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Optimization of facility layout

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Iowa State University, 1989

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**300 N. Zeeb Rd.
Ann Arbor, MI 48106**

Optimization of facility layout

by

Geeju Moon

**A Dissertation Submitted to the
Graduate Faculty in Partial Fulfillment of the
Requirements for the Degree of
DOCTOR OF PHILOSOPHY**

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**Iowa State University
Ames, Iowa**

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INTRODUCTION

The objective of this research is to develop a new method to solve facility layout problems with practical constraints and objectives. Considerable research work has been done to solve the facility layout problems; however, none of the developed tools' performance with real-sized problems is completely satisfactory. Computer-aided layout techniques, which appear to be the best approach for complex layout problems, are not commonly used in practice. One of the important reasons could be the generation of unrealistic layouts.

The generation of unrealistic layouts with computer routines comes from the ignoring important practical constraints and objectives involved in layout problems. These are ignored due to the difficulties in converting them into mathematical statements. However, a way to implement these important constraints and objectives in the course of a layout must be designed to obtain a more realistic layout.

Overview of Facility Layout

Facility layout has tended to be more concerned with plant location and office layout problems than with plant layout by management scientists and operations researchers (23). This research focuses specifically on facility layout in a manufacturing plant due to the large capital investment involved and the effects on the productivity of a company. The importance of facility layout can be seen by the effects of a layout on the material handling cost and

productivity of a company. Rushton and Williams (65, 66) report that total material handling cost is equivalent to about 30% of the total gross domestic product in the U.S. and agree with Tompkins and White (75) who claimed the material handling cost to be between 20% and 50% of total gross domestic product. Furthermore, Tompkins and White (75) claim that an effective facility layout can reduce these costs by at least 10% to 30% and thus increase productivity. Their claim is well supported by Nicol and Hollier's (53) survey results in Great Britain. In their survey, the labor costs of personnel employed in handling, storage, and transport duties are about 12% of total labor costs. The possible benefits of an effective layout may make their claim more reasonable. Shorter production cycle times, lower in-process inventories, fewer work stoppages, a reduced number of bottleneck operations, increased production volumes, and lower material handling times can be achieved by an efficient layout (23).

Necessities of the Research

As the trend to less mass production and more job-shop operation has continued dating from the late 1960s and early 1970s, the task of facilities layout has become more complex, and therefore more sophisticated layout techniques are required. The main approaches to facility layout can be grouped into four categories. These are: 1) template juggling, 2) mathematical models, 3) graphical techniques, and 4) computerized routines. However, it should be noted that the

performance of these methods is not completely satisfactory except in simple layout problems (71). Template juggling is not useful for the layout of real facilities of any complexity. Mathematical models give impractical solutions due to their unrealistic built-in assumptions. Graphical techniques require too much arithmetic and they are virtually useless for problems dealing with more than 15 departments. Finally, the computer routines generate unrealistic layouts such as unrealistic locations, and shapes or alignments of departments or of whole plants (71).

The lack of realism of the computer-aided layout technique comes from the lack of necessary data during the problem-solving process. These necessary data include the constraints and objectives that are ignored due to the difficulties in converting them into mathematical statements. For example, an unrealistic location of a department is generated when the constraint that a department should not be placed in a certain position is ignored. Incorporating proper objectives is a problem in almost all techniques, including the computer-aided layout technique. This is because most of the techniques have a single-minded approach that considers distance as the most important variable. Konz explains the unreasonableness of this assumption by pointing out that the distance moved is almost irrelevant to material handling cost in factories or warehouses with automatic guide-path equipment (34).

Tompkins (71) states that computer-aided layout techniques constitute the only possible approach to solving the current complex

layout problems. He explains clearly why it should be used and how it must be used to build a realistic and high-quality layout. Tompkins (71) also points out the advantages of computer routines, such as short processing time and the capability to check numerous alternatives in a short time. His recommendation for quality layouts is to repeat the process incorporating the modifications of output from a computer until a realistic and satisfactory layout is obtained. Muther's (50) statement that 'we use a computer on almost every large project, but do not expect it to create the layout,' essentially agrees with Tompkins' point of view. Therefore, it can be concluded that computers must be used to develop a quality layout for complex layout problems, with new approaches needed to handle the important constraints and objectives involved in real problems.

Practically important objectives and constraints will be collected and organized during the course of this research. Also, a method to solve layout problems using them will be developed and an experimental system will be constructed for demonstration purposes.

THE FACILITY LAYOUT PROBLEM

Facilities layout has existed ever since the beginning of recorded history. But it is only in the past few decades the industrial processes have become so complex that experience and subjective reasoning are no longer enough for the facilities layout task. In the last decade over 500 papers have been published or presented at national meetings on the subject of facility layout and locations, and various quantitative tools have been developed. These can be classified as template juggling, mathematical models, graphical techniques and computerized routines. However, none of these approaches is completely satisfactory. In this chapter, facility layout, conventional tools, and three typical approaches for layout problems are briefly reviewed.

Overview

Facility layout can be defined as the method of arranging physical facilities such as departments, machines, etc. The total facility planning design activity consists of structural design of a plant, facilities layout, and material handling system design (16). Although facility layout is one component in the total facility planning or design activity, the development of the best possible layout must be central to the facility planning activity (16, 23). The main objectives of facility planning are (16): 1) to support the organizational mission through improved material handling, material

control and good housekeeping, 2) to provide flexibility, 3) to allow for effective utilization of employees, 4) to minimize capital investment, and 5) to provide employee's safety and job satisfaction. In a sense, facility layout has the same objectives as facility planning due to its important role in facility planning.

The facility layout problems can occur in numerous ways, such as a change in the design of a product, the addition or deletion of a product, a significant increase or decrease in the demand for a product, changes in the design of the process, the replacement of one or more features in the design of the process, the replacement of one or more pieces of equipment, the adoption of a new safety standard, organizational changes within the company, or a decision to build a new plant (23). Layout problems may also develop because of gradual changes over time that finally manifest themselves in terms of bottlenecks in production, crowded conditions, excessive temporary storage space, failure to meet schedules, and a high ratio of material handling time to production time.

Objective functions

Usually two objectives, a quantitative and a qualitative one, are optimized over the facility layout problem domain. An example of quantitative objective is material handling cost, and an example of qualitative objective is some measure of closeness. These two objectives are not the only ones a plant designer should consider in designing or re-designing a plant. The lack of success with these

objectives is well explained by Konz (34). According to Konz (34), the distance moved is almost irrelevant to material handling cost in a factory or warehouse with automatic guide-path equipment. The single-minded approach of using primarily distance as the important variable is not helpful in finding a practical solution.

Criteria to be considered

Muther (49) gives potential criteria for the evaluation of layouts as shown in Table 1. These criteria should be considered in any objective function, because these will be used in the evaluation of any layout. Some of them could be achieved through the selection of facilities, and others through the process of area allocation or department layout.

Several authors claim that health (16), energy (16), flexibility (77) and dynamics of layout (53) should be considered for a high-quality layout. Employee health and safety is an area that has recently been a major source of motivation behind many facilities planning studies. In 1970 the Occupational Safety and Health Act (OSHA) was voted into law and brought with it a far-reaching mandate: "to assure as far as possible every working man and woman in the nation safe and healthful working conditions and to preserve our human resources." Under the provisions of the law an employer is required to provide a place of employment free from recognized hazards (16). The equipment or processes which may create hazards to a worker's health and safety must be placed where employee contact is minimal. Energy is

TABLE 1. Potential criteria for evaluation of a layout (Muther (49))

-
1. Ease of future expansion or contraction
 2. Adaptability and versatility
 3. Layout flexibility
 4. Flow or movement effectiveness
 5. Materials-handling effectiveness
 6. Storage effectiveness
 7. Space utilization
 8. Supporting service integration
 9. Safety and housekeeping
 10. Working conditions and employee satisfaction
 11. Ease of supervision and control
 12. Appearance, promotional value, public or community relations
 13. Quality of product
 14. Maintenance
 15. Fit with organization structure
 16. Equipment utilization
 17. Security and theft
 18. Utilization of natural conditions
 19. Ability to meet capacity
 20. Compatibility with long-range plans
-

another important and expensive input which should be considered in the initial design phase (16). For example, some of the energy-intensive industries have modified their layouts to use the energy discharged from the manufacturing processes to heat their office areas.

It is generally agreed that flexibility of job-shop layouts is a desirable goal which must be planned in a systematic fashion; yet few people agree on what the word flexibility includes. Flexibility in the facilities design literature is often defined as the capability of a

layout to react to disturbances caused by future changes. The four areas that can affect a shop layout, mentioned by Craig et al. (15) are: 1) changes in product mix, 2) changes in product volume, 3) changes in the process, and 4) changes in raw materials used in producing these products. Moore (47) indicates that layout design should consider three areas for flexibility: 1) building and services, 2) selection of equipment, and 3) plans for plant expansion to improve flexibility. However, if there is no means to evaluate the costs or the cost versus benefit ratio of the added flexibility, difficulty in the attempt to implement some or all of the suggestions mentioned above would be encountered (77).

Generally, the problem of facilities layout has been treated as a static one. But there is a need to treat the layout problem as a dynamic one, according to Nicol and Hollier (53). They point out that "Radical layout changes occur frequently and that management should therefore take this into account in their forward planning." Furthermore, if the effective life time of a layout is defined as the elapsed time from installation until at least one-third of all key manufacturing operations are replaced, it has been found that nearly half of the companies surveyed had an average layout stability of two years or less (53). The mean of all the firms was just over three years and was shorter for the engineering companies (53). If an organization continually updates its production operations to be as productive as possible to compete with other organizations, then the

organization must continuously change the layout and re-arrange the activities in progress. Only rarely can a new process or piece of equipment can be introduced into a system without disrupting the ongoing activities (16). A single change in a layout may impact significantly on the integrated technological and management systems. These problems can be solved with the understanding of the dynamic nature of facility layout problems.

Computer-Aided Facility Layout

Computer routines can be classified into two groups. One is the construction type and the other is the improvement type. A good evaluation of computer routines is given by Konz (34), Tompkins (73), and Tompkins and Moore (74). A brief review of the five commonly used programs is given below.

Five common computer routines

CRAFT Computerized Relative Allocation of Facilities

Techniques (CRAFT) is an improvement type program and the goal is to minimize the transportation cost. The transportation cost in CRAFT is calculated by $(\text{from-to matrix}) \cdot (\text{move cost matrix}) \cdot (\text{distance matrix})$. This routine assumes that there are no negative relationships, that all flows start and stop at department centroids, and that all movements are by rectangular distance. An initial layout, a from-to matrix, and a move cost matrix should be given by the user. Dummy departments can be used to represent fixed facilities, to represent aisles, and to fill

building irregularities. For the best results, the program should be run multiple times using various initial layouts and various from-to values.

COFAD Computerized Facility Design (COFAD) is an improvement type routine and is an improved version of CRAFT. This routine makes more realistic calculation of material handling costs possible. The goal in COFAD is to minimize material handling cost. Just like CRAFT, better results are obtained by multiple runs using varying initial layouts, from-to values, and move costs.

CORELAP Computerized Relationship Layout Planning (CORELAP) is a construction type routine and is a computerized version of Muther's Systematic Layout Planning. This program tries to find a layout which places "high-ranking" departments closer together. Therefore, the objective here can be thought of as the minimization of material handling cost as well as the optimization of the multiple criteria of the relationship chart.

ALDEP Automated Layout Design Program (ALDEP) is a construction type routine and requires input data similar to that of CORELAP. It produces many layouts while CORELAP produces the one best layout. ALDEP also rates each layout. Therefore, it can help evaluation of different layouts. In addition, it has a special capability to produce layouts up to three floors.

PLANET Plant Layout Analysis Evaluation Technique (PLANET) is a construction type routine and requires the usual input of departments

and areas but it allows the closeness to be determined by a from-to matrix with move cost. Also this program attempts to minimize the material handling cost. All the moves are assumed to be rectangular from the department centroid and the move cost to be linear with move length and independent of equipment utilization.

Konz (34) points out that the problem with these computer-aided layout routines is in the single-minded approach of using the material handling cost as the single most important variable. The computer-aided layout routines generally tend to ignore service and support areas since these areas have less "material handling" costs involved. The proceeding problem is common in operations research (OR) or in any mathematical model building approaches which rely on many assumptions to build a model. One of the problems with a computerized approach is that not all the components of a layout problem are reducible to a mathematical statement. The general tendency is to disregard all the criteria which are not amenable to mathematical analysis. Computer routines often generate layouts placing shipping and receiving departments in the middle of the facility, shaping departments 300 ft long and 10 ft wide, or giving irregular configurations that aisle placements become impossible (74).

Review of Three Typical Approaches

The DESIGN PROBLEM SOLVER (DPS) (58), FACILITIES DESIGN EXPERT SYSTEM (FADES) (20), and a modified version of CRAFT (40) are reviewed

in this section. DPS is a heuristic search program which can be used for placing furniture or equipment in a room. FADES is a prototype expert system which can be used as a pre-process for conventional layout tools. The modified version of CRAFT is an attempt to solve layout problem as a multi-objective function problem.

DPS

DPS is a heuristic search problem solver developed in the field of computer science. The objective of the research is to develop a computer program which can design furniture or equipment placement in a room while satisfying a set of constraints. Special attention is given to building a constraint-satisfying problem solver that can manipulate a two-dimensional spatial representation of the design.

The DPS represents the objects and the layout as sets of convex polygons. The polygons are in turn made up of sides and the sides of points. Each of the points, sides, polygons and objects has a description list which describes the element and the relation of the element to other elements. The problem solver uses this spatial representation to generate and evaluate alternatives.

The difference between this type of approach and the departments allocation approach is in the existence of objective function and consideration of the shape of objects. DPS finds a layout which satisfies constraints while department allocation approach finds a layout which maximizes or minimizes an objective function. Handling fixed shape of objects in DPS makes a big difference from the approach

for department allocation problems. Specific constraints used by DPS include distance, position, orientation, adjacency, spatial, view, and path (58). Refer to Pfefferkorn (58) for further details.

FADES

FADES (20) is a typical expert system application developed in the field of industrial engineering. The goal is to develop a facility planning and design system to make quantitative methods more accessible to facilities designers, and to make them easier to use by combining them with the logic of an expert human designer.

The knowledge in this system is represented in the form of rules implemented in logic procedures and first order predicates. FADES can perform economic investment analysis, development of relationship ratings, selection and invocation of assignment and layout algorithms and retrieval of information from an existing company data base.

This software addresses three main areas of facilities design. These are design problem definition and objectives, facilities selection and specification, and facilities layout. For facilities layout, FADES works such as a pre-processor for CORELAP, CRAFT, or assignment algorithms.

A CRAFT revision

The work by Malakooti and D'Souza (40) to solve facility layout problems by multiple objective programming is reviewed as one of the possible CRAFT revisions. The approach is basically a modification of

CRAFT designed to incorporate multiple criteria such as material handling cost, production rate, and flexibility. This requires the input of new weights to calculate the objective function Z which is set equal to $\sum w_i f_i(s)$.

OBJECTIVES AND CONSTRAINTS

The question of the objectives to be achieved from proper facility layout has only been stated in general terms and is still not well defined (18). Defining the constraints in a layout problem is not an easy question, either. However, the most common objectives and constraints which have been suggested by several authors could be collected and organized to use on the design of a new method.

In this research, the objectives and constraints are collected not only from the lists under the names 'objectives' and 'constraints.' More often, they are taken from under the title 'checklist for layout' or 'criteria for the evaluation of layout.' It seems reasonable to treat the evaluation criteria as the objectives on the development of a layout. Another step is the selection of criteria which are applicable within the boundaries of area allocation or department block layout, as some of the criteria cannot be met by area allocation alone.

Considerations in Facility Layout Work

Computer-aided layout tools tend to be oversimplifications of the realistic criteria. Even though they are designed only to yield a block diagram that specifies the relative position of departments, realistic criteria must be considered to obtain a usable output. Every author seems to conceive a different set of objectives. Moreover, these objectives are not quantifiable and not specific. They include the effective utilization of resources, smooth work flow, overall simplification, high work-in-progress turnover, effective supervision,

co-ordination and control, and the maximization of return on investment (18).

Apple

Apple (1) considers area allocation as the last preliminary planning step prior to the detailed planning of material handling methods, individual work stations, and the final plant layout. Factors that must be considered in area allocation stage are given in Table 2.

TABLE 2. Factors to consider in area allocation

-
1. Material flow relationship and pattern
 2. Expansion plan
 3. Flexibility to meet changing needs
 4. Building characteristics
 - type, construction, size, shape, restriction
 5. Special requirements of certain departments
 - environmental requirements, undesirable characteristics, etc.
 6. Personal preferences
 7. Activity interrelationships
-

Expansion is one of the most perplexing problems facing both management and the facilities designer. In a well-run, progressive, successful enterprise, expansion should be inevitable. Among various considerations in planning for expansion, legal restrictions, orientation of buildings, and the direction of expansion feasibility can be implemented in area allocation. Apple also gives good

suggestions for expansion planning and flexibility. Some relevant suggestions in area allocation are given in Table 3.

TABLE 3. Suggestions for expansion (Apple (1))

-
1. Locate activities most likely to expand in best position for expansion
 2. Locate service departments for convenient use in expanded layout
 3. Locate permanent equipment in fixed locations - ie., not to be moved later- because of special foundations, utilities, installation problems, etc. (such as washrooms, offices, heavy machines, and ovens).
 4. Plan utility location, arrangement, and capacity for ease of extension (water, electricity, plumbing, air, heating, ventilation, air conditioning, sewer, drain, etc.).
 5. Locate such activities as receiving, shipping, and utilities for minimum re-arrangement or re-location in expansion.
 6. Locate receiving and shipping for convenience after planned expansion.
-

In designing the facility, there are a number of actions that can be taken to insure the varying degrees of flexibility required by future demands. Most of the actions are more closely related to the installation of utility systems than the area allocation (1). For example, the suggestions such as 'provide for uniform lighting over entire the plant area, locate light fixtures between rather than below bar joints or beams, avoid the use of specialized equipment, provide wide doorways, etc.' can not be done by area allocation.

Muther

As discussed before, Muther (49) provided twenty potential criteria for the evaluation of layouts as given in Table 1. These criteria could be considered as objectives because these will be used in the evaluation of a layout. Some of them can be achieved through the selection of facilities rather than area allocation. Others could be achieved during the process of area allocation. The criteria to be considered in area allocation are:

1. Ease of future expansion or contraction
2. Layout flexibility
3. Flow or movement effectiveness
4. Space utilization
5. Supporting service integration
6. Safety and housekeeping
7. Ease of supervision and control

Francis and White

Francis and White (23) say that the material handling cost is one of the criteria commonly used to evaluate alternative layouts. They also mention that for many situations material handling cost may not be an appropriate criterion. Their opinion about the objectives of the plant layout study are listed as follows:

1. minimize investment in equipment
2. minimize overall production time
3. utilize existing space most effectively
4. provide for employee convenience, safety, and comfort

5. maintain flexibility of arrangement and operation
6. minimize material handling cost
7. minimize variation in types of material handling equipment
8. facilitate the manufacturing process
9. facilitate the organizational structure

Clearly, the consideration about equipment can not be implemented in area allocation.

They also mention the existence of a number of constraints in facility layout. These include allowable noise levels, ventilation, temperature, lighting, building geometry, and so on. The present location of walls and columns, equipment, footings to support heavy equipment, loading docks, windows, lights, ventilating equipment, storage and office areas, water and sewage, and power lines are the detailed examples. Therefore, consideration should be given to the costs of relocating facilities along with the advantages derived from the relocation.

Craig et al.

Good suggestions for minimizing the difficulty of future changes are given by Craig, Moore, and Turner (15). They claim that flexibility can be built into a facility in four ways: (1) building design, (2) plant service, (3) equipment selection, and (4) planned expansion and contraction. Only (1) and (4) would be possible to be implemented in area allocation.

The suggestion in building design is to place fixed obstructions in areas that will not change, to permit the other areas maximum flexibility. Storage is the easiest area to expand or contract. Therefore, the storage area should be located close to the equipment area. Then if equipment space needs to expand, storage space can contract. They also suggest to note where expansion or contraction will take place in the next layout.

Hales

Hales (27) reviews what the layout planner is trying to accomplish and says that layout planning can be described as the attainment or satisfaction of multiple objectives, subject to a variety of constraints. The objectives which may be conflicting typically include (27):

1. Effective movement of materials and personnel
2. Effective utilization of space
3. Adaptability to unforeseen changes
4. Easy expansion
5. Safety
6. Control of noise
7. Easy supervision and control
8. Good appearance
9. Security
10. Low cost

The planning constraints include (27):

1. One or more fixed activities
2. Activities which must be separated
3. Architectural limitations
4. Material handling limitations
5. Utility limitations
6. Organizational restrictions
7. Budget
8. Code restrictions
9. Time

Others

Health, energy, and flexibility concerns must be considered for the development of a high-quality layout. Employee health and safety is an area that has recently been a major source of motivation behind many facilities planning studies. In 1970 the Occupational Safety and Health Act (OSHA) was voted into law, and under the provisions of that law an employer is required to provide a place of employment free from recognized hazards (16). The equipment or processes which may create hazards to a worker's health and safety must be placed where employee contact is minimal. Also, energy is an important and expensive raw material, which should be considered in the initial design phase (16).

It is generally agreed that flexibility in job-shop layouts is a desirable goal which must be planned for in a systematic fashion, yet few people agree on what that flexibility includes. Flexibility in

facilities design literature is often defined as the capability of a layout to react to the disturbances caused by future changes.

Organization

There are various objectives and constraints to be considered during the development of a layout as discussed so far. In this section those important objectives and constraints will be summarized, classified, and reorganized. Also, some of the elements related to the objectives and constraints will be discussed in this section.

Summary

The objectives and constraints involved in layout are numerous, however, a simple list of objectives and constraints can be constructed within the boundary of area allocation. Flexibility depends upon the definition of the term. It could be achieved by the selection of ease to move equipment, by universal equipment, or by the consideration of various production schedules. However, finding a formal definition of flexibility, developing a methodology for increasing flexibility, or evaluating flexibility is beyond the scope of this research. The flexibility will be considered only as a future expansion plan.

The design of a new method for accurate calculation of material handling costs or accurate moving distance measurement is also beyond the scope of this research; CRAFT-like material handling cost calculation will be used. The concerns of material flow will not be studied separately from material handling cost. The minimization of

material handling cost will be assumed to mean good material flow. Supervision and control will be considered in activity relationships and preferences.

TABLE 4. Summary of objectives and constraints

-
1. Health and safety
 2. Material handling cost/distance
 3. Expansion
 4. Utility limitations
 5. Energy
 6. Activity relationship
 7. Architectural limitations
-

Based on the items given in the Table 4, suggestions or recommendations from the authors are summarized as below. Certainly, there are more considerations than these. But, the following suggestions and common sense to maintain the feasibility of outputs will be implemented in this research.

1. Health and safety
 - free from recognized hazard
 - flames and explosive material must be apart
 - uncovered furnaces, chemical vat - minimum contact area
 - noise, bad smells, etc. - away from people
2. Material handling cost
 - minimize total cost - (distance)·(cost)·(quantity)

3. Expansion

- storage - close to equipment area
- locate heavy, permanent equipment so it does not block expansion
- locate activities most likely to expand in the best position for expansion
- locate service departments for convenient use in an expanded layout
- locate permanent equipment in fixed locations - ie., not to be moved later- because of special foundations, utilities, installation problems, etc.
- plan utility location, arrangement, and capacity for ease of extension
- locate such activities as receiving, shipping, parking, walks, roads, and utilities for minimum re-arrangement or re-location after expansion.

4. Utility limitations

- plan for adequate water, electricity, plumbing, compressed air, heating, ventilation, air conditioning, drain, etc.
- locate walls and columns, equipment, and footings necessary to support heavy equipment, loading docks, windows, lights, ventilating equipment, storage and office areas, water and sewage, and power lines
- fixed activities

5. Energy

- place heat required area together
- plan for the efficient use of the heat generated

6. Activity relationships

- determine which activities must be separated
- determine which activities must be placed together

7. Architectural limitations

- locate office where they can have window
- locate container docks close to road
- decide on building geometry
- determine floor loading limit

Classification

Three different types of research in the layout problem domain have been discussed before. The Design Problem Solver (58) which is done in the computer science area is an example of solving layout problems using physical constraints. However, no objective functions are introduced. The other two are the application of Artificial Intelligence (AI) to facility design, and a modification of CRAFT from industrial engineering. The FADES (20) and the CRAFT revision (40) are the examples. In a sense the last two are the same research since FADES makes use of CRAFT or COFAD. From the development of layout point of view, the CRAFT revision is more interesting. FADES uses current CRAFT or COFAD, while the CRAFT revision tries to improve the logic of CRAFT by changing the objective function.

A good layout can not be obtained by using an objective function only or constraints only. Both of them must be considered to develop a good layout. From the collection of objectives, constraints, and suggestions, it can easily be seen that there exists a certain boundary to classify them into two categories. One is the 'hard constraint type' and the other is the 'soft constraint type.' The 'hard constraint type' includes the kind of physical constraints like the ones used in DPS, and can be used as real constraints in problem solving. The other type is a flexible one such as used in the CRAFT revision. This type is more close to an objective function.

1. Hard constraint type

- Architectural limitations
- Preference - hard

2. Soft constraint type

- Health and safety
- Utility limitations
- Expansion
- Preference - soft
- Material handling cost

Elements to be considered

There are a number of elements to be considered in the course of area allocation. In this section, elements in the classification list will be discussed, and then reorganized based on the department and floor.

Expansion

1. fixed obstruction
2. storage
3. heavy equipment
4. receiving, shipping

Health and safety

1. noise
2. ventilation
3. recognized hazard - uncovered furnace, chemical vat
4. flame
5. explosive material
6. bad smell

Preference - hard

1. special requirements on certain departments - environmental requirements
2. requirements by user

Utility limitations

1. water/sewer
2. compressed-air
3. heating
4. ventilation
5. power lines

Architectural limitations

1. building characteristics - type, construction, size, shape, restrictions
2. loading limits
3. loading docks
4. windows
5. exit/doors
6. fixed activities

Material handling cost

1. distance between two departments
2. handling cost per unit
3. number of unit to move

Preference - soft

1. user preferred to be close together if possible
2. user preferred to be apart each other if possible

The elements to be used in the layout process are summarized in Table 5 and Table 6. In addition to these, other elements to be recognized include production quantity between two departments, neighboring departments to a specific department, information on user preference, and current violation status of each department. A detailed discussion about these elements will be given in the next chapter.

TABLE 5. Elements related to department

Name	Possible values
name	name of department
noise	produce, control, no need for concern
explosion	flame, explosive, no need for concern
vibration	produce, control, no need for concern
minimum side	minimum required length or width
movable	hard, no need for concern
weight	heavy, no need for concern
exit/door	required, no need for concern
compressed-air	required, no need for concern
power-line	required, no need for concern
water-sewer	required, no need for concern
heat	produce, control, required, no need for concern

TABLE 6. Elements related to floor blocks

Name	Possible values
name	index of floor block
load	light, no need for concern
exit	available, not
compressed-air	available, not
power-line	available, not
water-sewer	available, not
expansion-side	yes, no

SYSTEM STRUCTURE

In this chapter the suggested problem solving method and the factors considered for layout development will be discussed in detail. An expert system approach will be reviewed as one of the best ways to construct the system, and then the problem solving method will be explained stage by stage.

