_8('Facility 15','Facility
16')+Adj_9('Facility 15','Facility 16')+ Adj_10('Facility 15','Facility 16')+Adj_11('Facility 15','Facility
16')+Adj_12('Facility 15','Facility 16')+ Adj_13('Facility 15','Facility 16')+Adj_14('Facility 15','Facility
16')+Adj_15('Facility 15','Facility 16')+ Adj_16('Facility 15','Facility 16')+Adj_17('Facility 15','Facility
16')+Adj_18('Facility 15','Facility 16')+ Adj_19('Facility 15','Facility 16')+Adj_20('Facility 15','Facility
16')+Adj_21('Facility 15','Facility 16')+ Adj_22('Facility 15','Facility 16')+Adj_23('Facility 15','Facility
16')+Adj_24('Facility 15','Facility 16')+ Adj_25('Facility 15','Facility 16')+Adj_26('Facility 15','Facility
16')+Adj_27('Facility 15','Facility 16')+ Adj_28('Facility 15','Facility 16')+Adj_29('Facility 15','Facility
16')+Adj_30('Facility 15','Facility 16')+ Adj_31('Facility 15','Facility 16')+ Adj_1('Facility 16','Facility
17')+Adj_2('Facility 16','Facility 17')+Adj_3('Facility 16','Facility 17')+ Adj_4('Facility 16','Facility
17')+Adj_5('Facility 16','Facility 17')+Adj_6('Facility 16','Facility 17')+ Adj_7('Facility 16','Facility
17')+Adj_8('Facility 16','Facility 17')+Adj_9('Facility 16','Facility 17')+ Adj_10('Facility 16','Facility
17')+Adj_11('Facility 16','Facility 17')+Adj_12('Facility 16','Facility 17')+ Adj_13('Facility 16','Facility
17')+Adj_14('Facility 16','Facility 17')+Adj_15('Facility 16','Facility 17')+ Adj_16('Facility 16','Facility
17')+Adj_17('Facility 16','Facility 17')+Adj_18('Facility 16','Facility 17')+ Adj_19('Facility 16','Facility
17')+Adj_20('Facility 16','Facility 17')+Adj_21('Facility 16','Facility 17')+ Adj_22('Facility 16','Facility
17')+Adj_23('Facility 16','Facility 17')+Adj_24('Facility 16','Facility 17')+ Adj_25('Facility 16','Facility
17')+Adj_26('Facility 16','Facility 17')+Adj_27('Facility 16','Facility 17')+ Adj_28('Facility 16','Facility
17')+Adj_29('Facility 16','Facility 17')+Adj_30('Facility 16','Facility 17')+ Adj_31('Facility 16','Facility 17')+
Adj_1('Facility 17','Facility 16')+Adj_2('Facility 17','Facility 16')+Adj_3('Facility 17','Facility 16')+
Adj_4('Facility 17','Facility 16')+Adj_5('Facility 17','Facility 16')+Adj_6('Facility 17','Facility 16')+
Adj_7('Facility 17','Facility 16')+Adj_8('Facility 17','Facility 16')+Adj_9('Facility 17','Facility 16')+
Adj_10('Facility 17','Facility 16')+Adj_11('Facility 17','Facility 16')+Adj_12('Facility 17','Facility 16')+
Adj_13('Facility 17','Facility 16')+Adj_14('Facility 17','Facility 16')+Adj_15('Facility 17','Facility 16')+
Adj_16('Facility 17','Facility 16')+Adj_17('Facility 17','Facility 16')+Adj_18('Facility 17','Facility 16')+
Adj_19('Facility 17','Facility 16')+Adj_20('Facility 17','Facility 16')+Adj_21('Facility 17','Facility 16')+
Adj_22('Facility 17','Facility 16')+Adj_23('Facility 17','Facility 16')+Adj_24('Facility 17','Facility 16')+
Adj_25('Facility 17','Facility 16')+Adj_26('Facility 17','Facility 16')+Adj_27('Facility 17','Facility 16')+
Adj_28('Facility 17','Facility 16')+Adj_29('Facility 17','Facility 16')+Adj_30('Facility 17','Facility 16')+