Overview

Facility layout is a very complex subject which requires most of the knowledge that an industrial engineer deals with. However, this research focuses on the development of a better method to solve layout problems rather than the organization of the knowledge to be used for it. Knowledge to be used for layout development would be better if the subjective judgements or rules of thumb taken from field experts could be added, but this research is confined to literature only.

The best strategy for solving a large combinatorially explosive problem would be the interchange heuristics. The well known layout computer routine CRAFT serves as an effective example. This approach is designed to continue the repetitive interchange process until no more improvement is possible. The main problem with this approach is the assumption that the material handling cost is the only factor to be considered. Naturally, the output is made only for a minimum material handling cost and it can not be a practical solution.

Factors which a human planner considers during the layout process are not be easy to list. They could be different place by place, or planner to planner. The suggested method here may not include all the factors that human planners would consider. However, it includes the most common and critical factors which are helpful to develop a realistic layout.

CRAFT interchanges department positions continuously to find the layout with minimum material handling cost. If no more improvement is made, then it stops. A problem with CRAFT is that it does not consider the shape or location of a specific department. For instance, suppose a 100 unit department needs to have a 5x5 machine in it. The configuration of 10x10 will be able to have the machine in it, but not 4x25. How can this problem be solved? If a human planner tries to interchange department positions to find the best layout, how would the planner approaches it? Clearly, the ways to interchange department would not be identical from planner to planner, but no planner is going to make a department shape or department position which is unrealistic. If there are two departments which can not be placed close to each other due to safety or other reasons, no planner is going to place them close together. A planner would remove any unrealistic or problem causing department and replace it with another department which is more compatible in a particular situation. This is exactly the basic design of the system which will be discussed here.

The factors considered in this system are classified into two different groups. The first one is the 'hard constraint group' and the second one is the 'soft constraint group.' Any constraints or requirements which must be met or are wanted to be met by user are classified into the 'hard constraint group.' The hard constraints are used to reject a suggested layout, if it violates any one of the constraints in the group. Other constraints which can be met 'if possible ...' belong in the 'soft constraint group.' These are the constraints which can be violated as long as the violation can reduce the total objective function value. The summary table of the constraints considered in this system is provided in Table 7.

This system begins the layout process by checking the initial layout with the hard constraints as listed in Table 7. If any violation to these constraints is found, then the initial layout is rejected. If there is no violation, then the control stage moves to the department removal stage.

The department removal stage is performed using the soft constraints. This is an attempt to reach a solution by directly moving the department which makes objective function value worse, instead of moving departments in numeric sequence. Certainly, this process is not sufficient to find the global optimum solution. However, this could force the process of layout to reach an optimum or optimum tending solution more quickly.

TABLE 7. Hard and soft constraints

Hard Constraint Group	Soft Constraint Group
<ul style="list-style-type: none"> . Floor loading limit . User preference (hard) <ul style="list-style-type: none"> . close . separate . Fixed location department . Department shape 	<ul style="list-style-type: none"> . Explosion hazard . Dangerous equipment . Vibration . Noise . Ventilation . Door . Water-sewer . Expansion . Compressed air . Power facility . Heat control . User preference (soft) <ul style="list-style-type: none"> . close . separate . Energy saving . Material handling cost

Removal of a department due to the violation of a hard constraint means that it is necessary to select a department for its replacement. The best replacement would be one in which neither of the interchanged departments will violate constraints in their new positions. This capability is not implemented in this system. Currently, the replacement is selected among same sized or neighboring departments only, as in the CRAFT. This restriction is necessary to avoid a shape adjustment which could cause an unrealistic layout. Suppose that a human planner was trying to manually switch a department with one which was neither same size nor neighboring. The human planner may have to

move or change the shape of all the departments placed between the two departments. A human planner can perform this task by trial and error, but it is not an easy task to implement with a computer.

In this system, the suggested department switch will be checked with the constraints in hard group first to know if a violation exists. If the suggested layout violates any one of the hard constraints, it is rejected. If not, an objective function value is calculated and compared with the old one. The constraints in the soft group are not used to check the suggested layout, but to switch department positions and to calculate an objective function value. The objective function value calculation with soft constraints is done by multiplying the frequency of violations by the penalties given by the user. Different penalties can be entered by the user to find a better layout.

Knowledge-based Expert System

Artificial intelligence (AI) is the field of computer science that is concerned with designing a computer system that exhibits characteristics associated with human intelligence. AI techniques and applications involve the manipulation of human knowledge as well as the manipulation of the experiments. In AI, knowledge must be represented and structured in some logical manner. Also this structured knowledge should be easy to retrieve and modify. Symbolic processing techniques are the core of AI. Four techniques, namely inference, pattern matching, search, and knowledge representation, are the major

differences between AI and traditional software development techniques (59). The various applications of AI include symbolic processing, expert system (ES), natural language processing, speech recognition, computer vision, etc. (59). A comparison of AI with Operations Research (OR) is given in Table 8.

TABLE 8. Comparison of AI with OR (Grant (25), Phelps (59))

1. Differences		
	OR	AI
Emphasis	Algorithms	Heuristics
Implement- ation	Over simplification of real life	Match the variety of the environmental information
Main concern	Scientific model (difficult to model)	Workable, understandable system
Heuristic search	Guarantee to find an optimum, if exists	May relax the guarantee, often satisfying

2. Similarities

- a. Build models.
- b. Use heuristic procedures in the absence of optimal ones.
- c. Use mathematics.
- d. Use computer implementations.

Of the various AI applications, the expert system technology has received the most publicity and it has achieved considerable success in recent years. Though most of the systems developed initially belongs in the area of the medical diagnosis, interest has expanded into other areas such as mineral exploration, computer configuration, management decision making, planning and control, etc. Whenever human experts are in great demand and also in short supply, a computer based assistant can amplify and disseminate the needed expertise. Hayes-Roth et al. (29) defined ES as to be a computer system which can achieve high levels of performance in task areas where it will require years of special education and training for human beings. First of all, the word 'expert' may need to be defined to make the term expert system clear. Experts are the people who are very good in solving specific types of problems. Their skills usually come from extensive experience, and detailed specialized knowledge of the problems they handle. Like a human expert, an expert system can handle real-world, complex problems which generally require an expert's interpretation, it can solve these problems using a computer model with expert human reasoning, and it will reach the same conclusions that a human expert will reach for these problems (60). The basic structure of an expert system is provided in Figure 1.

Structure of basic expert systems

The reasons for building an expert system are in the dissemination of rare and costly expertise, and in the more effective and efficient use of the human expert. From a scientific point of view, the most

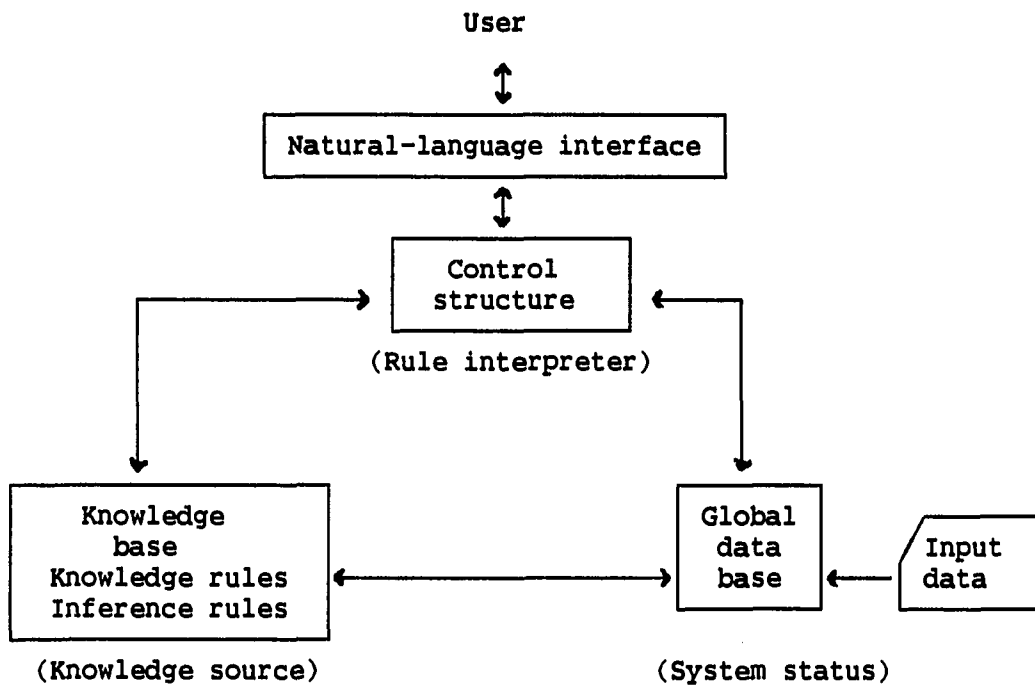


FIGURE 1. The structure of a basic expert system (Grant (25))

important reason is in the formalization and classification of knowledge which results from having the human expert making his reasoning explicit. Another reason for building expert systems is the possibility of combining the expertise from many human experts into a shared knowledge base that can be studied for the consistency and reliability of its advice.

ESs have succeeded in such problem domains as medical diagnosis and therapy, computer configuration, and mineral exploration. Some successful ESs and their characteristics are given in Hayes-Roth et al. (29). For examining the facility layout problem, two classes of AI/ES tasks are common. They are diagnosis/recommendation and planning/design. Some of the existing ESs which perform these tasks are now briefly reviewed.

MOLGEN (69), which was developed by Stanford researchers in the area of computer science and genetics, gives intelligent advice to a molecular geneticist on planning experiments which involves manipulation of DNA. MOLGEN uses generate-and-test techniques to assure that all the possible molecular structures are considered and it also integrates various kinds of diverse knowledge.

DENDRAL (10) is another generate-and-test system which uses a rule-based, generate-and-test approach to infer chemical structures of organic molecules. The DENDRAL system deals with a complex configuration task, applies generate-and-test methods, makes inferences concerning substructures and employs an automatic knowledge acquisition system to acquire new rules. This system usually performs faster and more accurately than human experts in its domain.

ISIS (21, 22) is a constraint-directed reasoning system developed at Carnegie-Mellon University for job-shop scheduling. This system uses a variety of constraint categories including physical requirements, gating, organizational goals, preferences, etc., to develop production schedules.

FADES (20) is a facility planning and design system. The knowledge in this system is represented in the form of rules implemented in logic procedures and first order predicates. FADES can perform the analysis of economic investment, the development of relationship ratings, the selection and invocation of assignment algorithms and algorithms for layout planning, and the retrieval of information from an existing company data base. It is also designed to work as a pre-processor for CORELAP, CRAFT or assignment algorithms.

Other systems of interest in the planning domain are GARI, developed by Descotte and Latombe (17) and TOM, developed by Matsushima et al. (41). GARI was developed in France in the late 1970s and it generates plans for sequencing the machining cuts of mechanical parts. TOM (Technostructure of Machining) was developed at the University of Tokyo and IPK/IWF Berlin in the early 1980s and employs production rules and goal-directed control to develop the machining process plan. TOM's search process starts from the finished part geometry and using a back track search, attempts to find the best possible machining process plan.

Tools

Expert system tools are the programming systems that simplify the job of constructing expert systems. They range from very high-level programming languages to low-level support facilities. The language-tool continuum with some examples is given in Figure 2. A programming language is a computer language developed to control and direct the

operation of a computer. Tool kits are expressly designed for constructing and debugging expert systems. They provide special facilities for constructing and debugging expert systems but are often less flexible than ordinary programming languages (76). There are several tools applicable to manufacturing planning and control problems. A good summary of the tools are provided in Waterman (76).

LISP LISP is a list processing language developed at MIT in the late 1950s with a basis in the lambda calculus. This is the most popular and widely used programming language for expert system applications. LISP is normally an interpreted language but compilers do exist.

PROLOG PROLOG is a computer language that is used for solving problems that involve objects and the relationships between objects (13). This language uses the clausal form of first order predicate logic to represent knowledge and seems to be steadily gaining in popularity.

INTERLISP INTERLISP is for procedure-oriented representation. This language has all the standard LISP features plus an elaborate support environment that includes sophisticated debugging facilities.

MLISP A high level list processing language developed at Stanford University. MLISP programs are translated into LISP for execution and the translator itself written in LISP.

OPS5 The OPS5 consists of two key components: a data base called working memory and the productions that manipulate the data

base. The language's run time system uses a recognize-act cycle to process the contents of working memory and the productions (7).

KEE KEE is for frame-based representation. It also supports rule-based, procedure-oriented, and object-oriented representation methods. KEE is written in INTERLISP.

EMYCIN EMYCIN was developed at Stanford University as a research system and is essentially MYCIN stripped of its domain knowledge. The principal characteristics include a restrictive backward chaining control scheme suitable for diagnosis and consultation-type problems, certainty handling mechanisms, and automatic user querying facilities. The system is implemented in INTERLISP.

LOOPS LOOPS is for object-oriented representation. It also supports rule-based, access-oriented, and procedure-oriented representation methods. LOOPS is implemented in INTERLISP-D.

M.1 M.1 is for rule-based representation. Its principal characteristics include a backward chaining control scheme and an English-like language syntax. M.1 is implemented in PROLOG and runs on the IBM PC or compatible.

S.1 S.1 is for rule-based representation, but it also supports frame-based and procedure-oriented representation methods. Its principal characteristics include a backward chaining control scheme and built-in certainty handling mechanisms. S.1 is written in INTERLISP.

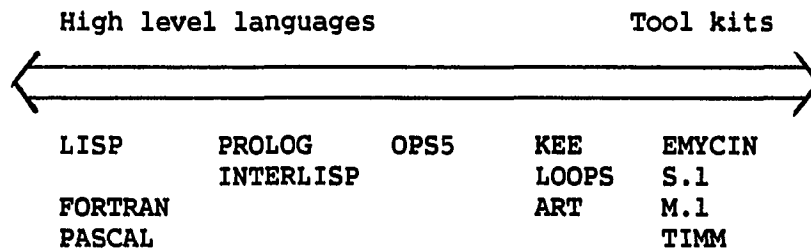


FIGURE 2. The language-tool continuum (Harmon and King (28))

Advantages and disadvantages

An expert system approach can be evaluated against conventional programming or a human planner. The advantages over conventional programming are the ease with which human knowledge can be encoded, the ease of modification, and the capability of explaining decisions. Ease of modification is essential in ES development because ESs are never finished. The knowledge-base of an expert system will be grow with time. No substantial overhaul will be necessary unlike conventional programs, when a modification to the design process is necessary. Modification of a few rules will be all that is necessary.

All the power and flexibility of expert systems has a cost. More programming code means more computer processing time. Programs take longer to run and require larger computer memories to hold them at one time (31). Also, development cost is high as shown in Figure 3.

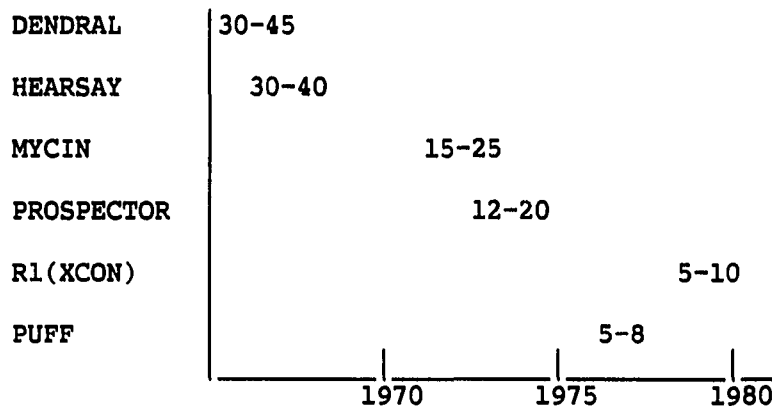


FIGURE 3. Development time and man-years of effort (Horn (31))

OPS5

The name OPS5 stands for the Official Production System version 5. OPS5 is a production system programming language. It was originally developed at Carnegie-Mellon University as a tool for psychological research aimed at understanding human memory and cognition (28).

It is not clear whether OPS5 is a tool kit or an AI language. By one analysis, it is a very general programming environment (28). In the hands of a skilled knowledge engineer, it could easily be considered a hybrid system building tool. On the other hand, it has generally been used as a production rule, forward chaining system; and, thus, it can be classified as a narrowly focused tool that can aid a developer in building rule-based, forward chaining systems. OPS5, as in any pattern directed inference system, has three components: a working memory, a production memory, and an inference engine.

Working memory The working memory in OPS5 holds data which represents the state of the problem. The working memory elements are in the form of attribute value pairs which can be created, deleted, examined or modified by the productions (rules) stored in production memory. Figure 4 shows an example of a working memory definition for a department.

```
(literalize department
  name      ; name of department
  noise     ; produce, control, nil
  vibration ;
  explosion ; explosive, flame, nil
  heat      ; produce, required, control, nil
  weight    ; heavy or nil
  exit      ; yes or nil
  compressed-air ; required or nil
  power     ;
  water     ;
  movable   ; hard, nil
  dangerous ; yes or nil
  assigned-to ; floor index
)
```

FIGURE 4. Working memory element class definition

The attribute of a working memory element is prefixed with '^' and the value of the attribute follows it immediately. An instance of a working memory element of class department is given in Figure 5.

```
(department
  ↑name      machining
  ↑noise     produce
  ↑vibration  produce
  ↑explosion  nil
  ↑heat      nil
  ↑weight    heavy
  ↑exit      nil
  ↑compressed-air required
  ↑power     required
  ↑water     required
  ↑movable   hard
  ↑dangerous yes
  ↑assigned-to 5
)
```

FIGURE 5. An instance of a working memory element

Production memory The productions in OPS5 are in the form of "IF .. THEN" clauses. Figure 6 shows an example of a production memory. The OPS5 form of the rule starts with '(p' which signals the start of a rule, followed by 'RESTRICTION::LOAD::REMOVE' which is the name of the rule. The English form of the rule is also given in the figure.

The OPS5 inference engine The inference engine cycles over the three states of match, select, and execute. In each cycle, it decides which rules are eligible for execution based on the working memory elements and then chooses the rules to be executed based on one of

```

IF  all floor-blocks are occupied by departments
    active expert is restriction
    there's floor <index> which can load light dept. only
    there's dept. <name> which is heavy and assigned to
        the light only floor <index>

THEN remove the heavy dept. from the floor <index>
    make the floor <index> available
    report the changes

```

(a)

```

(p RESTRICTION::LOAD::REMOVE
  {(open ↑floor nil) <open>}
  (active ↑expert restriction)
  (floor ↑index <index> ↑load light)
  {(department ↑name <name> ↑weight heavy ↑assigned-to
    <index>) <heavy>}
  -->
  (modify <heavy> ↑assigned-to nil)
  (modify <open> ↑floor <index>)
  (write (crlf) |Department| <name> |is removed from floor|
    (crlf) <index> |by restriction expert due to |
    (crlf) |heavy weight.|(crlf))
)

```

(b)

(a) English form (b) OPS5 form

FIGURE 6. An example of rules in OPS5

either LEX or MEA strategy. Figure 7 shows how it works. The modification of rules can be called the learning capability of OPS5.

LEX stands for Lexicographic-Sort strategy and MEA stands for the Means-Ends-Analysis. These strategies apply the rules in the following order: refraction, recency, and specificity. However, the MEA strategy includes an extra step after refraction, which helps organize large programs. This step orders the instantiations according to the recency of the working memory element matching the first condition element in each production.

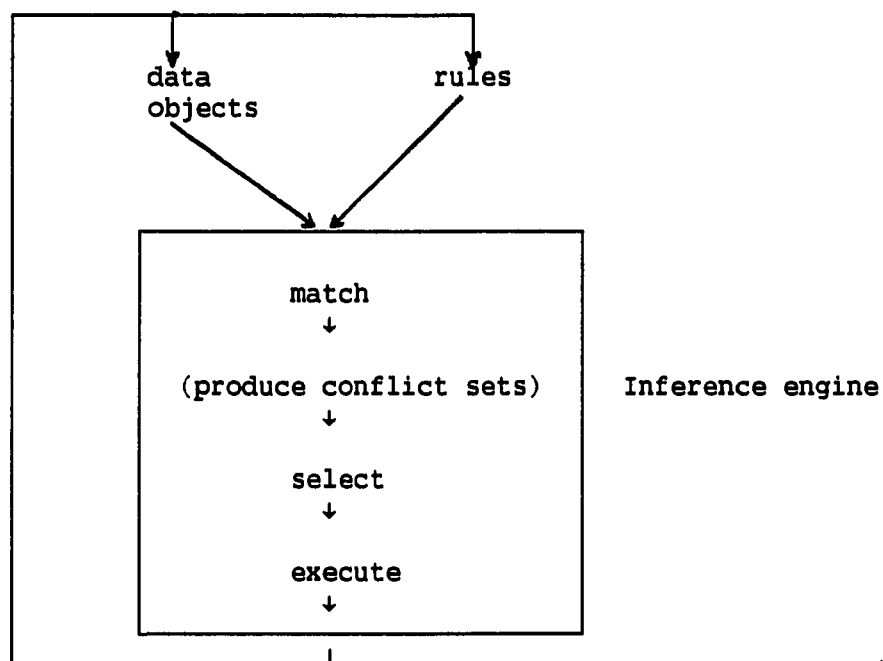


FIGURE 7. Match-Select-Execute cycle

FLUKES

The name FLUKES stands for Facility Layout Using Knowledge-based Expert System. The approach requires practical layout knowledge which may not be universally accepted. Also, the knowledge must be modified and updated as necessary. The characteristic of this approach determine that an expert system technique application could be valuable. All layout-related knowledge parts were first written in OPS5. However, they were later re-written in FORTRAN to avoid difficulties in calculation, in linking with FORTRAN, and in execution time. The name FLUKES may not be applicable for the new version due to the program structure and execution process. However, the name FLUKES is still used here for the upcoming version which will be modified in program structure.

Solution search and initial layout

The method used here can be summarized by the flow chart given in Figure 8. The process begins with checking a given layout with the soft-type constraint which has the largest penalty and then, if that constraint is not violated, it moves to the next constraint. If a department is found that violates a soft-type constraint, it is removed from current assignment and a replacement is selected among same-size or neighboring departments. The positions of these two departments will be switched if no violation against hard-type constraints occurs and decreased objective function value can be obtained. This is the

base rule to improve a layout which a human planner might apply. For a detailed description of violation checking, position switching, evaluation of alternatives, etc., please refer to next sections.

Violation of hard-type constraints can be recognized after switching department positions. However, only a department index switch is done in the pre-checking stage to avoid the complex and time consuming department switching process. Checking for violations by substituting a smaller department index for a bigger department index is not exactly same as checking after physically switching the two departments. This will reject some alternatives which would not violate hard-type constraints in real life. However, this will be sufficient to reject an alternative which violates any hard-type constraints. If the index switch indicates no hard-type constraint violations, then it is followed by a physical position switch. After this process, the department shape checking is done.

There is a restriction which must be met on the development of an initial layout. The method used here is an improvement type. Therefore, the initial layout given by the user is also considered as an alternative to those generated by computer during the layout development process.

Hard-type constraints are checked with the position switched departments only, since all others are unchanged. This makes it possible to keep the checking stage simple, but it requires the user to supply an initial layout which does not violate any of the hard

constraints. If there are too many hard-type constraints and the user can not supply an acceptable initial layout, then this solution search can not proceed. FLUKES will stop its process by rejecting the initial layout with note about violation.

Problem representation

This system develops a layout based on several factors supplied by user. The necessary information can be supplied in various formats. However, the FORTRAN version of this system is designed to work with numbers. CRAFT requires initial layout, flow data, and cost data, but requires additional data to reach a realistic or at least close to a realistic layout. As shown in Figure 9, the departments and floor are divided into a manageable number of identical blocks. A department index is assigned to the floor blocks based on the size of the departments.

The user needs to be careful not to violate any hard constraints and not to make the shape of departments unrealistic when he/she constructs the initial layout. And if user wants to separate two departments, then the user must separate them in the initial layout. For example, if a particular portion of floor is not in a strong enough location, then the user must be careful not to assign a department with heavy equipment on it in the initial layout.

If any one of the constraints in the hard group is violated, then FLUKES will stop the execution and write about the violation. It would be possible to design FLUKES to fix this kind of problem and continue

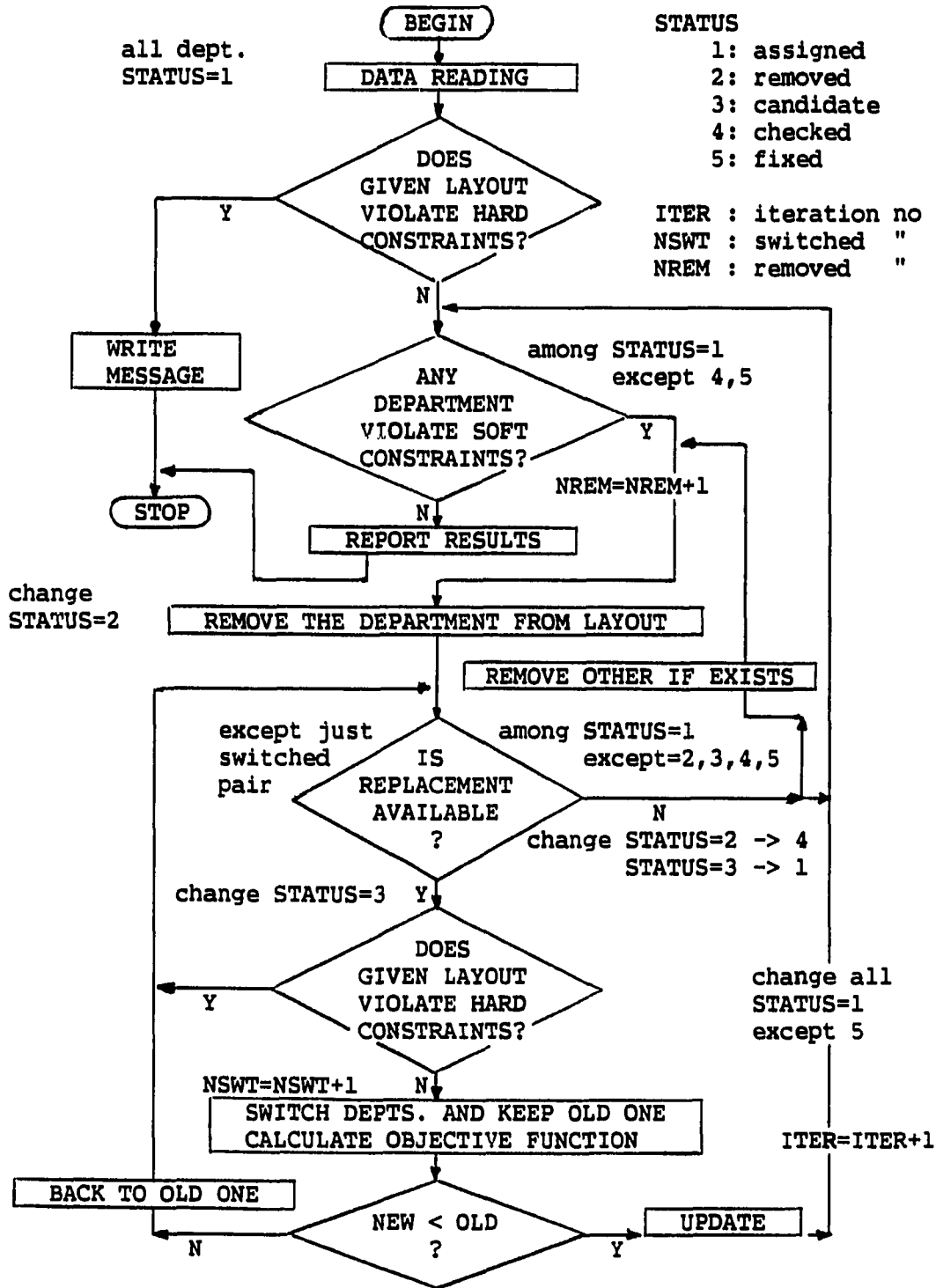


FIGURE 8. Data flow

Department	Area(ft ²)	No. of Squares	Floor																																																																																																				
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-	-	-	-	-	-	-	-	-	-																																																																																														
2	420	21																																																																																																					
3	200	10																																																																																																					
4	250	12																																																																																																					
5	210	11																																																																																																					
6	175	9																																																																																																					
7	145	7																																																																																																					
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FIGURE 9. Floor and departments representation for layout

the layout process, but this has not been done. The hard constraints checking stage after making the departments switch is designed only to reject the switch if it causes constraint violations.

The numbers under the title 'Initial Layout' in Figure 10 are department indices in an initial layout given by the user. The numbers indicate department assignment on floor blocks. For example, department 1 is assigned on floor blocks of (1,1), (1,2), (1,3), (1,4), (1,5), (2,1), (2,2), (2,3), (2,4), and (2,5). 'Flow Data' and 'Cost' are the number of moving units between two departments in a unit period of time and unit cost for moving, respectively.

'Availability of Utilities' is an additional information than the data file for CRAFT. In this data file, '1 or 0' means 'available or not'. For example, it can be seen that the floor blocks which have compressed air are (1,1), (1,8), (2,1), and (2,8). Power facilities,

[Initial Layout]

```

1 1 1 1 1 2 2 2
1 1 1 1 1 2 2 2
3 3 3 3 4 4 4 4
3 3 3 3 4 4 4 4

```

[Flow Data]

	1	2	3	4
1	0.0	2.0	4.0	4.0
2	1.0	0.0	1.0	3.0
3	2.0	1.0	0.0	2.0
4	4.0	1.0	0.0	0.0

[Cost]

	1	2	3	4
1	0.0	80.0	100.0	220.0
2	40.0	0.0	65.0	75.0
3	50.0	65.0	0.0	80.0
4	220.0	25.0	0.0	0.0

[Availability of Utilities]

Compressed Air	Power	Water
1 0 0 0 0 0 0 1	0 1 0 0 0 0 0 1	0 1 0 0 0 0 0 0
1 0 0 0 0 0 0 1	0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 1
0 0 0 0 0 0 0 1	0 1 0 0 0 0 0 1	0 1 0 0 0 0 0 0
0 1 1 0 0 0 0 1	0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 1

Exit-Door	Loading Limit	Expansion Side
1 0 0 0 0 0 0 0	0 0 0 0 0 0 0 0	1 1 1 1 1 1 1 1
1 0 0 0 0 0 0 0	0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 0
1 0 0 0 0 0 0 0	0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 0
0 0 0 0 0 1 1 1	0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 0

FIGURE 10. An example layout problem

[Special Requirements]

Dsc.	Dept.	1	2	3	4
MIN. LENGTH		2	1	1	1
NOISE	make	protect			
MOVING	hard				
VIBRATION	make	protect			
EXPLOSION					
HEAT					
WEIGHT					
EXIT/DOOR					required
COMPRESS AIR	required				
POWER FACLTY	required				
WATER FACLTY		required			
USER PREFERN	User has no department pairs to be placed closed or separate each other on this example.				

[Penalty to Violation]

VIOLATION	PENALTY
USER PREFRC	100.0
EXPANS PLAN	500.0
NOISE CNTRL	200.0
VIBRATION C	600.0
EXPLOSION C	1000.0
AIR-COMPRES	300.0
POWER-FACIL	100.0
WATER-FACIL	600.0
DOOR-EXIT C	800.0
HEAT CNTRL	50.0
ENERGY SAVE	20.0

FIGURE 10. (Continued)

water/sewer, doors, etc., have a similar representation. All '0's under the title 'Loading limit' means that there is no problem block on the floor. The '1' indicates the direction of future expansion under the title 'Expansion side.' The '1s' in 'Ventilation', for example, indicate the floor blocks which have ventilation.

Figure 10 includes all the information about departments which is needed for a layout development by FLUKES. Also, this figure includes the penalties to be used for violations of soft constraints. For instance, if departments requiring compressed air are not assigned on the floor block with compressed air, then 300 will be charged for each violation of this requirement; if two departments which require compressed air facility are not assigned on the floor blocks with compressed air equipment, then 600 will be charged to the objective function.

STAGE 1 - Data reading and check up with hard constraints

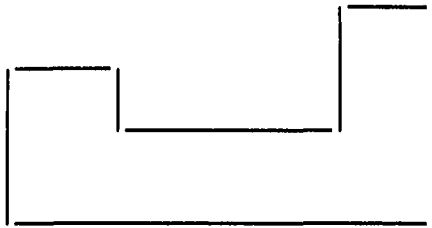
In the very first stage of this system, the data file given by the user is read in and the initial layout is checked with hard constraints. During the process of data reading, the departments which must or would best be fixed on specific floor blocks can be entered. Also, the acceptable rate of department shape can be entered. Those departments which occupy fixed positions can be kept on their assigned positions by assigning a specific index '5' to the 'STATUS' of the departments, which indicates 'fixed.'

The acceptable rate of department shape is the ratio of the department area to the smallest possible rectangle which can include the department, as shown in Figure 11. The department shape given in (a) of the figure is the most common in the layout. In most cases, department interchanges will create department shapes closer to the one in (a), not in (b). Therefore, it is necessary to find a way to determine whether a department shape is acceptable.

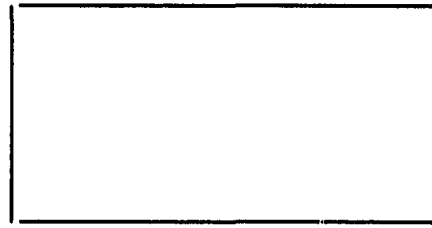
The shapes of departments A and B in (a) of Figure 12 can be modified easily to rectangles as shown, while the shapes of departments A and B in (b) are not easy to modify. The purpose of using a rate of acceptable shape is to reject a shape which would cause problems for modification, like those in (b) of Figure 12. Shape checking can be done by calculating the shape rate as in Figure 11 and comparing the rate with the one given by the user.

Of course, it is true that an unrealistic department shape can be changed to realistic shape by hit or miss during the process of layout. The problem is that the probability of changing the department shape into a 'realistic' shape by luck is very low. In reality, the chance is greater that unrealistic department shapes will remain the same or that other unrealistic shapes will be created during the course of layout process.

FLUKES is designed to compare the shape rates to avoid this problem. The shape rate of newly moved department is compared with the rate given by the user. If it is lower than the rate given by the



(a) department shape



(b) the smallest possible rectangle

SHAPE RATE = (AREA OF DEPT. B) / (AREA OF IDEAL SHAPE)

IF SHAPE RATE IS SMALLER THAN THE ONE USER WANTED, REJECT

AREA
165

```

      B B B B B B B B
      B B B B B B B B
      B B B B B B B B
      B B B B B B B B
      B B B B B B B B B B B B B B B B
      B B B B B B B B B B B B B B B B
      B B B B B B B B B B B B B B B B
      B B B B B B B B B B B B B B B B
      B B B B B B B B B B B B B B B B
      B B B B B B B B B B B B B B B B
      B B B B B B B B B B B B B B B B

```

AREA
242

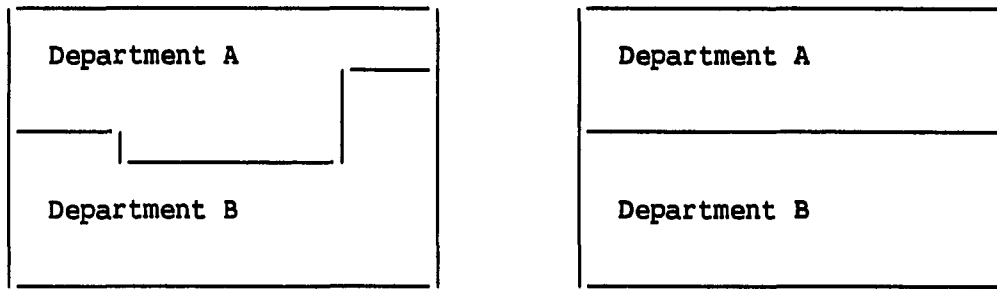
```

      B B B B B B B B B B B B B B B B B B
      B B B B B B B B B B B B B B B B B B
      B B B B B B B B B B B B B B B B B B
      B B B B B B B B B B B B B B B B B B
      B B B B B B B B B B B B B B B B B B
      B B B B B B B B B B B B B B B B B B
      B B B B B B B B B B B B B B B B B B
      B B B B B B B B B B B B B B B B B B
      B B B B B B B B B B B B B B B B B B
      B B B B B B B B B B B B B B B B B B
      B B B B B B B B B B B B B B B B B B

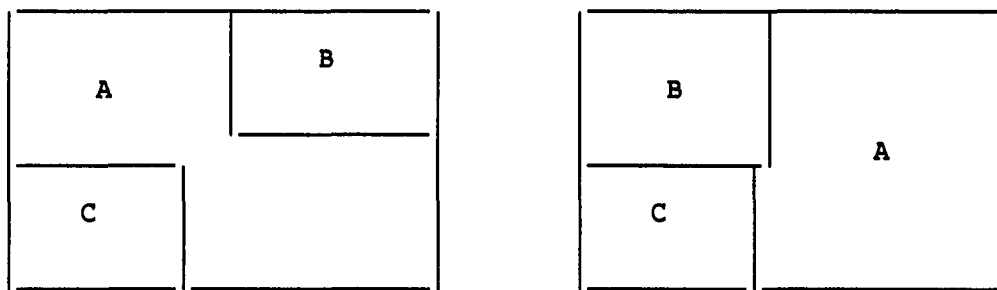
```

$$\text{SHAPE RATE} = 165 / 242 = 0.6818$$

FIGURE 11. Department shape checking



(a) Alteration is simple



(b) Alteration is not simple. Additional moving is required.

FIGURE 12. Alteration of department shape

user, the suggested layout is rejected. It is true that human planners can fix the shape problem and make the layout feasible even in the case in (b) of Figure 12. For instance, department B could be moved to the left hand side and then a minor shape adjustment will make the layout feasible as in the Figure 12. This kind of shape adjustment will be the next step in the research to improve this system.

In addition to excluding a fixed-position department from consideration for removal or replacement, the shape of the interchanged departments and physical limitations on floor blocks such as loading limits are checked. If any one of these restrictions is violated, then the program is stopped after writing a message about the violation. If the violation happens with a suggested layout which will be checked in stage 3, then the suggested layout is rejected, the current layout is kept, and the layout process continues.

Another hard constraint is user preference. If a user wants to place two departments apart or close, then this constraint can be used to keep them as the given configuration at the beginning. This procedure is summarized in Figure 13.

STAGE 2 - Department removal with soft constraints

Stage 2 involves several constraints, as shown in Figure 14. The order in which the constraints are considered is determined based on the importance of the constraints, or in other words, the value of penalties assigned to the constraints. It is not always true that the constraint assigned the largest penalty value must be checked first to reach the global optimum solution. A trial to remove the largest penalty causing department and switch it with others could create several small penalties, sum of which could be greater than the original penalty. However, the old and new objective function value comparison protects FLUKES from this problem. The correct order to reach the global optimum can be known only after finding the global

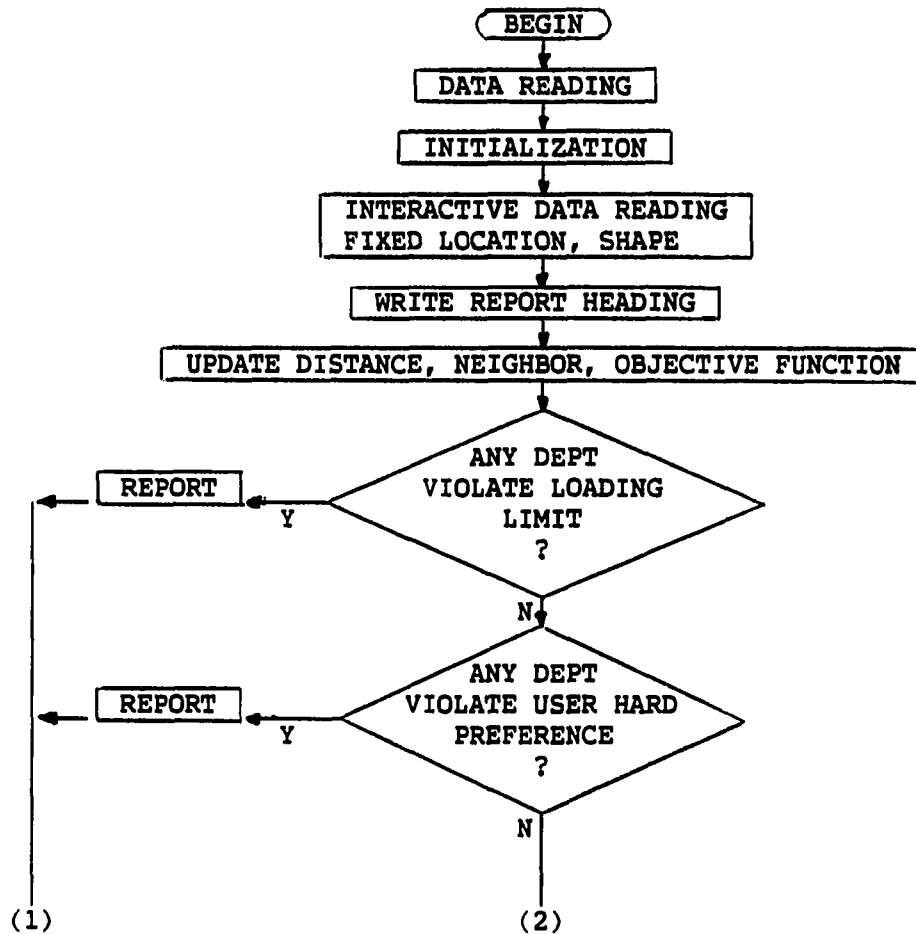


FIGURE 13. Flow chart of Stage 1

optimum. If it is preferred, the user can switch the order of constraint execution.

When a department is found to be violating any one of the soft constraints, the department is replaced with another department. The

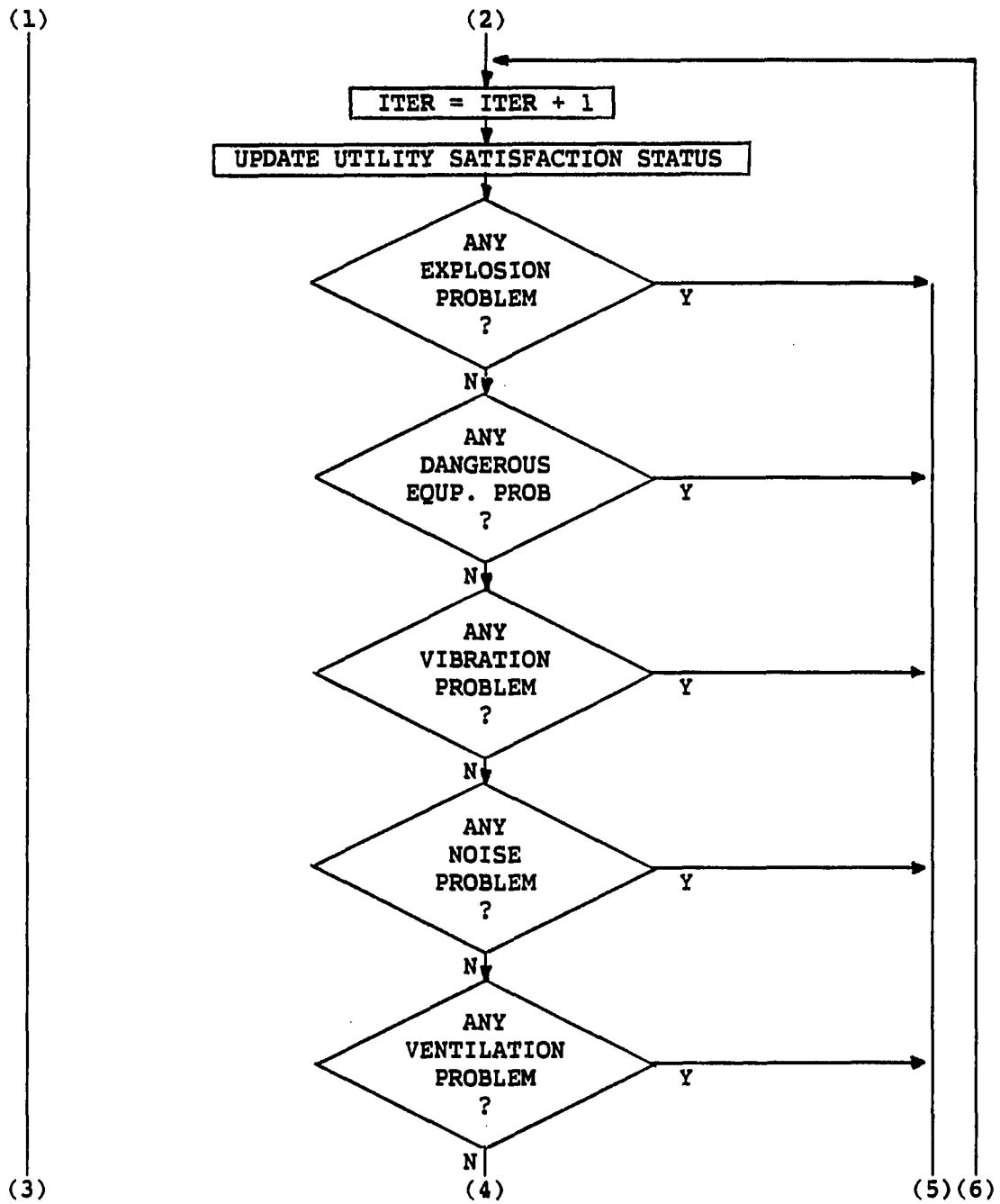


FIGURE 14. Flow chart of Stage 2

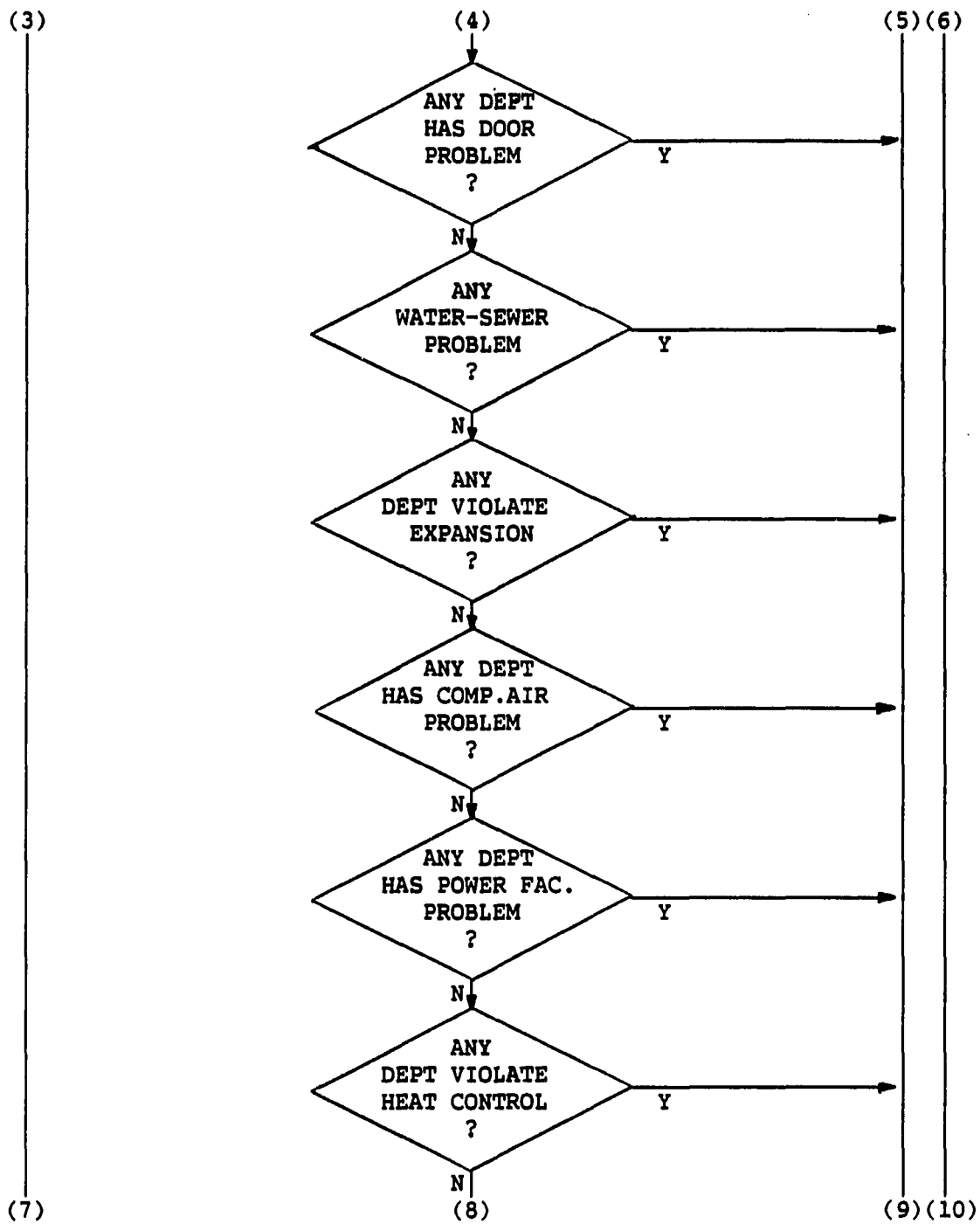


FIGURE 14. (Continued)

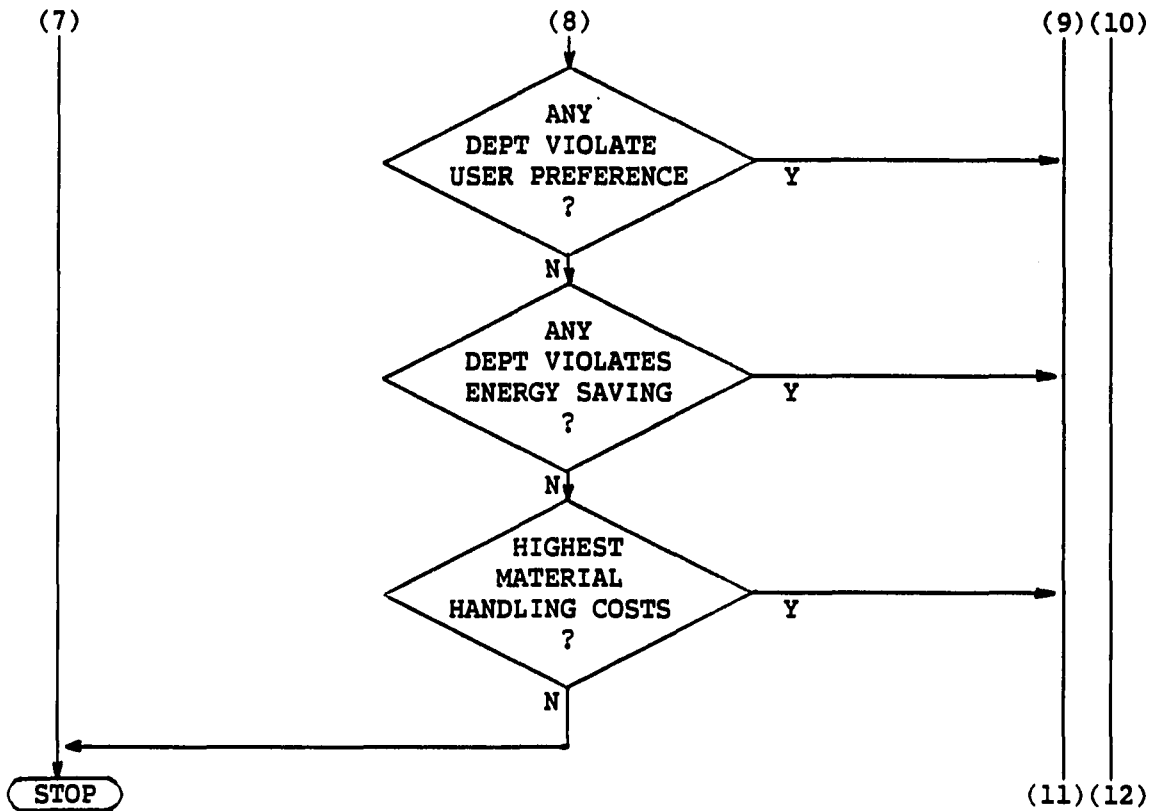


FIGURE 14. (Continued)

conditions which must be met are that the interchange must not create any hard constraint violation, and that the interchange must reduce the objective function value.

Examples of soft constraints violation are various. Two departments might be placed side by side with one department handling explosive material and the other with flames. A department which could harm people might be assigned a position right beside one in which many people work. Vibration generated in one department could make accurate

work or handling fragile materials impossible in an adjacent one. A department which makes noise above 90dB might be assigned a position right beside office. Ventilation, doors, water-sewer, compressed-air, and power facilities must taken into account to properly allocate the departments which need to have those utilities.

If any department has very heavy machines or fixed obstructions, it is better not to have the department on the future expansion side. Heat control and energy saving require attention to placement of departments which produce heat, require heat, or need to be away from heat. Storing any materials which need to be kept in cool near furnace is a good example of heat control violation. Energy saving requires placing a heat producing department by a heat requiring department. User preference in the soft constraint group is about the placement of two departments close or apart from each other 'if possible', rather than the strict condition of 'must' as in the hard constraint group. If any constraint which is not provided in the current FLUKES exists, it could be possible to implement using this or the other 'user preference' in the hard constraint group as necessary.

Whenever a department is found to be violating any one of the soft constraints, the department will be examined for replacement with another department. If all these constraints are checked and all possible replacements have been tested, then material handling costs between every pair of departments are checked. Either one of the departments in the pair which generates highest material handling cost

will be removed randomly and checked whether any improvement is possible. If no improvement is available, then the other in the pair is removed and checked. This process continues until no departments are left in current configuration without removing once.