Adj_31('Facility 17','Facility 16') >= 1
```

```
    }
  }
  Constraint Gen_Adj_15 {
    Definition: {
      Adj_1('Facility 16','Facility 17')+Adj_2('Facility 16','Facility 17')+Adj_3('Facility 16','Facility 17')+
Adj_4('Facility 16','Facility 17')+Adj_5('Facility 16','Facility 17')+Adj_6('Facility 16','Facility 17')+
Adj_7('Facility 16','Facility 17')+Adj_8('Facility 16','Facility 17')+Adj_9('Facility 16','Facility 17')+
Adj_10('Facility 16','Facility 17')+Adj_11('Facility 16','Facility 17')+Adj_12('Facility 16','Facility 17')+
Adj_13('Facility 16','Facility 17')+Adj_14('Facility 16','Facility 17')+Adj_15('Facility 16','Facility 17')+
Adj_16('Facility 16','Facility 17')+Adj_17('Facility 16','Facility 17')+Adj_18('Facility 16','Facility 17')+
Adj_19('Facility 16','Facility 17')+Adj_20('Facility 16','Facility 17')+Adj_21('Facility 16','Facility 17')+
Adj_22('Facility 16','Facility 17')+Adj_23('Facility 16','Facility 17')+Adj_24('Facility 16','Facility 17')+
Adj_25('Facility 16','Facility 17')+Adj_26('Facility 16','Facility 17')+Adj_27('Facility 16','Facility 17')+
Adj_28('Facility 16','Facility 17')+Adj_29('Facility 16','Facility 17')+Adj_30('Facility 16','Facility 17')+
Adj_31('Facility 16','Facility 17')+ Adj_1('Facility 17','Facility 16')+Adj_2('Facility 17','Facility
16')+Adj_3('Facility 17','Facility 16')+ Adj_4('Facility 17','Facility 16')+Adj_5('Facility 17','Facility
16')+Adj_6('Facility 17','Facility 16')+ Adj_7('Facility 17','Facility 16')+Adj_8('Facility 17','Facility
16')+Adj_9('Facility 17','Facility 16')+ Adj_10('Facility 17','Facility 16')+Adj_11('Facility 17','Facility
16')+Adj_12('Facility 17','Facility 16')+ Adj_13('Facility 17','Facility 16')+Adj_14('Facility 17','Facility
16')+Adj_15('Facility 17','Facility 16')+ Adj_16('Facility 17','Facility 16')+Adj_17('Facility 17','Facility
16')+Adj_18('Facility 17','Facility 16')+ Adj_19('Facility 17','Facility 16')+Adj_20('Facility 17','Facility
16')+Adj_21('Facility 17','Facility 16')+ Adj_22('Facility 17','Facility 16')+Adj_23('Facility 17','Facility
16')+Adj_24('Facility 17','Facility 16')+ Adj_25('Facility 17','Facility 16')+Adj_26('Facility 17','Facility
16')+Adj_27('Facility 17','Facility 16')+ Adj_28('Facility 17','Facility 16')+Adj_29('Facility 17','Facility
16')+Adj_30('Facility 17','Facility 16')+ Adj_31('Facility 17','Facility 16')+ Adj_1('Facility 15','Facility
17')+Adj_2('Facility 15','Facility 17')+Adj_3('Facility 15','Facility 17')+ Adj_4('Facility 15','Facility
17')+Adj_5('Facility 15','Facility 17')+Adj_6('Facility 15','Facility 17')+ Adj_7('Facility 15','Facility
17')+Adj_8('Facility 15','Facility 17')+Adj_9('Facility 15','Facility 17')+ Adj_10('Facility 15','Facility
17')+Adj_11('Facility 15','Facility 17')+Adj_12('Facility 15','Facility 17')+ Adj_13('Facility 15','Facility
17')+Adj_14('Facility 15','Facility 17')+Adj_15('Facility 15','Facility 17')+ Adj_16('Facility 15','Facility