STAGE 3 - Replacement and checking with hard constraints

As shown in Figure 15, departments of the same size as the removed department are checked first for replacement. If none are available, then neighboring departments of the removed department are checked. This approach is taken to make the department interchange process simple. As discussed before, interchange of two departments which are neither same size nor neighboring, creates a very complicated problem of moving or altering the shapes or positions of all the departments between the two interchanged departments. Figures 16 and 17 show examples of these cases in detail. Only the departments 1 and 12 are interchanged, but others such as departments 2, 3, 5, 6, and 7 are moved or altered in their shape and position as shown in Figure 16. This type of altering could be programmed into this system. However, formalizing the process of human judgement about the acceptable shape of a department is left as a later step of the research.

Interchange of two departments of the same size is simple. Switching the indices of the two departments is all that needs to be done. However, the interchange of two neighboring departments of different sizes requires some calculations. As shown in Figure 18,

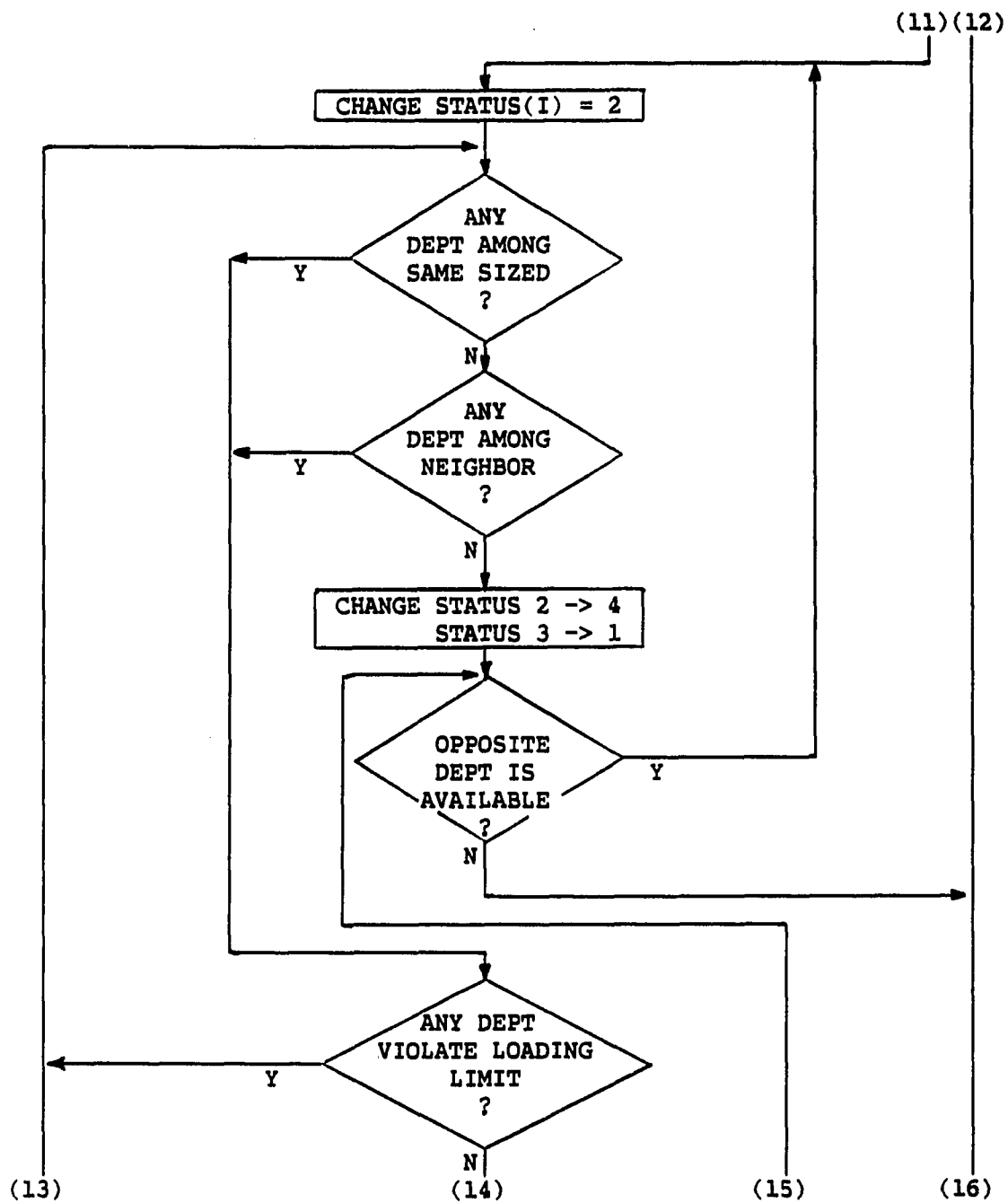


FIGURE 15. Flow chart of Stage 3

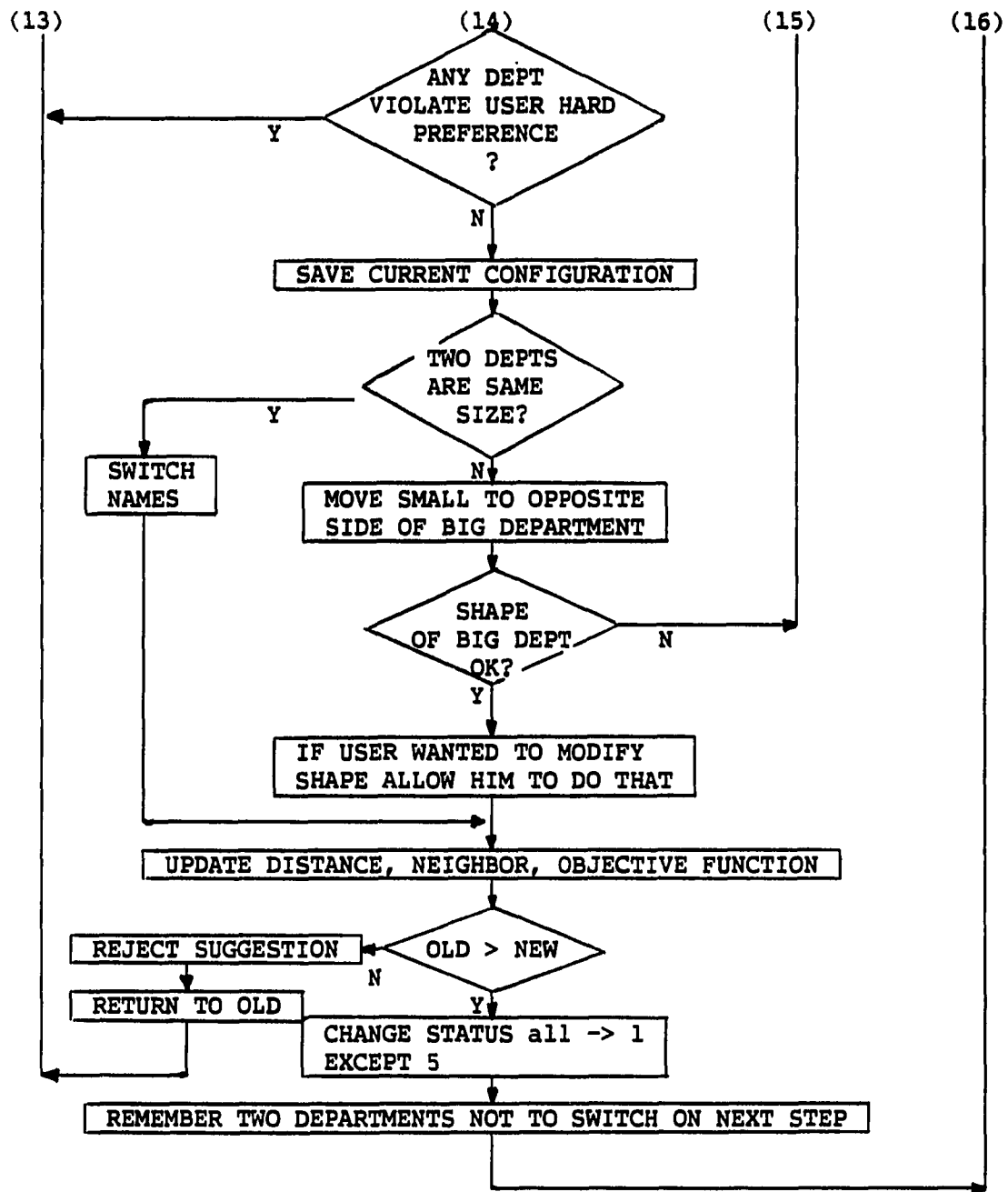


FIGURE 15. (Continued)

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1  1  1  1  1  1  1  3  3  3  9  9  9  9  9  9
1  1  1  1  1  1  1  3  3  3  9  9  9  9  9  9
1  1  1  1  1  1  3  3  3  3  9  9  9  9  9  9
1  1  1  1  1  1  3  3  3  8  8  8  8 10 10 10
1  1  1  1  1  1  7  7  7  8  8  8  8 10 10 10
1  1  1  1  1  1  7  7  7  8  8  8  8 10 10 10
2  2  2  2  2  2  7  7  8  8  8  8  8 11 11 11
2  2  2  2  2  2  6  6 12 12 12 12 12 12 11 11
2  2  2  2  2  6  6  6 12 12 12 12 12 12 12 12
2  2  2  2  2  6  6  6 12 12 12 12 12 12 12 12
2  2  2  2  2  6  6  6 12 12 12 12 12 12 12 12
4  4  4  4  5 12 12 12 12 12 12 12 12 12 12 12
4  4  4  5  5  5 12 12 12 12 13 13 13 13 13 13
4  4  4  5  5  5 13 13 13 13 13 13 13 13 13 13
4  4  4  5  5  5 13 13 13 13 13 13 13 13 13 13
4  4  4  5  5  5 13 13 13 13 13 13 13 13 13 13

```

```

12 12 12 12 12 12 12 3  3  3  9  9  9  9  9  9
12 12 12 12 12 12 12 3  3  3  9  9  9  9  9  9
12 12 12 12 12 12 12 3  3  3  9  9  9  9  9  9
12 12 12 12 12 12 12 3  3  8  8  8  8 10 10 10
12 12 12 12 12 12 12 3  8  8  8  8 10 10 10
12 12 12 12 12 12 12 3  8  8  8  8 10 10 10
2  2  2  2  2  2 12  7  8  8  8  8  8 11 11 11
2  2  2  2  2  2  7  7  1  1  1  1  1  1 11 11
2  2  2  2  2  7  7  7  1  1  1  1  1  1  1  1
2  2  2  2  2  6  7  7  1  1  1  1  1  1  1  1
2  2  2  2  2  6  6  6  1  1  1  1  1  1  1  1
4  4  4  4  6  6  6  6  1  1  1  1  1  1  1  1
4  4  4  5  6  6  6 13 13 13 13 13 13 13 13 13
4  4  4  5  5  5  5 13 13 13 13 13 13 13 13 13
4  4  4  5  5  5  5 13 13 13 13 13 13 13 13 13
4  4  4  5  5  5  5 13 13 13 13 13 13 13 13 13

```

FIGURE 16. Neither neighboring nor same sized case (1 and 12)


```

1  1  1  1  1  1  1  3  3  3
1  1  1  1  1  1  1  3  3  3
1  1  1  1  1  1  3  3  3  3
1  1  1  1  1  1  3  3  3
1  1  1  1  1  1  7  7  7
1  1  1  1  1  1  7  7  7
2  2  2  2  2  2  7  7
2  2  2  2  2  2  6  6 12 12 12 12 12 12
2  2  2  2  2  2  6  6  6 12 12 12 12 12 12 12
2  2  2  2  2  2  6  6  6 12 12 12 12 12 12 12
2  2  2  2  2  2  6  6  6 12 12 12 12 12 12 12
      5 12 12 12 12 12 12 12 12 12 12 12 12
      5 5  5 12 12 12 12 13 13 13 13 13 13
      5 5  5 13 13 13 13 13 13 13 13 13 13
      5 5  5 13 13 13 13 13 13 13 13 13 13
      5 5  5 13 13 13 13 13 13 13 13 13 13

```

FIGURE 17. Shape changed departments after switching 1 and 12

there are eight different possible patterns for positioning two neighboring departments. FLUKES recognizes the location pattern of two neighboring departments by comparing their centroids and then tries to move the smaller department on the 'X' point of the bigger department as shown in the figure. Moving the smaller department to the position opposite to the bigger department is one of the best strategies to keep the shape of a department good after moving, and also to keep the process of moving simple.

Two possible cases of department moving are given in Figures 19 and 20. The 'Bs' and 'Ss' stand for the indices for 'Bigger department' and 'Smaller department,' respectively. After completion of moving, department shape checking follows, as explained above. If

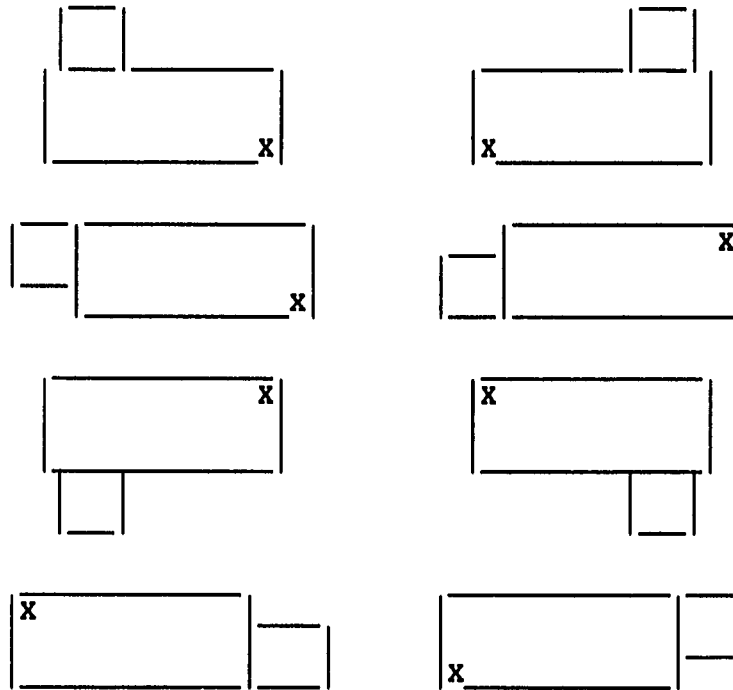


FIGURE 18. New position for the smaller department

the rate of a department shape is not acceptable, then the suggested layout is rejected and FLUKES continues its layout process from the previous layout. If no problem is found with the shape and if all the hard constraints are met, an objective function value is calculated and compared with the previous one.

The objective function value is calculated from the number of soft constraints violations times the penalties given to them, and their sum is added to the material handling cost. The material handling cost is

If maximum possible length of department S is longer than the length of short side of department B, change department index to S all the way down and repeat until the size of department is meet.

```

B B B B B B B B B B B B B B B
B B B B B B B B B B B B B B B
B B B B B B B B B B B B B B B
B B B B B B B B B B B B B B B
B B B B B B B B B B B B B B S S S S S S S S S S S S S S S S S S
B B B B B B B B B B B B B B B S S S S S S S S S S S S S S S S S
B B B B B B B B B B B B B B B S S S S S S S S S S S S S S S S S
B B B B B B B B B B B B B B B S S S S S S S S S S S S S S S S S
B B B B B B B B B B B B B B B S S S S S S S S S S S S S S S S S
B B B B B B B B B B B B B B B S S S S S S S S S S S S S S S S S
B B B B B B B B B B B B B B B S S S S S S S S S S S S S S S S S

```

```

S S S S S S S S S B B B B B B
S S S S S S S S S B B B B B B
S S S S S S S S S B B B B B B
S S S S S S S S S B B B B B B
S S S S S S S S S B B B B B B B B B B B B B B B B B B B B B B B
S S S S S S S S S B B B B B B B B B B B B B B B B B B B B B B B
S S S S S S S S S B B B B B B B B B B B B B B B B B B B B B B B
S S S S S S S S S B B B B B B B B B B B B B B B B B B B B B B B
S S S S S S S S S B B B B B B B B B B B B B B B B B B B B B B B
S S S S S S S S S B B B B B B B B B B B B B B B B B B B B B B B
S S S S S S S S S B B B B B B B B B B B B B B B B B B B B B B B

```

FIGURE 19. Moving a smaller department to a bigger one - case 1

calculated by rectilinear distance times unit cost times flow quantities between all pairs of departments. All these are penalties which increase the value of objective function value, but not the value which comes from energy saving. For example, the placement of a heat

If maximum possible length of department S is shorter than the length of short side of department B, change department index to S up to its maximum possible length and repeat until the size of department is meet.

```

B B B B B B B B B B B B B B
B B B B B B B B B B B B B B
B B B B B B B B B B B B B B
B B B B B B B B B B B B B B
B B B B B B B B B B B B B S S S S S S S
B B B B B B B B B B B B B B S S S S S S S
B B B B B B B B B B B B B B S S S S S S S
B B B B B B B B B B B B B B S S S S S S S
B B B B B B B B B B B B B B S S S S S S S
B B B B B B B B B B B B B B S S S S S S S
B B B B B B B B B B B B B B S S S S S S S

```

```

S S S S S S S B B B B B B B B
S S S S S S S B B B B B B B B
S S S S S S S B B B B B B B B
S S S S S S S B B B B B B B B
S S S S S S S B B B B B B B B B B B B B B B
S S S S S S S B B B B B B B B B B B B B B B
S S S S S S S B B B B B B B B B B B B B B B
B B B B B B B B B B B B B B B B B B B B B
B B B B B B B B B B B B B B B B B B B B B
B B B B B B B B B B B B B B B B B B B B B
B B B B B B B B B B B B B B B B B B B B B

```

FIGURE 20. Moving a smaller department to a bigger one - case 2

producing department by a heat requiring department would be a good allocation for energy saving. Therefore, any department allocation which meets the energy saving constraint is given some credit for that instead of being given penalties. This value is calculated from the number of cases times credit per case given by the user.

Example problem

An example problem and an output with comments from FLUKES are given in APPENDIX A and APPENDIX B, respectively. The written comments followed by the objective function value can be skipped, or all intermediate steps can be skipped and only the initial and the final layout can be printed.

On the first page of the output in APPENDIX B, the acceptable rates of shape and the indices for fixed departments on specific positions are printed. The initial layout given by the user with its evaluation follows. Messages are printed after the evaluation table. For example, the message 'DUE TO DANGEROUS EQUIP. - DEPARTMENT 5 IS REMOVED...' is printed to show that department 5 has been removed because it violates a safety restriction. As described in the problem, department 4 has dangerous equipment and department 5 needs to be away from it. But the two departments are neighboring in the initial layout. Therefore, FLUKES removes department 5 and picks department 3 for replacement. As shown in the next evaluation table, material handling cost is increased a little, but the dangerous equipment violation is resolved and the total objective function value is decreased from 202,193.03 to 188,306.53. The new suggestion for interchanging two departments is accepted and FLUKES continues the layout process with the new layout. The total number of iterations, the number of removed departments, and the number of trial switches are reported at the end of final report as well as CPU time. In all, 51

departments are removed and 124 departments are examined to switch with them. A total of 12 iterations are done to find the solution.

EVALUATION

This chapter summarizes the results produced by FLUKES. In the first section the process of data file preparation will be explained and then experimental test results will be discussed. In addition, the limitations involved in exchange heuristics as well as this system and a brief comparison with CRAFT will be given.

Data File Preparation

The data file given in Figure 21 looks very complicated to construct, but it can be done with the data file generation program. This program works with the user interactively. Therefore, all a user has to do is to answer the questions displayed on the screen. The data file construction program will organize the information supplied by user and then generate a data file. The data file which will be used for FLUKES does not contain the comments part under the column 'REMARKS' and some blank lines in Figure 21.

A sample session of the data file generation program is provided in Figure 22. As shown in the figure, generation of a new data file may be time consuming task, but not very hard. However, answering all the questions again to generate a little different data file from an existing one is tedious. To ease this process, the existing data file can be copied and then modified by referring to the comments provided in Figure 21.

DATA FILE	REMARKS
4 8 4	ROW NO., COLUMN NO., DEPT. NO.
2 10 1 1	MIN. LENGTH OR WIDTH, DEPT. SIZE
1 1 1 0 0 0 0 1 1 0	DANGER-EQUIPMENT, VENTILATION
1 6 0 0	NS,MV,VB,EP,HT,WT,ET,AR,PR,WR
2 0 2 0 0 0 0 0 0 1	[NS:noise MV:moving VB:vibration]
1 8 0 0	[EP:explosion HT:heat WT:weight]
0 0 0 0 0 0 0 0 0 0	[ET:exit AR:air PR:power WR:water]
1 8 2 0	
0 0 0 0 0 0 0 1 0 0 0	
1 0 0 0 0 0 0 0 1	COMPRESSED AIR AVAILABLE
1 0 0 0 0 0 0 0 1	FLOOR BLOCK
0 0 0 0 0 0 0 0 1	
0 1 1 0 0 0 0 0 1	
0 1 0 0 0 0 0 0 1	POWER FACILITY
0 0 0 0 0 0 0 0 0	
0 1 0 0 0 0 0 0 1	
0 0 0 0 0 0 0 0 0	
0 1 0 0 0 0 0 0 0	WATER/SEWER
0 0 0 0 0 0 0 0 1	
0 1 0 0 0 0 0 0 0	
0 0 0 0 0 0 0 0 1	
1 0 0 0 0 0 0 0 0	EXIT-DOOR
1 0 0 0 0 0 0 0 0	
1 0 0 0 0 0 0 0 0	
0 0 0 0 0 1 1 1 1	
1 0 0 0 0 1 1 1 1	VENTILATION EQUIPMENT
1 0 0 1 0 0 0 0 0	
1 0 0 1 0 0 0 0 0	
0 0 0 0 0 1 1 1 1	
0 0 0 0 0 0 0 0 0	LOADING LIMIT SPOT
0 0 0 0 0 0 0 0 0	
0 0 0 0 0 0 0 0 0	
0 0 0 0 0 0 0 0 0	

FIGURE 21. An example data file with comments

DATA FILE	REMARKS
1 1 1 1 1 1 1 1 0	EXPANSION PLANNED
1 1 1 1 1 2 2 2 1 1 1 1 1 2 2 2 3 3 3 3 4 4 4 4 3 3 3 3 4 4 4 4	BLOCK LAYOUT ASSIGNMENT
0 0 0 0 0 0	RELATIONSHIP OF DEPARTMENTS
0 0 0 0 0 0	TYPE OF RELATION
0.0 2.0 4.0 4.0 1.0 0.0 1.0 3.0 2.0 1.0 0.0 2.0 4.0 1.0 0.0 0.0	UNIT QUANTITY BETWEEN TWO DEPTS
0.0 80.0 100.0 220.0 40.0 0.0 65.0 75.0 50.0 65.0 0.0 80.0 220.0 25.0 0.0 0.0	MOVING COST
2000 6000 7000 8000 10000 9000 8000 4000 2000 6000 6000 3000 1000	USER PREFERENCE VIOLATION EXPANSION PLAN VIOLATION NOISE CONTROL VIOLATION VIBRATION CONTROL VIOLATION EXPLOSION CONTROL VIOLATION DANGEROUS EQUIPMENT VIOLATION VENTILATION EQUIPMENT UTILITY - COMPRESSED AIR POWER FACILITY WATER-SEWER DOOR HEAT CREDIT FOR ENERGY SAVING

FIGURE 21 (Continued)

```

$ RUN DATA
ENTER THE NUMBER OF ROW COLUMN AND DEPTS
16 16 13
DO YOU WANT TO CHANGE ANY? 1-YES 0-NO
0
ENTER THE SIZE OF DEPARTMENT 1
38
      :

DOES DEPARTMENT 4 NEED TO HAVE COMPRESSED AIR?
0-NO PROBLEM 1-REQUIRED
1
      :

ENTER DEPT. INDEX ASSIGNED ON FLOOR (16, 5)
5
      :

ENTER ROW & COLUMN INDEX OF FLOOR WHICH
HAS DOOR-EXIT ON IT. ENTER 0 0 IF NO MORE
1 11
6 1
16 3
0 0
      :

ANY TWO DEPTS. NEED TO BE PLACED SPECIALLY?
ENTER THE INDEX OF TWO DEPARTMENTS
RELATION      1-CLOSE      2-APART
AND TYPE      1-MUST BE    2-IF POSSIBLE.
ENTER 0 0 0 0 IF NO MORE
8 9 2 2
5 9 2 2
6 13 1 2
0 0 0 0
      :

DO YOU WANT TO CHANGE ANY? 1-YES 0-NO
0

```

FIGURE 22. A sample session of the data file generation program

The data file in Figure 21 is for the example problem in Figure 10 of the last chapter. It will be easy to understand if the Figure 21 is used with the example problem of the last chapter for comparison. The special requirements shown in Figure 10 are represented on the 3rd, 5th, 7th, and 9th rows in Figure 21. For example, the first row of '1 1 0 0 0 0 1 1 0' indicates that department 1 makes noise, is hard to move, causes vibration, needs compressed air, and needs power outlets. User preference is seen to be all 0s in this example since it is assumed that user has no preferences on department placement. Penalties to the violation of constraints are given at the end of the data file. If different penalties are preferred, then the last part of data file can be modified.

The example output file which is discussed briefly in the last chapter is provided in APPENDIX B. The output file in the APPENDIX B is one of the three options available for the generation of output files. The first option is to print only the given initial layout by the user along with the final layout found by FLUKES and an evaluation table. The second option is to print all intermediate layouts with evaluation tables except comment parts. The third option is to include comments as shown in the APPENDIX B.

Limitations of the Exchange Method

Endless exchanges will finally lead to the best solution in a combinatorial problem. However, it is not practical to continue the

search process until the optimum solution is found. To avoid the combinatorial explosion, exchange heuristics use stopping rules such as 'stop exchange if no more improvement is made from the current configuration.' Therefore, the solution obtained from those heuristics can not be called 'the optimum solution' since not all the necessary calculations and comparisons have been done to make sure no better solution exists.

The problem of 'local optimum' in FLUKES comes directly from the exchange mechanism. The restrictions in the current FLUKES exchange mechanism is that of finding a replacement for a removed department only from same sized or neighboring departments. Again, this was necessary only to avoid very complicated department shape adjustment and moving. Moving or re-shaping all departments between the two interchanged departments would not be an easy task to perform manually after every interchange. It is necessary to re-shape or move all of the departments placed between the two interchanged departments if the departments are neither neighboring nor same sized. As for a human planner, trial and error correction would be the best way to resolve this problem. If a human-like correction system could be programmed, then a better solution method in the layout problem domain could be developed based on it.

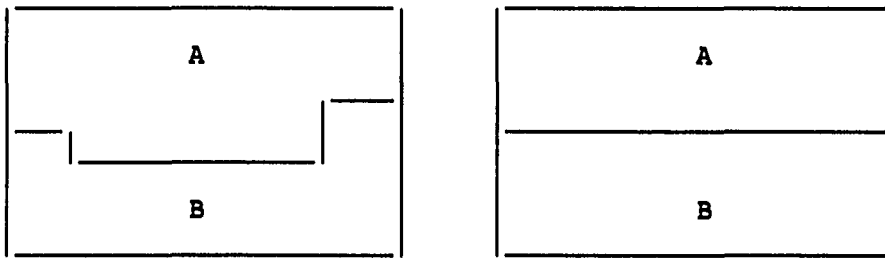
Minor adjustment of a department shape is not going to create any serious problems in block layout, but major adjustment is going to create serious problems such as demonstrated in Figure 23. A minor

adjustment as in (a) of the figure is not going to change the basic configuration of the layout but the major adjustment as in (b) will. For example, the department B in example (b) could be the department which has a furnace that must not to be placed in the new position. Also the material handling cost, one of the important factors in layout, could be increased significantly and make the new layout worse than before. Of course, it can be placed like department B and C on the right hand side and A on the left hand side. But this adjustment also could create another problem, such as the relationship with neighboring departments if this is only a part of the whole layout configuration.

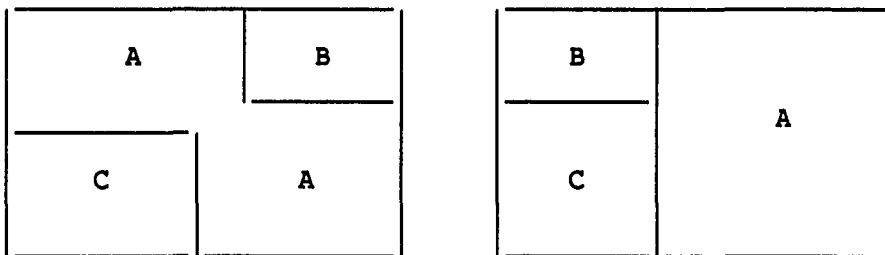
A three-way exchange gives more alternatives and therefore more chances to find a better solution. However, this also gives a high chance to create irregularly shaped departments which will be rejected by the shape checker in FLUKES. Therefore, a three-way interchange is not implemented here to avoid unnecessary departmental switches and complexities involved in the system construction. Development of a human-like shape recognition and adjustment mechanism will resolve these difficulties.

Unsolved Problems in Layout Problem Domain

There are several other remaining problems in addition to the shape adjustment and restrictions on department exchanges. Material handling cost does not totally depend upon the distance moved. The



(a) Adjustment of department shape



(b) Position and shape adjustment of department

FIGURE 23. Shape and position adjustment

moving distance might not be exactly a straight line or rectilinear. The centroid of a department is not the point where everything must move in and out. These are some of the problems in the area of facility layout and also in FLUKES.

Although the centroid is not the point where everything can possibly be moved in and out, it could be one of the best points from which to measure moving distance since the moving distance in inside of

a department also must be counted as well as the moving between departments. The moving distance calculated here is rectilinear. Certainly, some of paths could be straight lines or close to straight lines, but all are assumed to be rectilinear as in CRAFT.

Experimentation and Analysis

Two different models are designed for experimentation with FLUKES. The first one is designed to develop initial layouts using random number generator and the second one is to develop initial layouts manually. The first model is not concerned about the shape of a department while the second one is mainly concerned about it. The first case includes five different penalty values to see any changes with penalty values while the second one includes three different shape acceptable rates to see any changes base on that.

Case 1

For this experiment, initial layouts are generated based on random numbers. A department index chosen by a random number is assigned from the upper left four blocks down to the lower right four blocks. For example, the floor blocks (1,1), (1,2), (2,1), and (2,2) are assigned a department index first and then (1,3), (1,4), (2,3), and (2,4) as shown in Figure 24. Department sizes are assumed to be all the same to avoid generating an initial layout manually in this case.

Assigning department indices at random will be troublesome if department sizes are not the same. Some of the departments will not

cause any problems, but assigning some other departments on the left over floor blocks will make those department shapes irregular. The manual adjustments make this experiment extremely hard and only 51 different initial layouts are generated manually for the case 2 experiment.

	1	2	3	4	5	6
1	1	1	3	3		
2	1	1	3	3		
3						
4						
5						
6						

FIGURE 24. Department index assignment for initial layout

A department index is selected based on a random number as shown in Figure 25. 'RAN(number)' in the Figure 25 is the function to generate random numbers. This experimental program requires only two random numbers to be used during the process of layout development. One is to generate initial layouts and the other is for the decision making on the first removal department when either one can be removed

in a pair of departments. For instance, if two departments which should not be placed together are placed together, then the random number will be used to decide which one will be removed first.