17')+Adj_17('Facility 15','Facility 17')+Adj_18('Facility 15','Facility 17')+ Adj_19('Facility 15','Facility
17')+Adj_20('Facility 15','Facility 17')+Adj_21('Facility 15','Facility 17')+ Adj_22('Facility 15','Facility
17')+Adj_23('Facility 15','Facility 17')+Adj_24('Facility 15','Facility 17')+ Adj_25('Facility 15','Facility
17')+Adj_26('Facility 15','Facility 17')+Adj_27('Facility 15','Facility 17')+ Adj_28('Facility 15','Facility
17')+Adj_29('Facility 15','Facility 17')+Adj_30('Facility 15','Facility 17')+ Adj_31('Facility 15','Facility 17')+
Adj_1('Facility 17','Facility 15')+Adj_2('Facility 17','Facility 15')+Adj_3('Facility 17','Facility 15')+
Adj_4('Facility 17','Facility 15')+Adj_5('Facility 17','Facility 15')+Adj_6('Facility 17','Facility 15')+
Adj_7('Facility 17','Facility 15')+Adj_8('Facility 17','Facility 15')+Adj_9('Facility 17','Facility 15')+
Adj_10('Facility 17','Facility 15')+Adj_11('Facility 17','Facility 15')+Adj_12('Facility 17','Facility 15')+
Adj_13('Facility 17','Facility 15')+Adj_14('Facility 17','Facility 15')+Adj_15('Facility 17','Facility 15')+
Adj_16('Facility 17','Facility 15')+Adj_17('Facility 17','Facility 15')+Adj_18('Facility 17','Facility 15')+
Adj_19('Facility 17','Facility 15')+Adj_20('Facility 17','Facility 15')+Adj_21('Facility 17','Facility 15')+
Adj_22('Facility 17','Facility 15')+Adj_23('Facility 17','Facility 15')+Adj_24('Facility 17','Facility 15')+
Adj_25('Facility 17','Facility 15')+Adj_26('Facility 17','Facility 15')+Adj_27('Facility 17','Facility 15')+
Adj_28('Facility 17','Facility 15')+Adj_29('Facility 17','Facility 15')+Adj_30('Facility 17','Facility 15')+
Adj_31('Facility 17','Facility 15') >= 1
    }
  }
  Variable Assignment_S1 {
    IndexDomain: (s1,p1);
    Range: binary;
  }
  Constraint As_Con_s1_p1 {
    IndexDomain: s1;
    Definition: sum(p1, Assignment_S1(s1,p1))=1;
  }
  Variable Assignment_S2 {
    IndexDomain: (s2,p2);
    Range: binary;
  }
```

```
Constraint As_Con_s2_p2 {
   IndexDomain: s2;
   Definition: sum(p2, Assignment_S2(s2,p2))=1;
}
Variable Assignment_S3 {
   IndexDomain: (s3,p3);
   Range: binary;
}
Constraint As_Con_s3_p3 {
   IndexDomain: s3;
   Definition: sum(p3, Assignment_S3(s3,p3))=1;
}
Variable Assignment_S4 {
   IndexDomain: (s4,p4);
   Range: binary;
}
Constraint As_Con_s4_p4 {
   IndexDomain: s4;
   Definition: sum(p4, Assignment_S4(s4,p4))=1;
}
Variable Assignment_PerS_3 {
   IndexDomain: (pers3,p5);
   Range: binary;
}
Constraint As_Con_pers3_p5 {
   IndexDomain: (pers3);
   Definition: sum(p5, Assignment_PerS_3(pers3,p5))=1;
}
Variable pdc_1 {
   IndexDomain: (i,j,s1,p1);
   Range: binary;
}
Constraint pdc_1_1_y {
   IndexDomain: (i,j,s1,p1);
   Definition: pdc_1(i,j,s1,p1) <= Assignment(i,j);
}
Constraint pdc_1_2_y {
   IndexDomain: (i,j,s1,p1);
   Definition: pdc_1(i,j,s1,p1) <= Assignment_S1(s1,p1);
}
Constraint pdc_1_3_y {
   IndexDomain: (i,j,s1,p1);
   Definition: pdc_1(i,j,s1,p1) >= Assignment(i,j)  + Assignment_S1(s1,p1) - 1;
}
Variable pdc_2 {
   IndexDomain: (i,j,s2,p2);
   Range: binary;
}
Constraint pdc_2_1_y {