```

      LEFT = 9
      DO 1280 I = 1,9
1280    NECO(I) = I
      DO 1290 I = 1,5,2
          DO 1290 J = 1,5,2
              IF(LEFT.LE.0) JUST = 1
              IF(LEFT.LE.0) GO TO 1279
              DIVID = 10./LEFT
              ANY = (RAN(LEMON)/DIVID)*10
              JUST = INT(ANY)+1
1279    ASSIGN(I,J) = NECO(JUST)
          ASSIGN(I,J+1) = NECO(JUST)
          ASSIGN(I+1,J) = NECO(JUST)
          ASSIGN(I+1,J+1) = NECO(JUST)
          LEFT = LEFT-1
              DO 1290 K = 1,LEFT
                  IF(K.LT.JUST) GO TO 1290
1290    NECO(K) = NECO(K+1)

```

FIGURE 25. A program to generate initial layouts

This program finds one hundred solutions for the randomly generated one hundred initial layouts. At the end of each layout, it prints out solutions in one line such as the objective function value and material handling cost of the initial layout, objective function value and material handling cost of the final layout, number of iteration, number of removed departments, and number of trial switches.

The example problem used in this experiment is taken from the thirteen department case problem in Francis and White (23). Changes are made in department size, number of departments, and size of floor blocks. The rest are the same as used in the problem before. The penalties used in this example are given in Table 9.

TABLE 9. Penalties used in experiments

Description	Example 1	Example 2	Example 3	Example 4	Example 5
mtrl. handling	1	1	1	1	1
user preference	20	200	2000	10000	0
expansion plan	60	600	6000	30000	0
noise control	70	700	7000	35000	0
vibration cont.	80	800	8000	40000	0
explosion cont.	100	1000	10000	50000	0
dangerous equip.	90	900	9000	45000	0
ventilation eq.	80	800	8000	40000	0
compressed-air	40	400	4000	20000	0
power facility	20	200	2000	10000	0
door and exit	60	600	6000	30000	0
water/sewer	60	600	6000	30000	0
heat control	30	300	3000	15000	0
energy saving	10	100	1000	5000	0

As shown in Table 9, the differences among examples are due to the different penalty values. The values of penalties are increased from example 1 through example 4. The last example has 0 penalties except for material handling costs. This type of penalty assignment is designed to see the performance of FLUKES with various penalty values.

The logical flow of FLUKES relies highly on the removal of department which violates the constraints with the highest penalty first.

Therefore, it is valuable to see any trends shown by these experiments.

All these different examples are tested with 500 different initial layouts which are generated using random numbers. As shown in the figures all the example cases are analyzed by making histograms of objective function values of both initial and final layouts and also by plotting the initial objective function versus final objective function values, and final objective function value versus material handling costs.

There are two histograms in Figure 26. The first one is the histogram of the objective function values of the initial layout. The second one is the histogram of the objective function values of the final layout. The first histogram shows that the objective function value of the initial layout follows a normal distribution function while the histogram of the final layout follows an exponential distribution function. Therefore, it can be seen that the chance of finding a solution which is close to the optimum is good with FLUKES. The first histogram is for the initial layout which is generated randomly. This means any one of them also could be the optimum solution for the problem. As shown in the figures, the mean value of final objective function is lower than the minimum value of the randomly generated initial layouts.

In the next figure, two plotted graphs are provided. The first one is the plot of initial objective function values versus the final objective function values. This plotting is done to examine the performance of FLUKES to see whether the solution value is highly dependent on the value of initial layout. For instance, if an initial layout with high objective function value still has the high objective function value in the final layout, then it means the performance of the system is not good. As shown in the graph, there is no significant evidence that the objective function values of the final layout depend on the objective function values of the initial layout.

The second plot in the same figure is the plot of the objective function values versus the material handling cost of the final layout. This plotting is done to see whether the material handling cost dominates the total objective function value. The plot shows that the domination of material handling cost diminishes as the value of the penalty increases.

A summary of the five different examples is provided in Table 10. There is some indication that CPU time and the number of iteration are reduced with an increase of penalty values. Roughly speaking, the objective function value of final layout is reduced by 40% of the objective function value of initial layout.

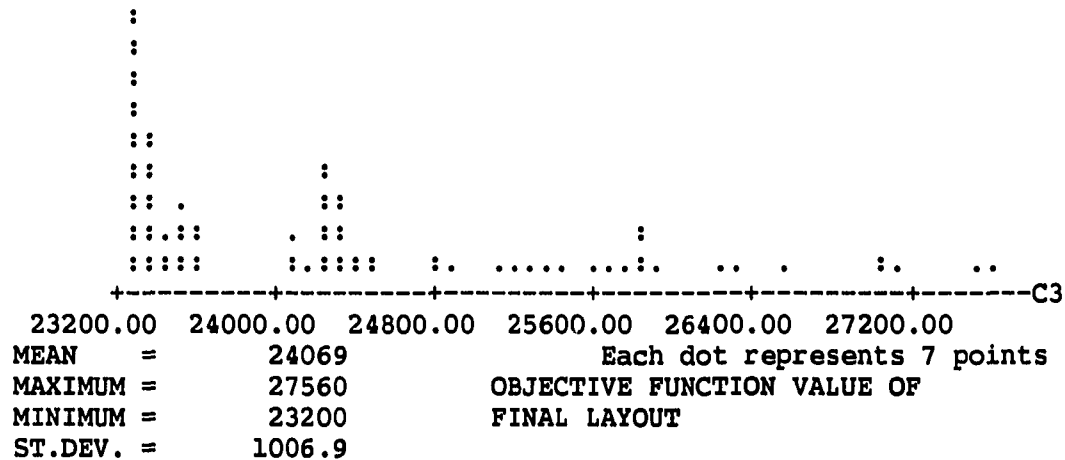
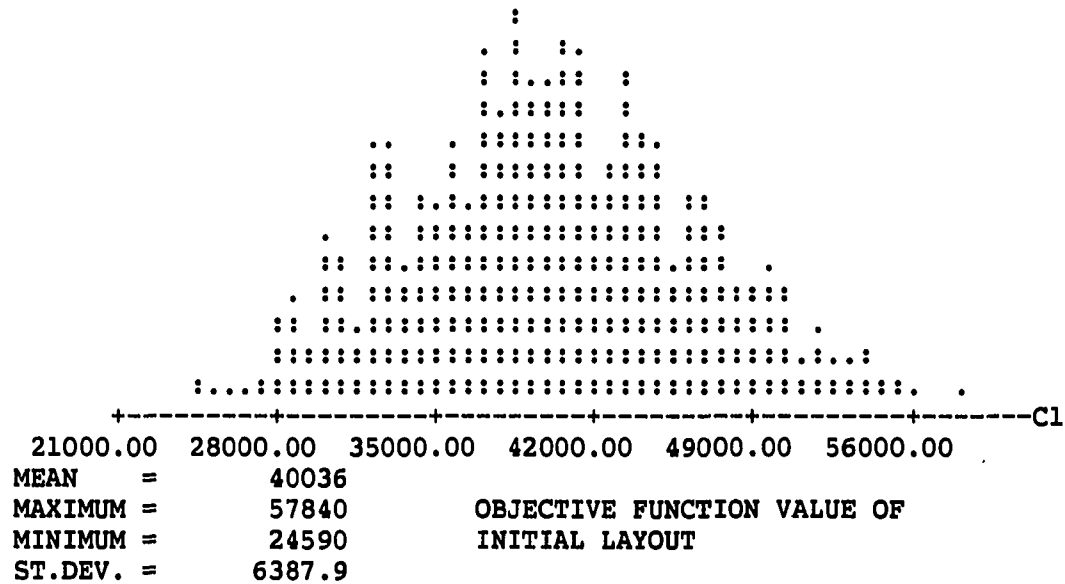


FIGURE 26. Histogram of objective function values - Example 1

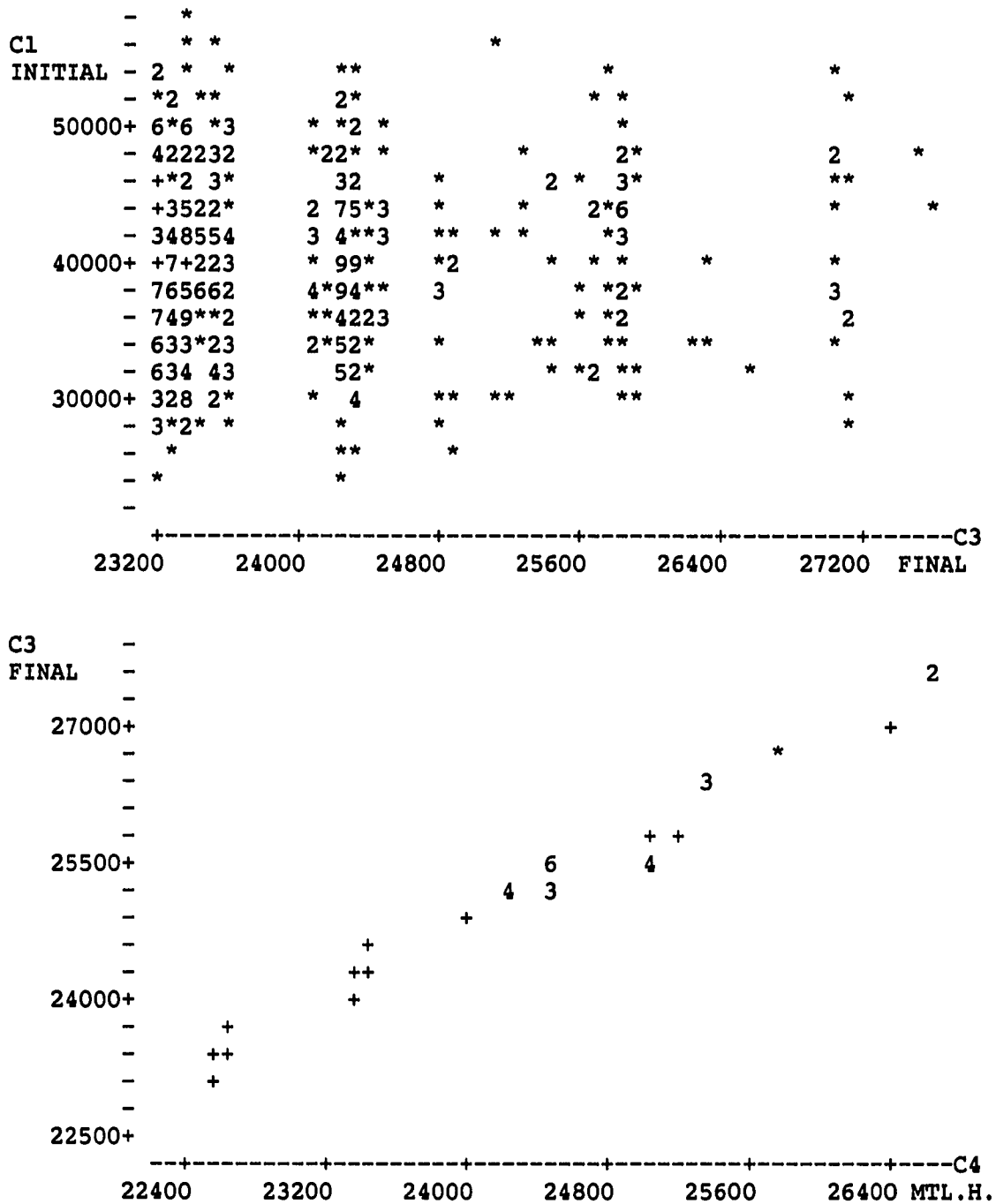


FIGURE 27. Plot of objective function values - Example 1

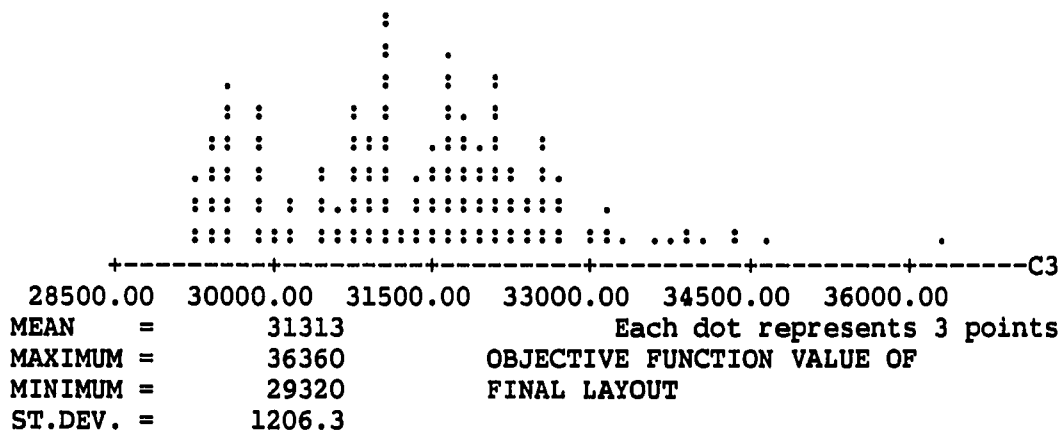
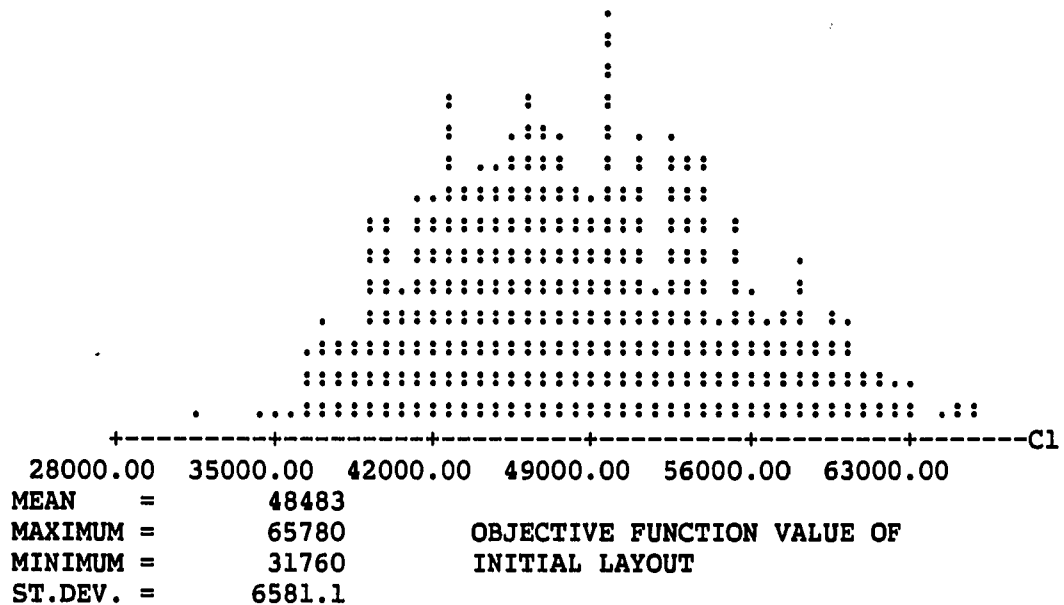


FIGURE 28. Histogram of objective function values - Example 2

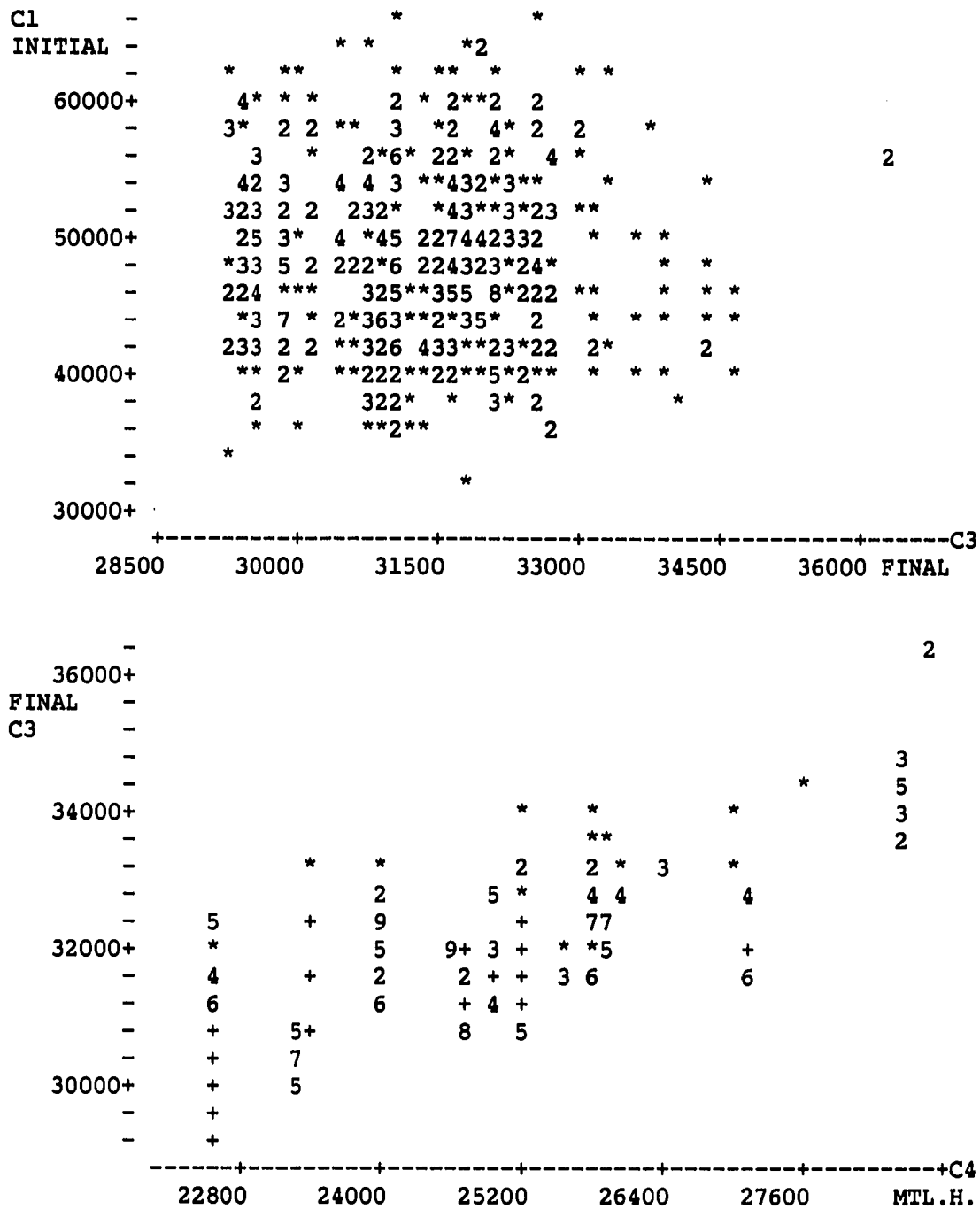


FIGURE 29. Plot of objective function values - Example 2

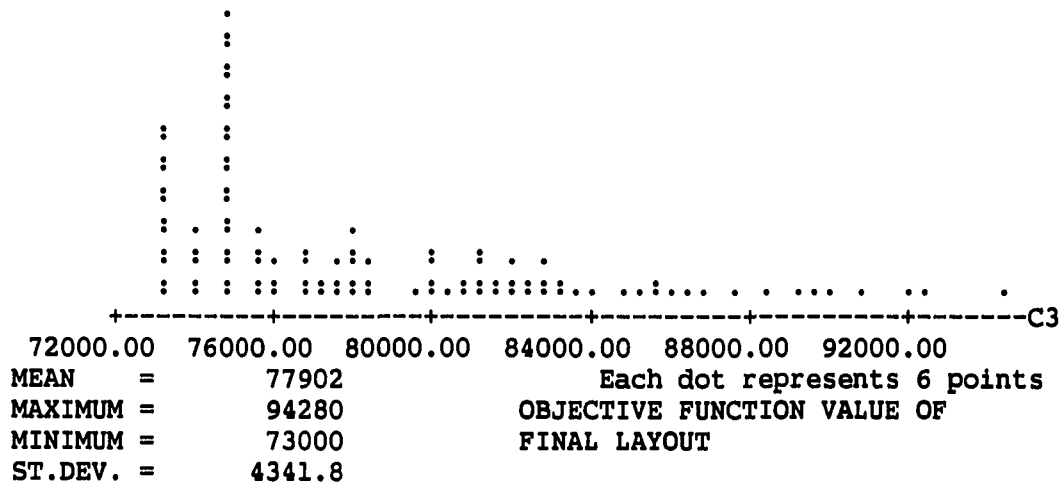
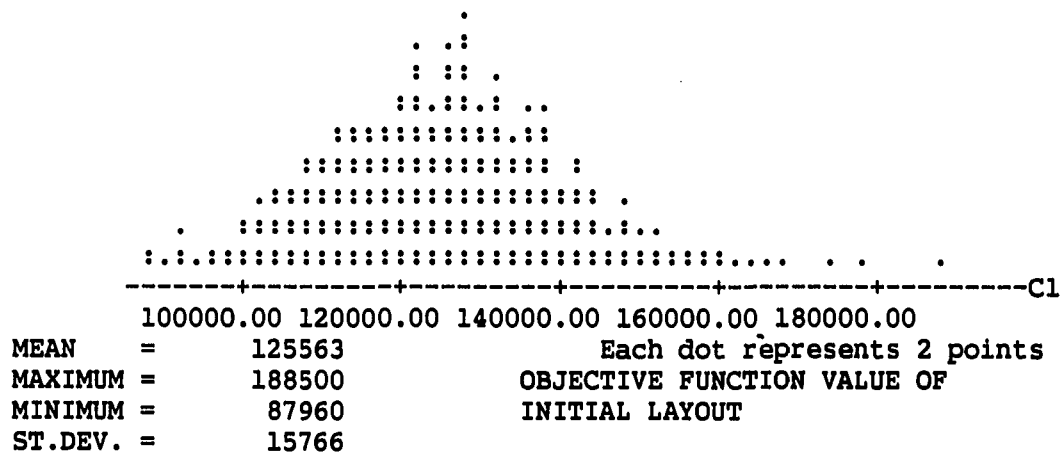


FIGURE 30. Histogram of objective function values - Example 3

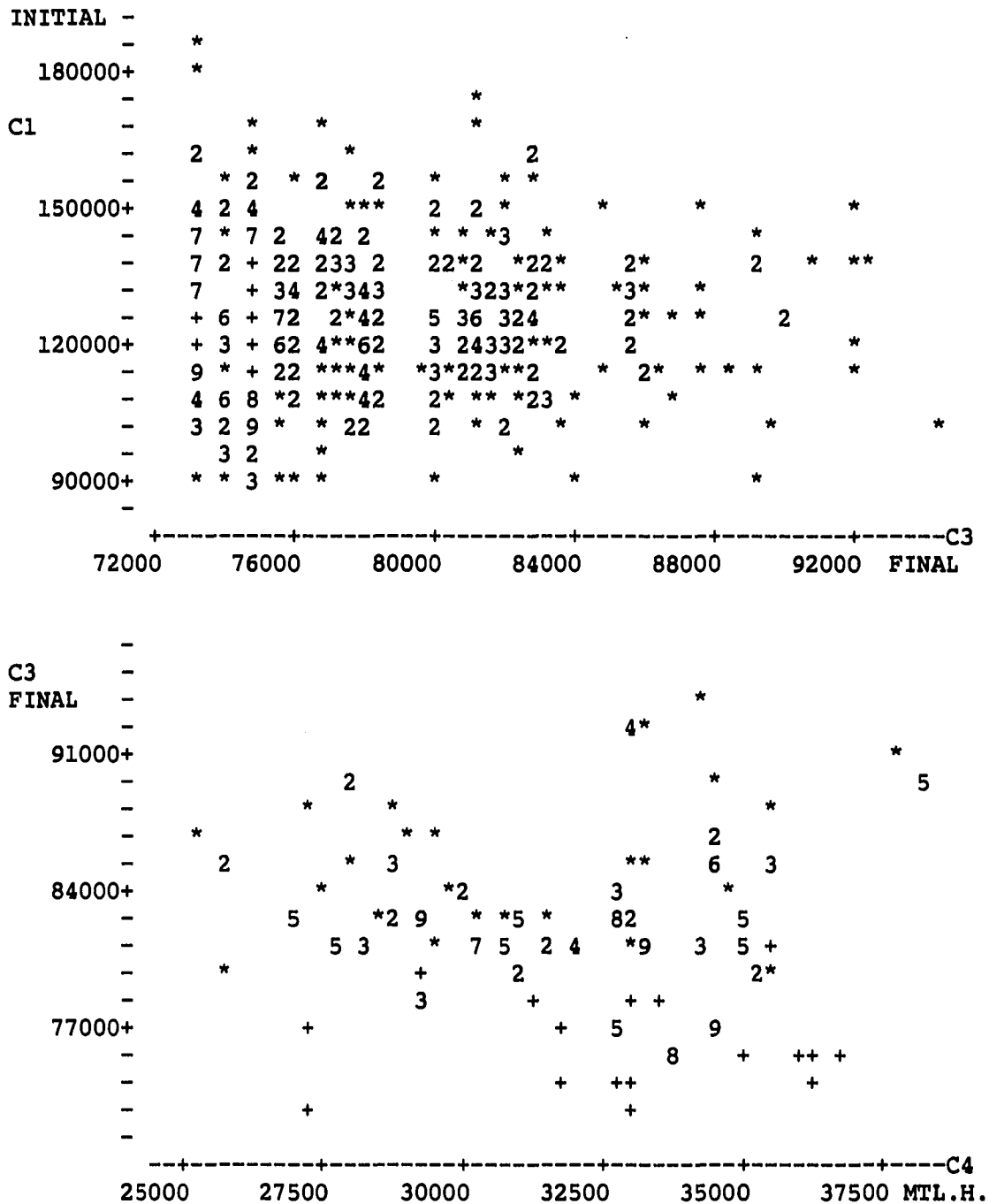


FIGURE 31. Plot of objective function values - Example 3

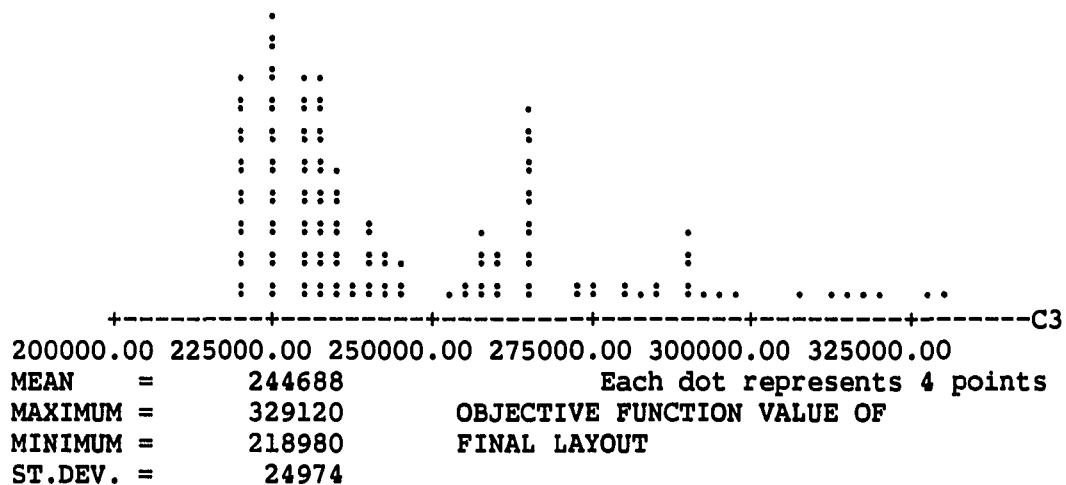
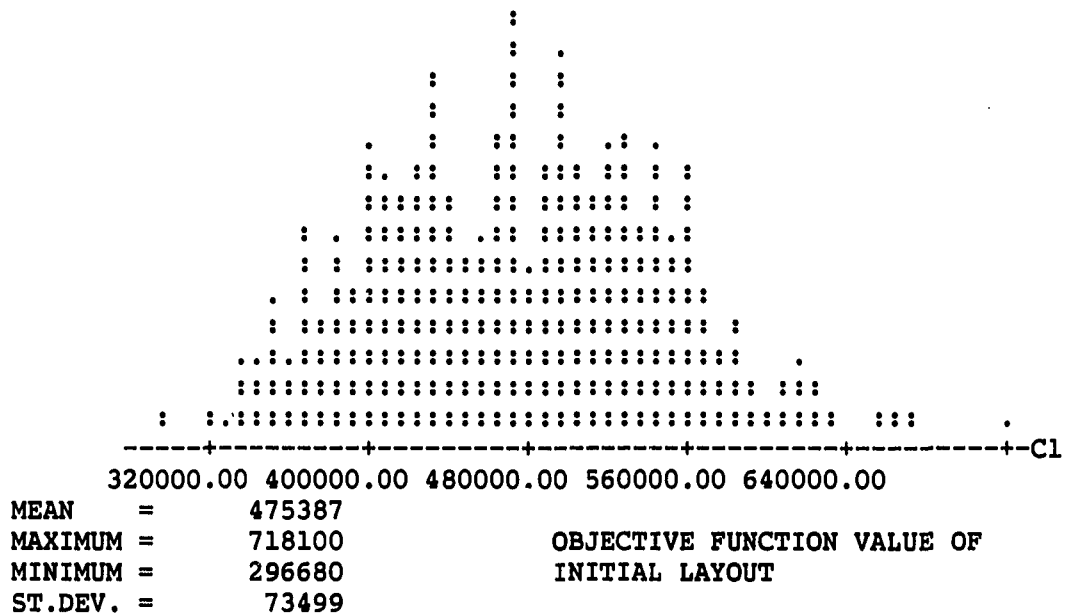


FIGURE 32. Histogram of objective function values - Example 4

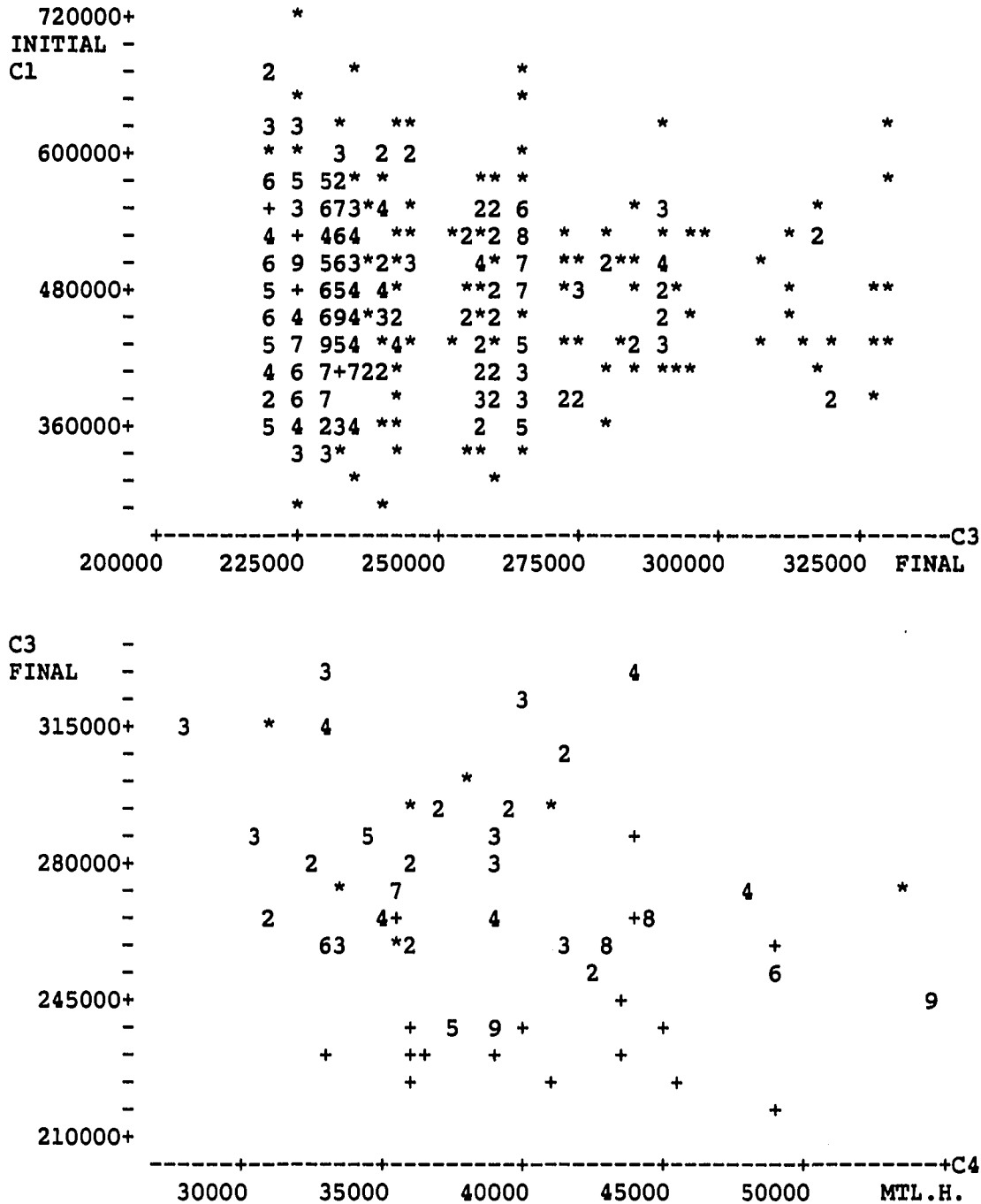


FIGURE 33. Plot of objective function values - Example 4

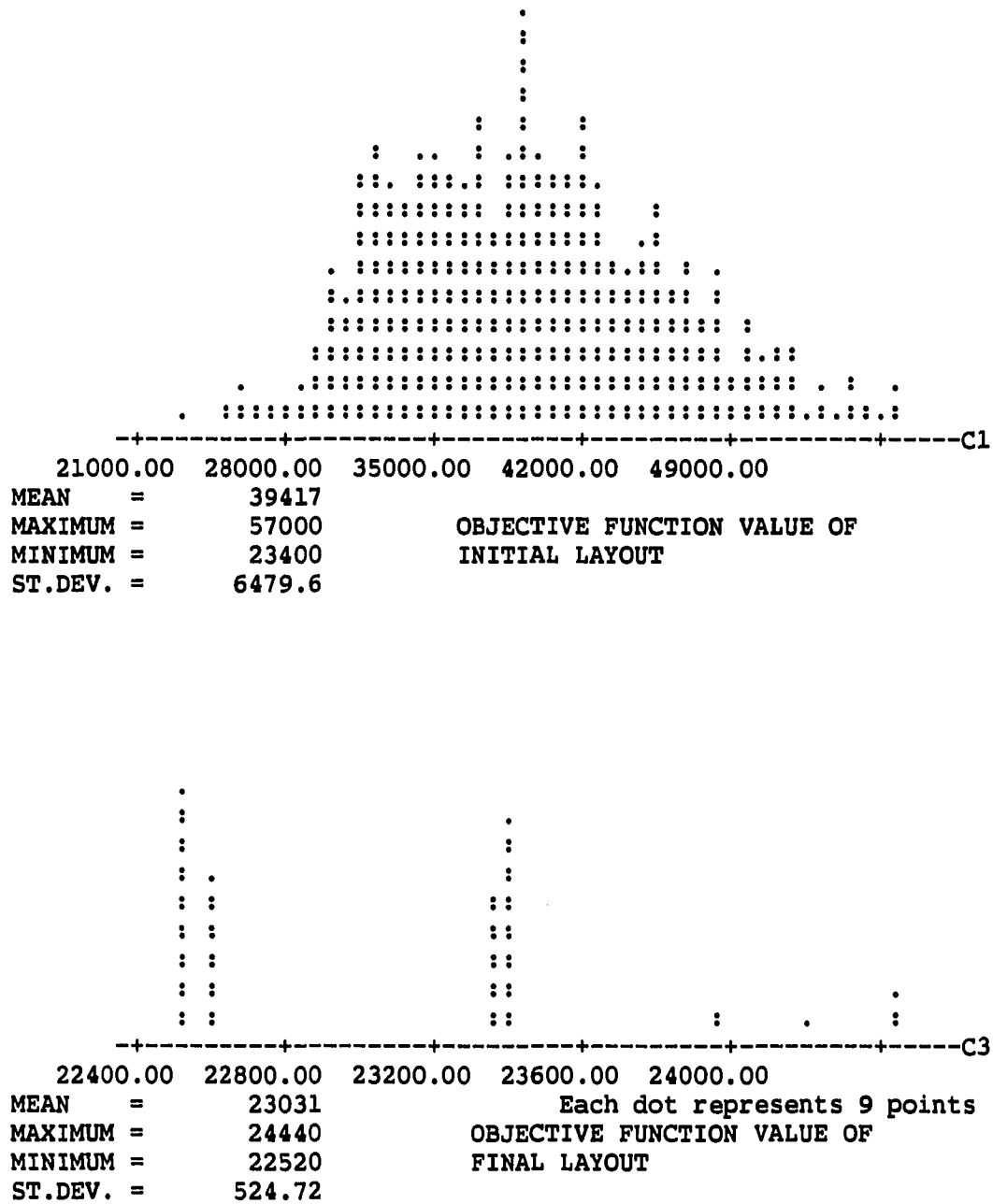


FIGURE 34. Histogram of objective function values - Example 5

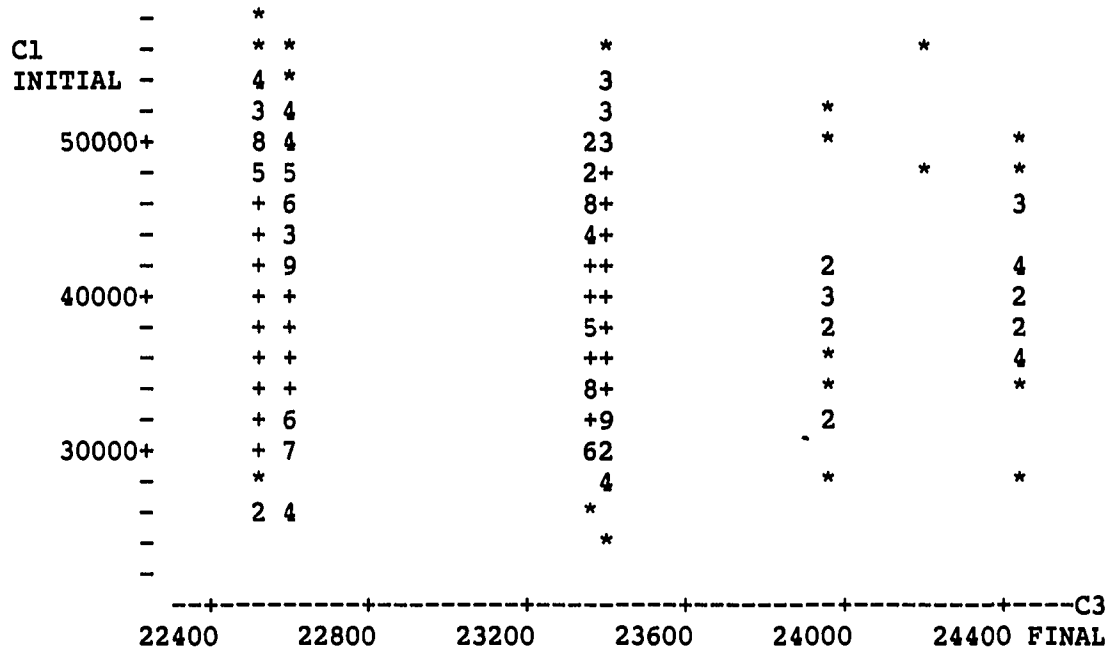


FIGURE 35. Plot of objective function values - Example 5

TABLE 10. Summary table of case 1

Description		Example 1	Example 2	Example 3	Example 4	Example 5
Mean	Init.	40036	48483	125563	475387	39417
	Final	24069	31313	77902	244688	23031
OBJ. Max	Init.	57840	65780	188500	718100	57000
	Final	27560	36360	94280	329120	24440
Min	Init.	24590	31760	87960	296680	23400
	Final	23200	29320	73000	218980	22520
STD	Init.	6388	6581	15766	73499	6480
	Final	1007	1207	4342	24974	525
CPU time		6.23	5.92	4.63	4.12	9.59
Iteration		9.20	9.11	8.92	9.01	13.62
Removed department		27.97	26.83	21.59	21.04	40.85
Trial switches		139.38	131.22	95.36	90.57	203.31

Case 2

The purpose of this experiment is to test the performance of FLUKES when the shape of a department is in handling. The initial layout is modified by exchanging the position of two departments and then adjusting the shape of each department. Fifty-one experimental initial layouts were generated. During the experiments, two different penalty values and three different acceptable shape rates are used. Therefore, a total of six different histograms and plots are provided.

The differences from the experiment of case 1 can be found in examples 1, 3, 4, and 6. Examples 2 and 5 use an acceptable shape rate of 0.6. The others use acceptable shape rate 0.4 and 0.8. It can be seen from histogram C3 in Figure 36, that the objective function values of the final layout, are not following the exponential trend. Here, thirty out of fifty-one contained irregular shape of departments in final layouts. Six out of thirty are not bad and can be fixed without changing the layout configuration much, but rest of them are not. Therefore, an acceptable shape rate of 0.4 is not recommended due to shape violation. Another noticeable trend is in the plot of final objective function values and the material handling costs. In the first three examples, lower penalties were used. Therefore, material handling cost dominates the total objective function values.

The second example is done with an acceptable shape rate of 0.6. Four out of fifty-one showed irregularly shaped departments, but in three of those four problems are minor. Only one example case

generated a bad layout with when the acceptable shape rate was chosen to be 0.6.

The noticeable trend in example 3 of Figure 41 is that the final layout is not independent from the initial layout. The reason can be easily guessed from the small number of iteration and the short execution time. Using an acceptable shape rate of 0.8 was too restrictive and most of the suggested new layouts were rejected.

Examples 4, 5, and 6 are not much different from the examples 1, 2, and 3. Most of them are the same except in the plot of objective function value versus material handling cost. The penalty values are higher than in the case of 1, 2, or 3. Therefore, the objective function value versus material handling cost does not show a trend as strong as in the other cases.

Comparison with CRAFT

The experiments in case 2 also provide information for a comparison study with CRAFT. Outputs from FLUKES and CRAFT are given in Figure 48. As shown in this example, the comparison does not have much meaning. The only objective function CRAFT is concerned with is the material handling cost. Therefore, it never considered the shape of departments and never considered the factors that FLUKES used.

It is natural that the material handling cost arrived by CRAFT is lower than the material handling cost obtained by FLUKES. The lower material handling cost indicates that the solution is violating some

Histogram of C1 N = 51 OBJECTIVE FUNCTION VALUE OF
INITIAL LAYOUT

Midpoint	Count	
110000	2	**
115000	4	****
120000	11	*****
125000	5	*****
130000	3	***
135000	6	*****
140000	7	*****
145000	3	***
150000	2	**
155000	5	*****
160000	1	*
165000	1	*
170000	1	*

MEAN	=	133404
MAXIMUM	=	169839
MINIMUM	=	109870
ST.DEV.	=	15262

Histogram of C3 N = 51 OBJECTIVE FUNCTION VALUE OF
FINAL LAYOUT

Midpoint	Count	
75000	1	*
80000	2	**
85000	5	*****
90000	8	*****
95000	17	*****
100000	12	*****
105000	4	****
110000	1	*
115000	1	*

MEAN	=	94962
MINIMUM	=	75536
MAXIMUM	=	113873
ST.DEV.	=	7139.9

FIGURE 36. Histogram of objective function values - Example 1

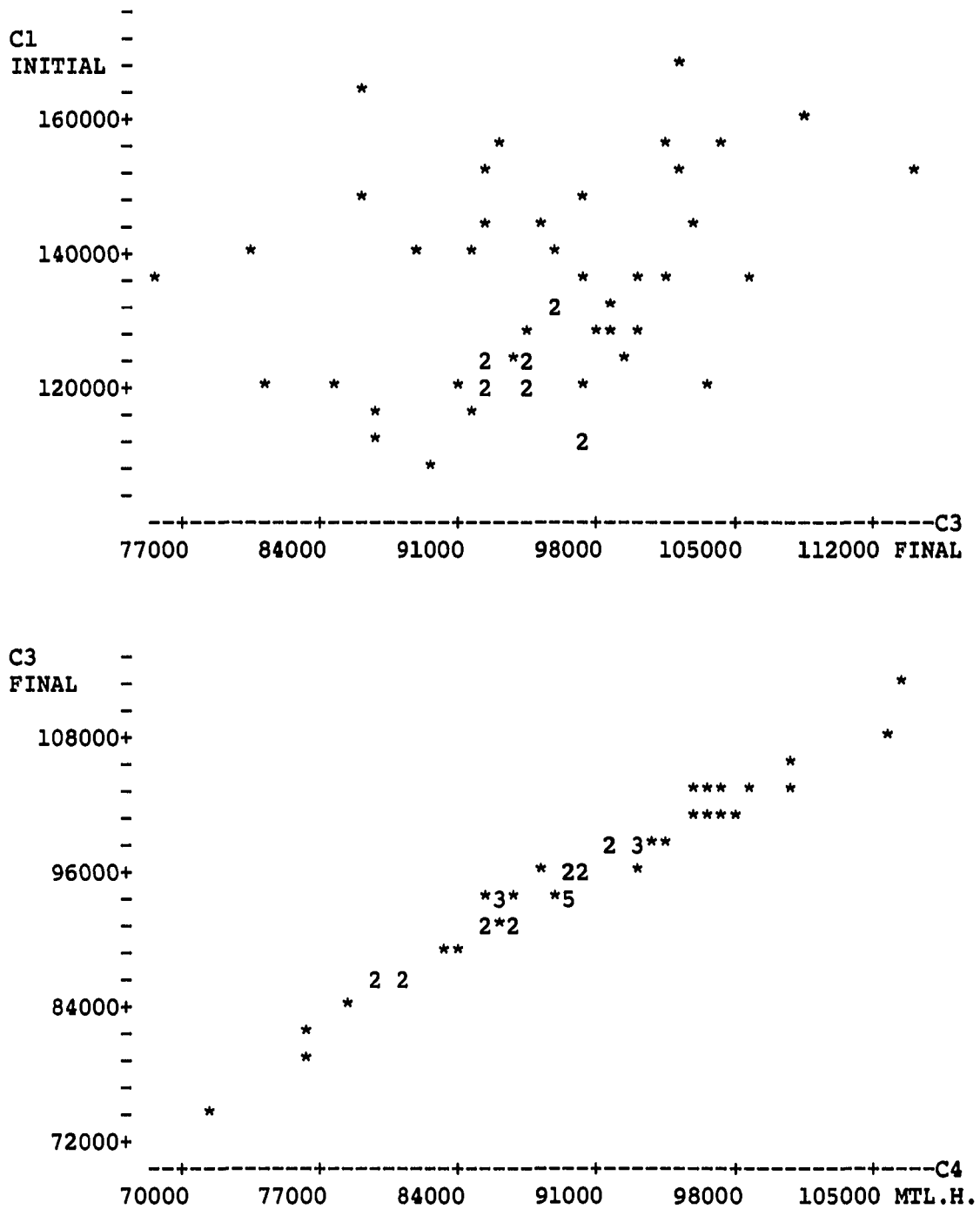


FIGURE 37. Plot of objective function values - Example 1

Histogram of C1 N = 51 OBJECTIVE FUNCTION VALUE OF
INITIAL LAYOUT

Midpoint	Count	
110000	2	**
115000	4	****
120000	11	*****
125000	5	*****
130000	3	***
135000	6	*****
140000	7	*****
145000	3	***
150000	2	**
155000	5	*****
160000	1	*
165000	1	*
170000	1	*

MEAN	=	133404
MAXIMUM	=	169839
MINIMUM	=	109870
ST.DEV.	=	15262

Histogram of C3 N = 51 OBJECTIVE FUNCTION VALUE OF
FINAL LAYOUT

Midpoint	Count	
95000	9	*****
100000	3	***
105000	18	*****
110000	11	*****
115000	6	*****
120000	3	***
125000	0	
130000	0	
135000	0	
140000	0	
145000	0	
150000	1	*

MEAN	=	106948
MAXIMUM	=	151901
MINIMUM	=	94410
ST.DEV.	=	9523.8

FIGURE 38. Histogram of objective function values - Example 2

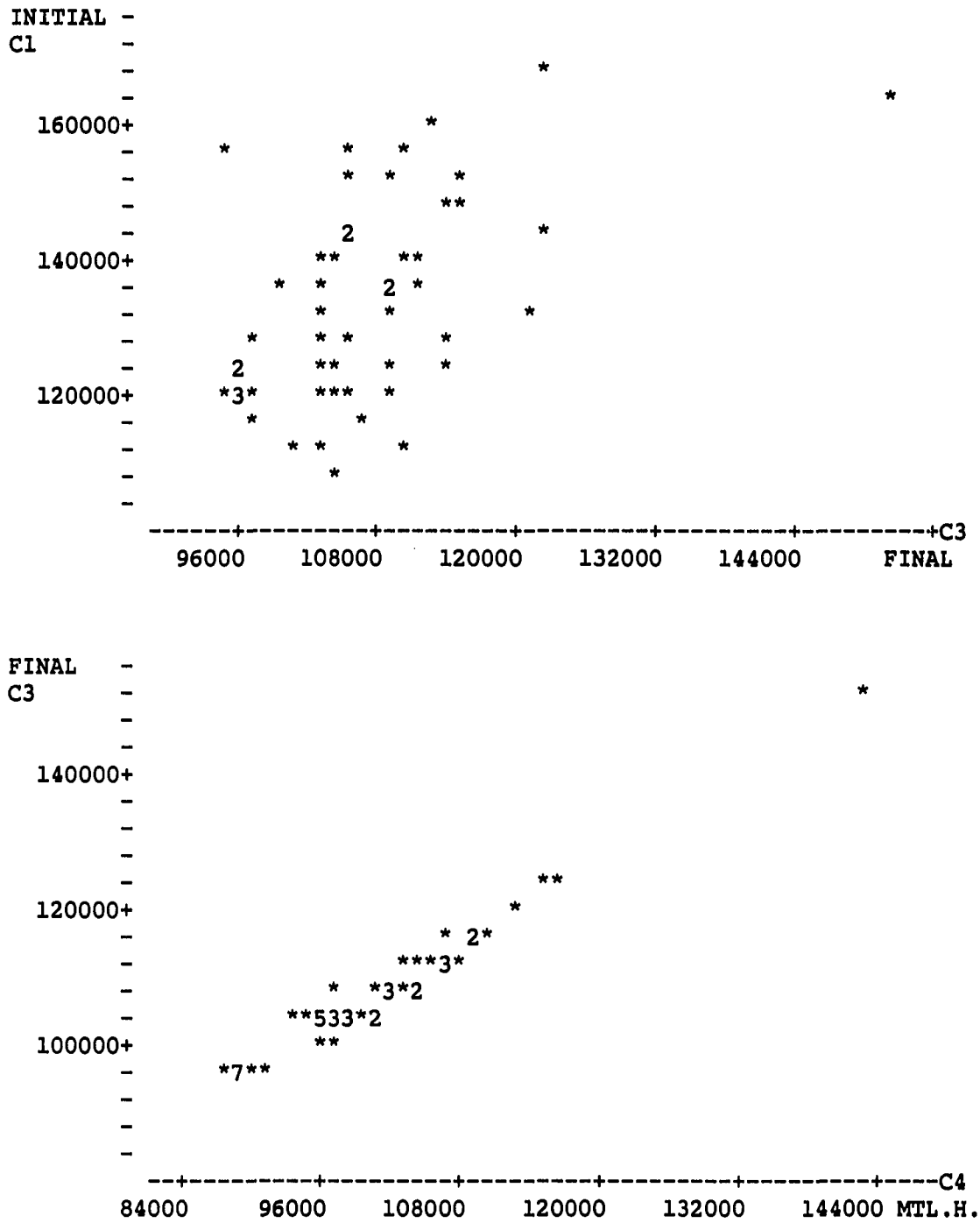


FIGURE 39. Plot of objective function values - Example 2

Histogram of C1 N = 51 OBJECTIVE FUNCTION VALUE OF
INITIAL LAYOUT

Midpoint	Count	
110000	2	**
115000	4	****
120000	11	*****
125000	5	*****
130000	3	***
135000	6	*****
140000	7	*****
145000	3	***
150000	2	**
155000	5	*****
160000	1	*
165000	1	*
170000	1	*

MEAN = 133404
 MAXIMUM = 169839
 MINIMUM = 109870
 ST.DEV. = 15262

Histogram of C3 N = 51 OBJECTIVE FUNCTION VALUE OF
FINAL LAYOUT

Midpoint	Count	
105000	4	****
110000	1	*
115000	8	*****
120000	16	*****
125000	7	*****
130000	4	****
135000	3	***
140000	1	*
145000	3	***
150000	1	*
155000	1	*
160000	0	
165000	2	**

MINIMUM = 105645
 MAXIMUM = 165978
 MEAN = 124872
 ST.DEV. = 13646

FIGURE 40. Histogram of objective function values - Example 3

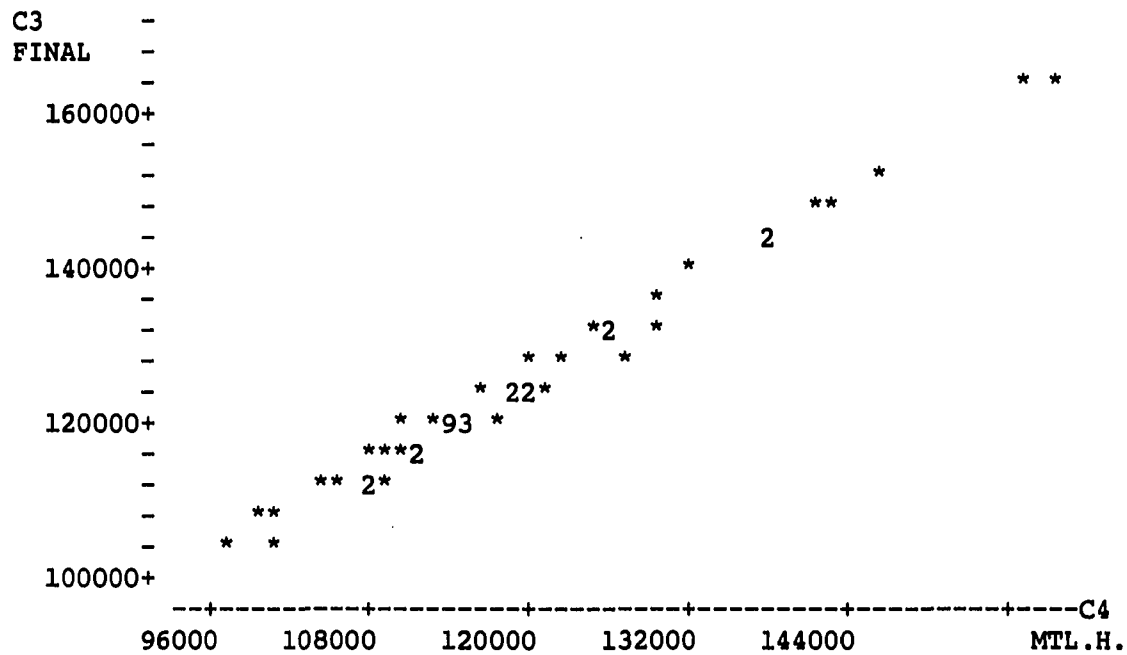
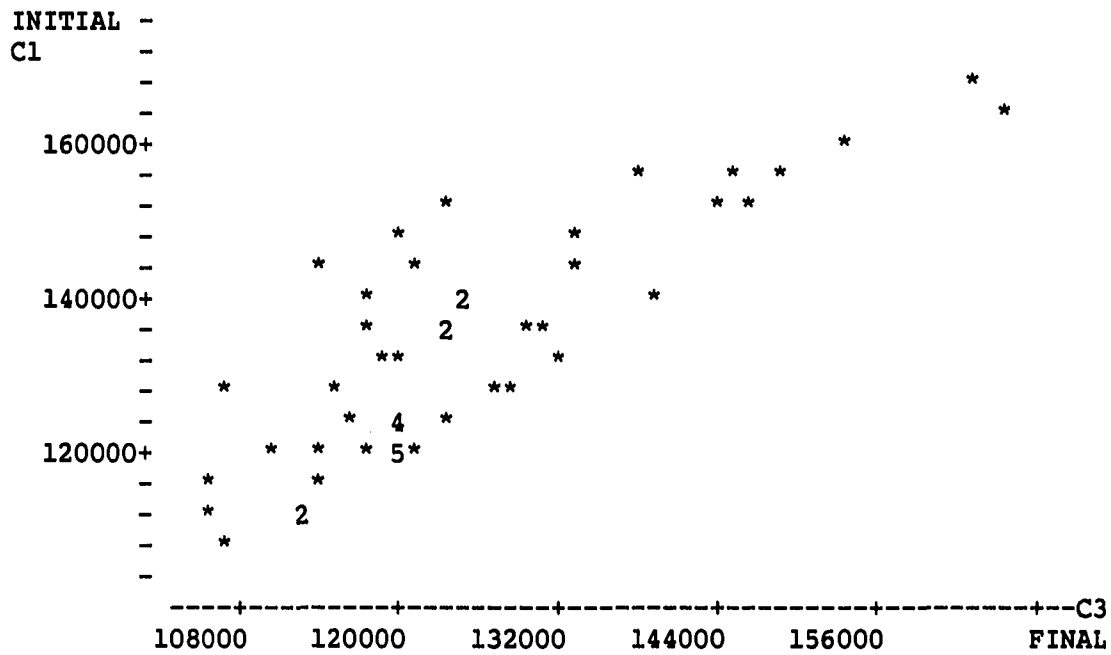


FIGURE 41. Plot of objective function values - Example 3

Histogram of C1 N = 51 OBJECTIVE FUNCTION VALUE OF
INITIAL LAYOUT

Midpoint	Count	
160000	2	**
170000	6	*****
180000	13	*****
190000	10	*****
200000	6	*****
210000	6	*****
220000	4	****
230000	3	***
240000	1	*

MEAN = 193846
 MAXIMUM = 243478
 MINIMUM = 155815
 ST.DEV. = 19103

Histogram of C3 N = 51 OBJECTIVE FUNCTION VALUE OF
FINAL LAYOUT

Midpoint	Count	
90000	1	*
100000	0	
110000	2	**
120000	9	*****
130000	19	*****
140000	16	*****
150000	2	**
160000	1	*
170000	0	
180000	0	
190000	1	*

MINIMUM = 90976
 MAXIMUM = 191316
 MEAN = 132691
 ST.DEV. = 13829

FIGURE 42. Histogram of objective function values - Example 4

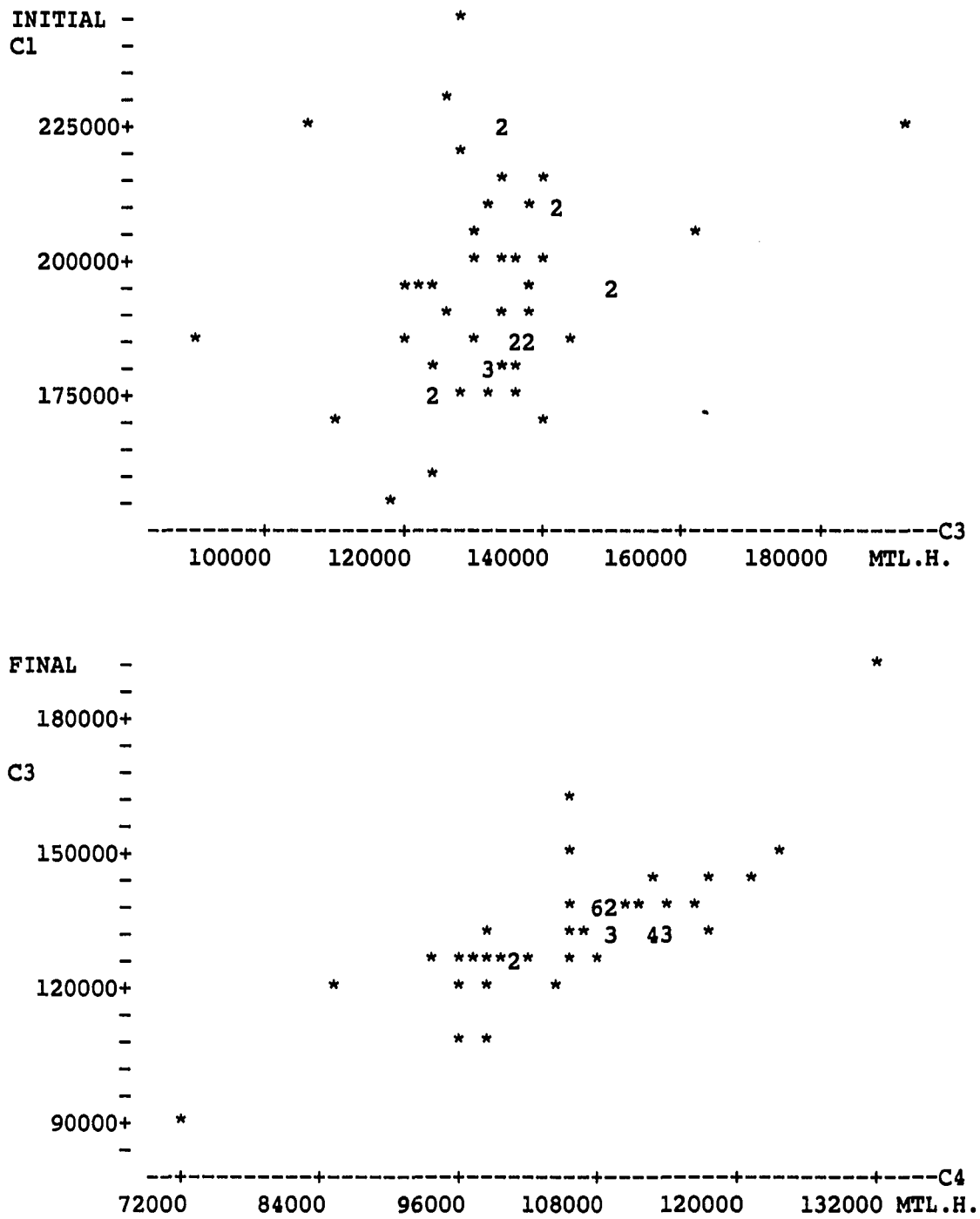


FIGURE 43. Plot of objective function values - Example 4

Histogram of C1 N = 51 OBJECTIVE FUNCTION VALUE OF
INITIAL LAYOUT

Midpoint	Count	
160000	2	**
170000	6	*****
180000	13	*****
190000	10	*****
200000	6	*****
210000	6	*****
220000	4	****
230000	3	***
240000	1	*
MEAN	=	193846
MAXIMUM	=	243478
MINIMUM	=	155815
ST.DEV.	=	19103

Histogram of C3 N = 51 OBJECTIVE FUNCTION VALUE OF
FINAL LAYOUT

Midpoint	Count	
130000	8	*****
140000	10	*****
150000	13	*****
160000	9	*****
170000	7	*****
180000	3	***
190000	0	
200000	0	
210000	0	
220000	1	*
MEAN	=	152823
MINIMUM	=	126697
MAXIMUM	=	216100
ST.DEV.	=	16296

FIGURE 44. Histogram of objective function values - Example 5



Histogram of C1 N = 51 OBJECTIVE FUNCTION VALUE OF
INITIAL LAYOUT

Midpoint	Count	
160000	2	**
170000	6	*****
180000	13	*****
190000	10	*****
200000	6	*****
210000	6	*****
220000	4	****
230000	3	***
240000	1	*

MEAN	=	193846
MAXIMUM	=	243478
MINIMUM	=	155815
ST.DEV.	=	19103

Histogram of C3 N = 51 OBJECTIVE FUNCTION VALUE OF
FINAL LAYOUT

Midpoint	Count	
150000	4	****
155000	4	****
160000	4	****
165000	4	****
170000	8	*****
175000	11	*****
180000	0	
185000	3	***
190000	4	****
195000	4	****
200000	2	**
205000	0	
210000	3	***

MEAN	=	174834
MINIMUM	=	149815
MAXIMUM	=	210215
ST.DEV.	=	16483

FIGURE 46. Histogram of objective function values - Example 6

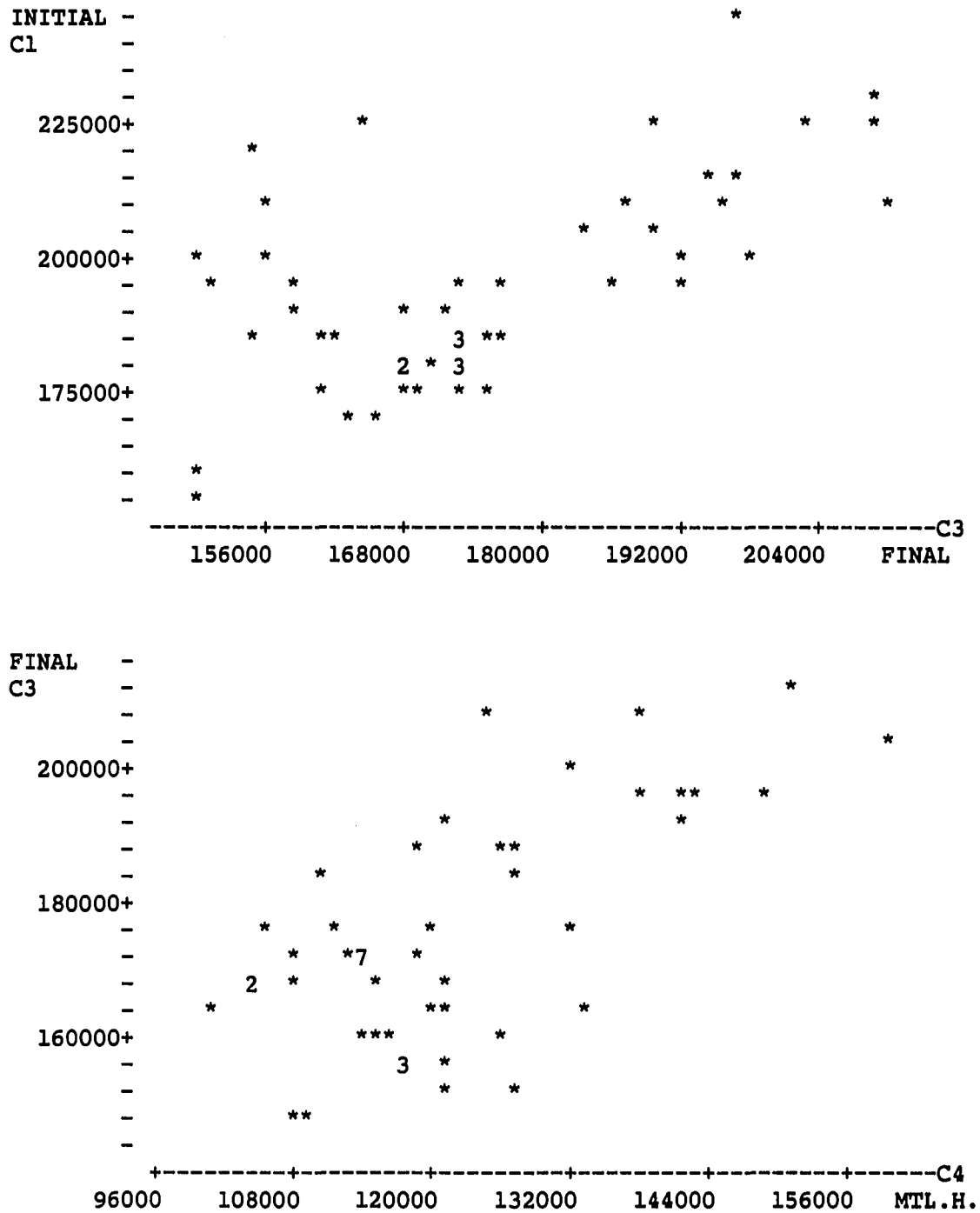


FIGURE 47. Plot of objective function values - Example 6

TABLE 11. Summary table of case 2

Description			Example 1	Example 2	Example 3
OBJ. FN.	Mean	Init.	133404		
		Final	94962	106948	124872
	Max	Init.	169839		
		Final	113873	151901	165978
	Min	Init.	109870		
		Final	75536	94410	105645
	STD	Init.	15262		
		Final	7340	9524	13646
CPU time			18.81	12.48	4.56
Iteration			10.78	7.43	1.90
Removed department			61.14	48.55	22.16
Trial switches			158.22	126.53	57.29

Description			Example 4	Example 5	Example 6
OBJ. FN.	Mean	Init.	193846		
		Final	132691	152823	174834
	Max	Init.	243478		
		Final	191316	216100	210215
	Min	Init.	155815		
		Final	90976	126697	149815
	STD	Init.	19103		
		Final	13829	16296	16483
CPU time			11.15	8.68	4.55
Iteration			8.55	5.63	1.84
Removed department			37.57	32.08	21.96
Trial switches			94.77	83.53	56.61

other constraints which can not be minimized together with the material handling costs. For example, user preference, expansion plan, noise control, and so on.

The example shown in Figure 48 was done earlier than the case 2 experiments. Examples 4, 5, and 6 used the same penalty values as the example in Figure 48. The examples 4, 5, and 6 generated the mean values of the final objective functions as 132,691, 152,823, and 174,834, respectively. The objective function value of 132,691 had been achieved in the example of 4, but 24 out of 51 of the final layouts included irregular shaped departments. Therefore, example 5 is more reasonable to use here for comparison. The mean value 152,823 is little bigger than the one used in this figure, but certainly it is not the best one. The minimum value shown here is 126,697.

The total objective function values from FLUKES and CRAFT are not much different; however, there is no guarantee that CRAFT will make same quality output again with any given problems. CRAFT does not consider any constraints except material handling costs. Therefore, important constraints which do not match with material handling cost will be violated.

Another point to mention here is the shape of department 'L' in the Figure 48. That is hard to fix without changing the current layout configuration. The department 'J' or 'G' may need to be moved around 'L' to fix the problem. Therefore, the total configuration must be changed and the objective function value is not going to be as good as this current layout. Assigning a penalty to the irregular shape for comparison may not be practical since the layout configuration with irregular shape department is not usable at all.

```

1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6
1 A A A A A A A H H H J J J I I I
2 A           A A H   H J   J I   I
3 A           A F H   H J J J I   I
4 A           A F H H H E E E E I   I
5 A           A F F H H E   E I   I
6 A A A A A A A F F H H E   E I I I
7 B B B B B B F F H E E E E E K K K
8 B           B B F F L L L L L L K K
9 B           B G G F L           L L L
0 B           B G G G L           L
1 B B B B B B G G G L           L
2 D D D D C L L L L L L L L L L L
3 D   D C C C L L L L M M M M M M
4 D   D C   C M M M M M           M
5 D   D C   C M           M           M
6 D D D C C C M M M M M M M M M M

```

(a) FLUKES output

```

1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6
1 A A A A A A A A L L L J J J I I I
2 A           A A L   L J   J I   I
3 A           A L L   L J J J I   I
4 A           A L L L L L L L I   I
5 A           A G G G L           L I   I
6 A A A A A A A G G G L           L I I I
7 B B B B B B G G L L           L K K K
8 B           B B C C L           L L L K K
9 B           B C C C L           L H H H H
0 B           B C   C L L L L H           H
1 B B B B B B C C C L F F F H           H
2 D D D D E C C F F F F H H H H H H
3 D   D E E E F F F F M M M M M M M
4 D   D E   E M M M M M           M
5 D   D E   E M           M           M
6 D D D E E E E M M M M M M M M M M

```

(b) CRAFT output

DESCRIPTION	COEFCNT	FLUKES	CRAFT
MTL HANDLNG	1	- \$ 111774.36	- \$ 87756.28
USER PREFRC	2000.0	0 0.00	2 4000.00
EXPANS PLAN	6000.0	1 6000.00	1 6000.00
NOISE CNTRL	7000.0	1 7000.00	2 14000.00
VIBRATION C	8000.0	0 0.00	1 8000.00
EXPLOSION C	10000.0	0 0.00	0 0.00
DANGER-EQUP	9000.0	0 0.00	1 9000.00
VENT. EQUIP	8000.0	0 0.00	0 0.00
AIR-COMPRES	4000.0	3 12000.00	4 16000.00
POWER-FACIL	2000.0	2 4000.00	2 4000.00
WATER-FACIL	6000.0	0 0.00	0 0.00
DOOR-EXIT C	6000.0	1 6000.00	1 6000.00
HEAT CONTRL	3000.0	0 0.00	0 0.00
ENERGY CRDT	1000.0	0 0.00	0 0.00
OBJECTIVE FUNCTION		146774.36	154756.28

FIGURE 48. Comparisons of FLUKES and CRAFT

CONCLUSIONS AND FUTURE WORK

The main objective of this research was to develop a new method to solve facility layout problem with practical objectives and constraints. The organization of layout knowledge and a way of breaking the combinatorial explosion with practical restrictions were expected to be accomplished through the development of this method. In the following sections the performance of FLUKES and some of the remaining problems are summarized.

Summary

The major differences between FLUKES and the other computer-aided layout technique, CRAFT, can be summarized by two points. One is on the number of factors considered through the course of layout, and the other is the method used to make improvements in facility layout. CRAFT considers material handling cost as the single most important factor in layout, while FLUKES considers architectural limitations, safety, user preferences, utilities, activity relationships, expansion plans, and the basic skeleton of departments in addition to the material handling cost. These factors are not only used in the calculation of objective functions, but also in the way of department interchanges in FLUKES. Instead of considering the department interchange in numeric order such as 1 and 2, 1 and 3, 1 and 4, ..., FLUKES interchanges departments based on the violation of soft constraints. It removes a department which violates the highest

penalty constraint first, and then finds replacement. As discussed in the last chapter, it can be concluded that this method works well.

It is very hard to compare FLUKES and CRAFT. As shown in Figure 48 in the last chapter, the value of objective function can not be used for comparison purpose because the output from CRAFT includes one irregularly shaped department. Any layouts which include irregularly shaped department are not usable in the real world, and are not accepted by FLUKES. Many realistic constraints conflict with the minimization of the material handling cost. Therefore, any layout routine which tries to minimize material handling cost alone will violate some other unknown, but important constraints to minimize its objective function. A summary table of advantages and disadvantages is provided in Table 12.

The factors considered by FLUKES are classified into two different groups, i.e., the hard constraint group and the soft constraint group. The constraints in the hard group must not be violated while those in soft group can be. Therefore, FLUKES uses the constraints in the hard group to reject many of the unrealistic layout alternatives from the consideration. It helps FLUKES to find a realistic solution while reducing the number of iterations.

The addition of knowledge to the system, especially in the hard constraint group, can not be used to guarantee the 'optimum,' but it will be helpful to break the combinatorial explosion. The layout knowledge used in this research was taken only from literature, not

TABLE 12. Advantages and disadvantages

	CRAFT-like	FLUKES
ADV.	1. Simple, no need to supply data for all others	1. overall optimum 2. practically acceptable layout 3. reduced number of alternatives
DIS ADV.	1. any practical limitation will be violated if they conflict with objective function 2. more alternatives which may not be practical solutions	1. need to supply more data which are hard to configure 2. reducing alternatives can be closing the way to reach optimum in exchange heuristic

from the field experts, but it was good enough to show the way of layout development with practical factors in consideration.

Combinatorial explosion appears in a many situations like in the assignment problem, traveling salesman problem, scheduling problem, and so on. The facility layout problem is the one such situation focused in this research. However, the basic idea of FLUKES may work well with any other problems.

Remaining Problems

The design of a method for department shape recognition is one of the largest remaining problems in this research. Finding more constraints could be an interesting research topic for further extension, but shape recognition would be more valuable. A method for shape adjustment or minor department moving can be accomplished as soon as shape recognition becomes possible. The major limitation of FLUKES is in the way it finds a replacement for a removed department among same sized or neighboring departments only. This painful limitation is caused by the difficulty involved in shape recognition and adjustment as discussed before. Making it possible to interchange any two departments will greatly improve the performance of FLUKES.

The problem involved with department shape is very interesting. Solving the furniture layout problem done in the area of computer science is not worse than solving the department layout problem from the combinatorial explosion point of view. Furniture is solid and never changes its shape, while department can be changed to any shape as long as it meets some critical restrictions as discussed. The combinatorial explosion could be even worse in this type of problem since changing the shape of one department may require changing the shapes of several other departments.

Another problem to mention is the value of coefficient used in the objective function. As mentioned in the CRAFT modified example, various values may be used to find a better looking layout. In this

research, the coefficients were roughly guessed values for calculating the dollar amounts of constraint violation in comparison with material handling cost.

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APPENDIX A. AN EXAMPLE PROBLEM

[Initial Layout]