   IndexDomain: (i,j,s2,p2);
   Definition: pdc_2(i,j,s2,p2) <= Assignment(i,j);
}
Constraint pdc_2_2_y {
   IndexDomain: (i,j,s2,p2);
   Definition: pdc_2(i,j,s2,p2) <= Assignment_S2(s2,p2);
}
Constraint pdc_2_3_y {
   IndexDomain: (i,j,s2,p2);
   Definition: pdc_2(i,j,s2,p2) >= Assignment(i,j) + Assignment_S2(s2,p2) - 1;
}
```

```
Variable pdc_3 {
    IndexDomain: (i,j,s3,p3);
    Range: binary;
}
Constraint pdc_3_1_y {
    IndexDomain: (i,j,s3,p3);
    Definition: pdc_3(i,j,s3,p3) <= Assignment(i,j);
}
Constraint pdc_3_2_y {
    IndexDomain: (i,j,s3,p3);
    Definition: pdc_3(i,j,s3,p3) <= Assignment_S3(s3,p3);
}
Constraint pdc_3_3_y {
    IndexDomain: (i,j,s3,p3);
    Definition: pdc_3(i,j,s3,p3) >= Assignment(i,j)  + Assignment_S3(s3,p3) - 1;
}
Variable pdc_4 {
    IndexDomain: (i,j,s4,p4);
    Range: binary;
}
Constraint pdc_4_1_y {
    IndexDomain: (i,j,s4,p4);
    Definition: pdc_4(i,j,s4,p4) <= Assignment(i,j);
}
Constraint pdc_4_2_y {
    IndexDomain: (i,j,s4,p4);
    Definition: pdc_4(i,j,s4,p4) <= Assignment_S4(s4,p4);
}
Constraint pdc_4_3_y {
    IndexDomain: (i,j,s4,p4);
    Definition: pdc_4(i,j,s4,p4) >= Assignment(i,j)  + Assignment_S4(s4,p4) - 1;
}
Variable pdc_5 {
    IndexDomain: (i,j,pers3,p5);
    Range: binary;
}
Constraint pdc_5_1_y {
    IndexDomain: (i,j,pers3,p5);
    Definition: pdc_5(i,j,pers3,p5) <= Assignment(i,j);
}
Constraint pdc_5_2_y {
    IndexDomain: (i,j,pers3,p5);
    Definition: pdc_5(i,j,pers3,p5) <= Assignment_PerS_3(pers3,p5);
}
Constraint pdc_5_3_y {
    IndexDomain: (i,j,pers3,p5);
    Definition: pdc_5(i,j,pers3,p5) >= Assignment(i,j)  + Assignment_PerS_3(pers3,p5) - 1;
}
Variable Fac_Weight {
    IndexDomain: i;
    Range: free;
    Definition: {
        sum[(j,k,s1,p1),pdc_1(i,j,s1,p1)*Veh_Weights_PerFac(i,k)*Frequency_Veh_S1(k,s1)*Distance_P1(j,p1)]
+       sum[(j,k,s2,p2),pdc_2(i,j,s2,p2)*Veh_Weights_PerFac(i,k)*Frequency_Veh_S2(k,s2)*Distance_P2(j,p2)]
+       sum[(j,k,s3,p3),pdc_3(i,j,s3,p3)*Veh_Weights_PerFac(i,k)*Frequency_Veh_S3(k,s3)*Distance_P3(j,p3)]
+       sum[(j,k,s4,p4),pdc_4(i,j,s4,p4)*Veh_Weights_PerFac(i,k)*Frequency_Veh_S4(k,s4)*Distance_P4(j,p4)]
+       sum[(j,r,pers1,pers2,pers3,p5), pdc_5(i,j,pers3,p5) * Per_Weight_PerFac(i,r) *
        [Freq_Per_PerS_1(r,pers1)*Distance_Locs(j,'Location13')
+ Freq_Per_PerS_2(r,pers2)*Distance_Locs(j,'Location20') + Freq_Per_PerS_3(r,pers3)*Distance_PerS3(j,p5)]]
    }
```

```
    }
    Variable Total_Fac_W {
        Range: free;
        Definition: sum[(i),Fac_Weight(i)];
    }
    MathematicalProgram Min_Problem_Weight {
        Objective: Total_Fac_W;
        Direction: minimize;
        Constraints: AllConstraints;
        Variables: AllVariables;
        Type: Automatic;
    }
    Procedure MainInitialization;
    Procedure MainExecution {
        Body: {
            ShowProgressWindow;
            solve Min_Problem_Weight
        }
    }
    Procedure MainTermination {
        Body: {
            return DataManagementExit();
        }
    }
}
```