```

7 7 7 1 1 1 1 3 3 3 9 9 9 9 9
7 7 7 1 1 1 1 3 3 3 9 9 9 9 9
7 7 1 1 1 1 1 3 3 3 9 9 9 9 9
1 1 1 1 1 1 1 3 3 8 8 8 10 10 10
1 1 1 1 1 1 1 3 8 8 8 8 10 10 10
1 1 1 1 1 1 1 3 8 8 8 8 10 10 10
2 2 2 2 2 2 1 1 8 8 8 8 11 11 11
2 2 2 2 2 2 6 6 12 12 12 12 12 11 11
2 2 2 2 2 6 6 6 12 12 12 12 12 12 12
2 2 2 2 2 6 6 6 12 12 12 12 12 12 12
2 2 2 2 2 6 6 6 12 12 12 12 12 12 12
4 4 4 4 5 12 12 12 12 12 12 12 12 12 12
4 4 4 5 5 5 12 12 12 12 13 13 13 13 13
4 4 4 5 5 5 13 13 13 13 13 13 13 13 13
4 4 4 5 5 5 13 13 13 13 13 13 13 13 13
4 4 4 5 5 5 13 13 13 13 13 13 13 13 13

```

[Availability of Utilities]

Compressed Air

```

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 1 1 0 0 0 1 1 0 0 0 1 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0
0 0 0 0 1 1 0 0 0 1 1 0 0 0 1 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

```

Power

```

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 1 1 0 0 0 1 1 0 0 0 1 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0
0 0 0 0 1 1 0 0 0 1 1 0 0 0 1 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

```


Ventilation

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	1	1	0	0	0	1	1	0	0	1	1	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	1	1	0	0	0	1	1	0	0	1	1	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	1	1	0	0	0	1	1	0	0	1	1	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	1	1	0	0	0	1	1	0	0	0	1	1	0

[Flow Data]

[illegible]

[Cost]

	1	2	3	4	5	6	7	8	9	10	11	12
1	0	3	1.5	0	0	0	0	0	0	0	0	0
2	0	0	1.2	1	0	0	0	0	0	0	0	0
3	0	1	0	1.2	0	1.1	0	0	0	0	0	0
4	0	0	0	0	2.1	0	0	0	0	0	0	0
5	0	0	0	0	0	1.8	1.5	0	0	0	0	0
6	0	0	0	0	0	0	1	1	0	1.2	0	0
7	0	0	0	0	0	1	0	0	0	1	0	2.4
8	0	0	0	0	0	0	1	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	1.3	2.1
10	0	0	0	0	0	0	0	0	1.7	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	2
12	0	0	0	0	0	0	0	0	0	0	0	0

[Special Requirements]

Dsc. Dept.	1	2	3	4	5
MIN. LENGTH	4	4	2	3	2
NOISE		make	make		protect
MOVING		hard			
VIBRATION		make			protect
EXPLOSION				fume	
HEAT	produce				control
WEIGHT					
VENT. EQUIP	required	required			required
DANGER EQUIP				dang.equip	away
EXIT/DOOR	required				
COMPRESS AIR		required	required	required	
POWER FACLTY		required		required	
WATER FACLTY					

Dsc. Dept.	6	7	8	9	10
MIN. LENGTH	2	2	3	3	2
NOISE		make			
MOVING					
VIBRATION			protect		
EXPLOSION				explosive	
HEAT		produce		control	
WEIGHT					
VENT. EQUIP				required	
DANGER EQUIP		danger	away		
EXIT/DOOR					
COMPRESS AIR		required		required	
POWER FACLTY					
WATER FACLTY				required	required

Dsc. Dept.	11	12	13
MIN. LENGTH	1	4	3
NOISE			protect
MOVING			
VIBRATION			protect
EXPLOSION			
HEAT			control
WEIGHT			
VENT. EQUIP	required		
DANGER EQUIP			
EXIT/DOOR		required	
COMPRESS AIR			
POWER FACLTY			
WATER FACLTY			

USER PREFERN	DEPT 5 and 9 be placed close if possible
" 6 13 "	apart "
" 8 9 "	apart "

[Penalty to Violation]

VIOLATION	PENALTY
USER PREFRC	2000
EXPANS PLAN	6000
NOISE CNTRL	7000
VIBRATION C	8000
EXPLOSION C	10000
DANG. EQUIP	9000
VENT. EQUIP	8000
AIR-COMPRES	4000
POWER-FACIL	2000
WATER-FACIL	6000
DOOR-EXIT C	6000
HEAT CONTRL	3000
ENERGY SAVE	1000

APPENDIX B. AN EXAMPLE OUTPUT FROM FLUKES

=== BLOCK PLAN LAYOUT BY FLUKES ===
 = ACCEPTABLE SHAPE ABOVE 0.70 =

[LOCATION PATTERN AND STATISTICS AT ITERATION 0]
 REMOVED DEPARTMENTS = 0 TRIAL SWITCH = 0

```

7 7 7 1 1 1 1 3 3 3 9 9 9 9 9 9
7 7 7 1 1 1 1 3 3 3 9 9 9 9 9 9
7 7 1 1 1 1 1 3 3 3 9 9 9 9 9 9
1 1 1 1 1 1 1 3 3 8 8 8 8 10 10 10
1 1 1 1 1 1 1 3 8 8 8 8 10 10 10
1 1 1 1 1 1 1 3 8 8 8 8 10 10 10
2 2 2 2 2 2 1 1 8 8 8 8 11 11 11
2 2 2 2 2 2 6 6 12 12 12 12 12 11 11
2 2 2 2 2 6 6 6 12 12 12 12 12 12 12
2 2 2 2 2 6 6 6 12 12 12 12 12 12 12
2 2 2 2 2 6 6 6 12 12 12 12 12 12 12
4 4 4 4 5 12 12 12 12 12 12 12 12 12 12
4 4 4 5 5 5 12 12 12 12 13 13 13 13 13
4 4 4 5 5 5 13 13 13 13 13 13 13 13 13
4 4 4 5 5 5 13 13 13 13 13 13 13 13 13
4 4 4 5 5 5 13 13 13 13 13 13 13 13 13

```

DESCRIPTION	VIOLATION	COEFCNT	SUM
MTL HANDLNG	140193.03	1	\$ 140193.03
USER PREFRC	2	2000.0	4000.00
EXPANS PLAN	1	6000.0	6000.00
NOISE CNTRL	1	7000.0	7000.00
VIBRATION C	1	8000.0	8000.00
EXPLOSION C	0	10000.0	0.00
DANGER-EQUIP	1	9000.0	9000.00
VENT. EQUIP	0	8000.0	0.00
AIR-COMPRES	3	4000.0	12000.00
POWER-FACIL	2	2000.0	4000.00
WATER-FACIL	1	6000.0	6000.00
DOOR-EXIT C	1	6000.0	6000.00
HEAT CNTRL	0	3000.0	0.00
ENERGY CRDT	0	1000.0	0.00

OBJECTIVE FUNCTION	202193.03
--------------------	-----------

DUE TO DANGEROUS EQUIP. -
DEPARTMENT 4 IS REMOVED FOR REPLACEMENT
DEPARTMENT 2 IS SELECTED FOR DEPARTMENT 4
DUE TO UNACCEPTABLE SHAPE -
THE SUGGESTION IS REJECTED - BACKING UP
DEPARTMENT 5 IS SELECTED FOR DEPARTMENT 4
DUE TO UNACCEPTABLE SHAPE -
THE SUGGESTION IS REJECTED - BACKING UP
DEPARTMENT 4 HAS NO REPLACEMENT -PICK ANOTHER
DEPARTMENT 4 IS REMOVED FOR REPLACEMENT
DEPARTMENT 2 IS SELECTED FOR DEPARTMENT 4
DUE TO UNACCEPTABLE SHAPE -
THE SUGGESTION IS REJECTED - BACKING UP
DEPARTMENT 5 IS SELECTED FOR DEPARTMENT 4
DUE TO UNACCEPTABLE SHAPE -
THE SUGGESTION IS REJECTED - BACKING UP
DEPARTMENT 4 HAS NO REPLACEMENT -PICK ANOTHER
DUE TO VIBRATION -
DEPARTMENT 2 IS REMOVED FOR REPLACEMENT
DEPARTMENT 1 IS SELECTED FOR DEPARTMENT 2
DUE TO UNACCEPTABLE SHAPE -
THE SUGGESTION IS REJECTED - BACKING UP
DEPARTMENT 5 IS SELECTED FOR DEPARTMENT 2
DUE TO UNACCEPTABLE SHAPE -
THE SUGGESTION IS REJECTED - BACKING UP
DEPARTMENT 6 IS SELECTED FOR DEPARTMENT 2

```
[ LOCATION PATTERN AND STATISTICS AT ITERATION 1]
REMOVED DEPARTMENTS = 3      TRIAL SWITCH = 7
```

[illegible]

4 4 4 5 5 5 13 13 13 13 13 13 13 13 13
 4 4 4 5 5 5 13 13 13 13 13 13 13 13 13

DESCRIPTION	VIOLATION	COEFCNT	SUM
MTL HANDLNG	137043.73	1	\$ 137043.73
USER PREFRC	2	2000.0	4000.00
EXPANS PLAN	0	6000.0	0.00
NOISE CNTRL	1	7000.0	7000.00
VIBRATION C	1	8000.0	8000.00
EXPLOSION C	0	10000.0	0.00
DANGER-EQUIP	1	9000.0	9000.00
VENT. EQUIP	0	8000.0	0.00
AIR-COMPRES	3	4000.0	12000.00
POWER-FACIL	2	2000.0	4000.00
WATER-FACIL	1	6000.0	6000.00
DOOR-EXIT C	1	6000.0	6000.00
HEAT CNTRL	0	3000.0	0.00
ENERGY CRDT	0	1000.0	0.00
OBJECTIVE FUNCTION			193043.73

THE SUGGESTION IS ACCEPTED
 DUE TO DANGEROUS EQUIP. -
 DEPARTMENT 4 IS REMOVED FOR REPLACEMENT
 DEPARTMENT 2 IS SELECTED FOR DEPARTMENT 4
 DUE TO UNACCEPTABLE SHAPE -
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 5 IS SELECTED FOR DEPARTMENT 4
 DUE TO UNACCEPTABLE SHAPE -
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 6 IS SELECTED FOR DEPARTMENT 4
 DUE TO UNACCEPTABLE SHAPE -
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 4 HAS NO REPLACEMENT -PICK ANOTHER
 DEPARTMENT 5 IS REMOVED FOR REPLACEMENT
 DEPARTMENT 3 IS SELECTED FOR DEPARTMENT 5

[LOCATION PATTERN AND STATISTICS AT ITERATION 2]
 REMOVED DEPARTMENTS = 5 TRIAL SWITCH = 11

7 7 7 1 1 1 1 5 5 5 9 9 9 9 9 9
 7 7 7 1 1 1 1 5 5 5 9 9 9 9 9 9
 7 7 1 1 1 1 1 5 5 5 9 9 9 9 9 9
 1 1 1 1 1 1 1 5 5 8 8 8 8 10 10 10

```

1 1 1 1 1 1 1 1 5 8 8 8 8 10 10 10
1 1 1 1 1 1 1 1 5 8 8 8 8 10 10 10
6 6 6 2 2 2 1 1 8 8 8 8 8 11 11 11
6 6 2 2 2 2 2 2 12 12 12 12 12 12 11 11
6 6 2 2 2 2 2 2 12 12 12 12 12 12 12 12
6 6 2 2 2 2 2 2 12 12 12 12 12 12 12 12
6 6 2 2 2 2 2 2 12 12 12 12 12 12 12 12
4 4 4 4 3 12 12 12 12 12 12 12 12 12 12 12
4 4 4 3 3 3 12 12 12 12 13 13 13 13 13 13
4 4 4 3 3 3 13 13 13 13 13 13 13 13 13 13
4 4 4 3 3 3 13 13 13 13 13 13 13 13 13 13
4 4 4 3 3 3 13 13 13 13 13 13 13 13 13 13

```

DESCRIPTION	VIOLATION	COEFCNT	SUM
MTL HANDLNG	138704.70	1	\$ 138704.70
USER PREFRC	1	2000.0	2000.00
EXPANS PLAN	0	6000.0	0.00
NOISE CNTRL	1	7000.0	7000.00
VIBRATION C	0	8000.0	0.00
EXPLOSION C	0	10000.0	0.00
DANGER-EQUIP	0	9000.0	0.00
VENT. EQUIP	0	8000.0	0.00
AIR-COMPRES	3	4000.0	12000.00
POWER-FACIL	2	2000.0	4000.00
WATER-FACIL	1	6000.0	6000.00
DOOR-EXIT C	1	6000.0	6000.00
HEAT CNTRL	1	3000.0	3000.00
ENERGY CRDT	0	1000.0	0.00
OBJECTIVE FUNCTION			178704.70

THE SUGGESTION IS ACCEPTED
 DUE TO NOISE -
 DEPARTMENT 13 IS REMOVED FOR REPLACEMENT
 DEPARTMENT 3 IS SELECTED FOR DEPARTMENT 13
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 12 IS SELECTED FOR DEPARTMENT 13
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 13 HAS NO REPLACEMENT -PICK ANOTHER
 DEPARTMENT 3 IS REMOVED FOR REPLACEMENT
 DEPARTMENT 2 IS SELECTED FOR DEPARTMENT 3
 DUE TO UNACCEPTABLE SHAPE -
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 4 IS SELECTED FOR DEPARTMENT 3
 DUE TO UNACCEPTABLE SHAPE -
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 12 IS SELECTED FOR DEPARTMENT 3

DUE TO UNACCEPTABLE SHAPE -
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 3 HAS NO REPLACEMENT -PICK ANOTHER
 DUE TO EXIT/DOOR -
 DEPARTMENT 12 IS REMOVED FOR REPLACEMENT
 DEPARTMENT 2 IS SELECTED FOR DEPARTMENT 12
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 8 IS SELECTED FOR DEPARTMENT 12
 DUE TO UNACCEPTABLE SHAPE -
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 11 IS SELECTED FOR DEPARTMENT 12
 SEARCHED MORE TO CONVERT TO SMALL
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 12 HAS NO REPLACEMENT -PICK ANOTHER
 DUE TO WATER EQP -
 DEPARTMENT 10 IS REMOVED FOR REPLACEMENT
 DEPARTMENT 8 IS SELECTED FOR DEPARTMENT 10
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 9 IS SELECTED FOR DEPARTMENT 10

[LOCATION PATTERN AND STATISTICS AT ITERATION 3]
 REMOVED DEPARTMENTS = 9 TRIAL SWITCH = 21

```

7 7 7 1 1 1 1 5 5 5 10 10 10 9 9 9
7 7 7 1 1 1 1 5 5 5 10 10 10 9 9 9
7 7 1 1 1 1 1 5 5 5 10 10 10 9 9 9
1 1 1 1 1 1 1 5 5 8 8 8 8 9 9 9
1 1 1 1 1 1 1 1 5 8 8 8 8 9 9 9
1 1 1 1 1 1 1 1 5 8 8 8 8 9 9 9
6 6 6 2 2 2 1 1 8 8 8 8 8 11 11 11
6 6 2 2 2 2 2 2 12 12 12 12 12 11 11
6 6 2 2 2 2 2 2 12 12 12 12 12 12 12
6 6 2 2 2 2 2 2 12 12 12 12 12 12 12
6 6 2 2 2 2 2 2 12 12 12 12 12 12 12
4 4 4 4 3 12 12 12 12 12 12 12 12 12 12
4 4 4 3 3 3 12 12 12 12 13 13 13 13 13
4 4 4 3 3 3 13 13 13 13 13 13 13 13 13
4 4 4 3 3 3 13 13 13 13 13 13 13 13 13
4 4 4 3 3 3 13 13 13 13 13 13 13 13 13
  
```

DESCRIPTION	VIOLATION	COEFCNT	SUM
MTL HANDLNG	136724.70	1	\$ 136724.70
USER PREFRC	2	2000.0	4000.00
EXPANS PLAN	0	6000.0	0.00

NOISE CNTRL	1	7000.0	7000.00
VIBRATION C	0	8000.0	0.00
EXPLOSION C	0	10000.0	0.00
DANGER-EQUIP	0	9000.0	0.00
VENT. EQUIP	0	8000.0	0.00
AIR-COMPRES	3	4000.0	12000.00
POWER-FACIL	2	2000.0	4000.00
WATER-FACIL	0	6000.0	0.00
DOOR-EXIT C	1	6000.0	6000.00
HEAT CNTRL	1	3000.0	3000.00
ENERGY CRDT	0	1000.0	0.00
OBJECTIVE FUNCTION			172724.70

THE SUGGESTION IS ACCEPTED

DUE TO NOISE -

DEPARTMENT 3 IS REMOVED FOR REPLACEMENT

DEPARTMENT 5 IS SELECTED FOR DEPARTMENT 3

THE SUGGESTION IS REJECTED - BACKING UP

DEPARTMENT 2 IS SELECTED FOR DEPARTMENT 3

DUE TO UNACCEPTABLE SHAPE -

THE SUGGESTION IS REJECTED - BACKING UP

DEPARTMENT 4 IS SELECTED FOR DEPARTMENT 3

DUE TO UNACCEPTABLE SHAPE -

THE SUGGESTION IS REJECTED - BACKING UP

DEPARTMENT 12 IS SELECTED FOR DEPARTMENT 3

DUE TO UNACCEPTABLE SHAPE -

THE SUGGESTION IS REJECTED - BACKING UP

DEPARTMENT 13 IS SELECTED FOR DEPARTMENT 3

THE SUGGESTION IS REJECTED - BACKING UP

DEPARTMENT 3 HAS NO REPLACEMENT -PICK ANOTHER

DEPARTMENT 13 IS REMOVED FOR REPLACEMENT

DEPARTMENT 12 IS SELECTED FOR DEPARTMENT 13

THE SUGGESTION IS REJECTED - BACKING UP

DEPARTMENT 13 HAS NO REPLACEMENT -PICK ANOTHER

DUE TO EXIT/DOOR -

DEPARTMENT 12 IS REMOVED FOR REPLACEMENT

DEPARTMENT 2 IS SELECTED FOR DEPARTMENT 12

THE SUGGESTION IS REJECTED - BACKING UP

DEPARTMENT 8 IS SELECTED FOR DEPARTMENT 12

DUE TO UNACCEPTABLE SHAPE -

THE SUGGESTION IS REJECTED - BACKING UP

DEPARTMENT 11 IS SELECTED FOR DEPARTMENT 12

SEARCHED MORE TO CONVERT TO SMALL

THE SUGGESTION IS REJECTED - BACKING UP

DEPARTMENT 12 HAS NO REPLACEMENT -PICK ANOTHER

DUE TO COMP. AIR -

DEPARTMENT 2 IS REMOVED FOR REPLACEMENT

DEPARTMENT 1 IS SELECTED FOR DEPARTMENT 2

DUE TO UNACCEPTABLE SHAPE -

THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 4 IS SELECTED FOR DEPARTMENT 2
 DUE TO UNACCEPTABLE SHAPE -
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 6 IS SELECTED FOR DEPARTMENT 2
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 2 HAS NO REPLACEMENT -PICK ANOTHER
 DUE TO COMP. AIR -
 DEPARTMENT 4 IS REMOVED FOR REPLACEMENT
 DEPARTMENT 6 IS SELECTED FOR DEPARTMENT 4
 DUE TO UNACCEPTABLE SHAPE -
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 4 HAS NO REPLACEMENT -PICK ANOTHER
 DUE TO COMP. AIR -
 DEPARTMENT 7 IS REMOVED FOR REPLACEMENT
 DEPARTMENT 1 IS SELECTED FOR DEPARTMENT 7
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 7 HAS NO REPLACEMENT -PICK ANOTHER
 DUE TO HEAT CONTROL -
 DEPARTMENT 5 IS REMOVED FOR REPLACEMENT
 DEPARTMENT 1 IS SELECTED FOR DEPARTMENT 5
 SEARCHED MORE TO CONVERT TO SMALL
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 8 IS SELECTED FOR DEPARTMENT 5

[LOCATION PATTERN AND STATISTICS AT ITERATION 4]
 REMOVED DEPARTMENTS = 16 TRIAL SWITCH = 37

7	7	7	1	1	1	1	8	8	8	10	10	10	9	9	9
7	7	7	1	1	1	1	8	8	8	10	10	10	9	9	9
7	7	1	1	1	1	1	8	8	8	10	10	10	9	9	9
1	1	1	1	1	1	1	8	8	8	5	5	5	9	9	9
1	1	1	1	1	1	1	1	8	8	5	5	5	9	9	9
1	1	1	1	1	1	1	1	8	8	5	5	5	9	9	9
6	6	6	2	2	2	1	1	8	5	5	5	5	11	11	11
6	6	2	2	2	2	2	2	12	12	12	12	12	12	11	11
6	6	2	2	2	2	2	2	12	12	12	12	12	12	12	12
6	6	2	2	2	2	2	2	12	12	12	12	12	12	12	12
6	6	2	2	2	2	2	2	12	12	12	12	12	12	12	12
4	4	4	4	3	12	12	12	12	12	12	12	12	12	12	12
4	4	4	3	3	3	12	12	12	12	13	13	13	13	13	13
4	4	4	3	3	3	13	13	13	13	13	13	13	13	13	13
4	4	4	3	3	3	13	13	13	13	13	13	13	13	13	13
4	4	4	3	3	3	13	13	13	13	13	13	13	13	13	13

DESCRIPTION	VIOLATION	COEFCNT	SUM
MTL HANDLNG	139495.20	1	\$ 139495.20
USER PREFRC	0	2000.0	0.00
EXPANS PLAN	0	6000.0	0.00
NOISE CNTRL	1	7000.0	7000.00
VIBRATION C	0	8000.0	0.00
EXPLOSION C	0	10000.0	0.00
DANGER-EQUIP	0	9000.0	0.00
VENT. EQUIP	0	8000.0	0.00
AIR-COMPRES	3	4000.0	12000.00
POWER-FACIL	2	2000.0	4000.00
WATER-FACIL	0	6000.0	0.00
DOOR-EXIT C	1	6000.0	6000.00
HEAT CNTRL	0	3000.0	0.00
ENERGY CRDT	0	1000.0	0.00
OBJECTIVE FUNCTION			168495.20

THE SUGGESTION IS ACCEPTED
 DUE TO NOISE -
 DEPARTMENT 13 IS REMOVED FOR REPLACEMENT
 DEPARTMENT 3 IS SELECTED FOR DEPARTMENT 13
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 12 IS SELECTED FOR DEPARTMENT 13
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 13 HAS NO REPLACEMENT -PICK ANOTHER
 DEPARTMENT 13 IS REMOVED FOR REPLACEMENT
 DEPARTMENT 3 IS SELECTED FOR DEPARTMENT 13
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 12 IS SELECTED FOR DEPARTMENT 13
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 13 HAS NO REPLACEMENT -PICK ANOTHER
 DUE TO NOISE -
 DEPARTMENT 3 IS REMOVED FOR REPLACEMENT
 DEPARTMENT 5 IS SELECTED FOR DEPARTMENT 3
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 2 IS SELECTED FOR DEPARTMENT 3
 DUE TO UNACCEPTABLE SHAPE -
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 4 IS SELECTED FOR DEPARTMENT 3
 DUE TO UNACCEPTABLE SHAPE -
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 12 IS SELECTED FOR DEPARTMENT 3
 DUE TO UNACCEPTABLE SHAPE -
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 3 HAS NO REPLACEMENT -PICK ANOTHER
 DUE TO EXIT/DOOR -
 DEPARTMENT 12 IS REMOVED FOR REPLACEMENT
 DEPARTMENT 2 IS SELECTED FOR DEPARTMENT 12

THE SUGGESTION IS REJECTED - BACKING UP
DEPARTMENT 5 IS SELECTED FOR DEPARTMENT 12
DUE TO UNACCEPTABLE SHAPE -
THE SUGGESTION IS REJECTED - BACKING UP
DEPARTMENT 8 IS SELECTED FOR DEPARTMENT 12
DUE TO UNACCEPTABLE SHAPE -
THE SUGGESTION IS REJECTED - BACKING UP
DEPARTMENT 11 IS SELECTED FOR DEPARTMENT 12
SEARCHED MORE TO CONVERT TO SMALL
THE SUGGESTION IS REJECTED - BACKING UP
DEPARTMENT 12 HAS NO REPLACEMENT -PICK ANOTHER
DUE TO COMP. AIR -
DEPARTMENT 2 IS REMOVED FOR REPLACEMENT
DEPARTMENT 1 IS SELECTED FOR DEPARTMENT 2
DUE TO UNACCEPTABLE SHAPE -
THE SUGGESTION IS REJECTED - BACKING UP
DEPARTMENT 4 IS SELECTED FOR DEPARTMENT 2
DUE TO UNACCEPTABLE SHAPE -
THE SUGGESTION IS REJECTED - BACKING UP
DEPARTMENT 6 IS SELECTED FOR DEPARTMENT 2
THE SUGGESTION IS REJECTED - BACKING UP
DEPARTMENT 2 HAS NO REPLACEMENT -PICK ANOTHER
DUE TO COMP. AIR -
DEPARTMENT 4 IS REMOVED FOR REPLACEMENT
DEPARTMENT 6 IS SELECTED FOR DEPARTMENT 4
DUE TO UNACCEPTABLE SHAPE -
THE SUGGESTION IS REJECTED - BACKING UP
DEPARTMENT 4 HAS NO REPLACEMENT -PICK ANOTHER
DUE TO COMP. AIR -
DEPARTMENT 7 IS REMOVED FOR REPLACEMENT
DEPARTMENT 1 IS SELECTED FOR DEPARTMENT 7

```
[ LOCATION PATTERN AND STATISTICS AT ITERATION 5]
REMOVED DEPARTMENTS = 23      TRIAL SWITCH = 54
```

[illegible]

4 4 4 3 3 3 12 12 12 12 13 13 13 13 13 13
 4 4 4 3 3 3 13 13 13 13 13 13 13 13 13 13
 4 4 4 3 3 3 13 13 13 13 13 13 13 13 13 13
 4 4 4 3 3 3 13 13 13 13 13 13 13 13 13 13

DESCRIPTION	VIOLATION	COEFCNT	SUM
MTL HANDLNG	128183.81	1	\$ 128183.81
USER PREFRC	0	2000.0	0.00
EXPANS PLAN	0	6000.0	0.00
NOISE CNTRL	1	7000.0	7000.00
VIBRATION C	0	8000.0	0.00
EXPLOSION C	0	10000.0	0.00
DANGER-EQUIP	1	9000.0	9000.00
VENT. EQUIP	0	8000.0	0.00
AIR-COMPRES	3	4000.0	12000.00
POWER-FACIL	2	2000.0	4000.00
WATER-FACIL	0	6000.0	0.00
DOOR-EXIT C	1	6000.0	6000.00
HEAT CONTRL	0	3000.0	0.00
ENERGY CRDT	0	1000.0	0.00
OBJECTIVE FUNCTION			166183.81

THE SUGGESTION IS ACCEPTED
 DUE TO DANGEROUS EQUIP. -
 DEPARTMENT 7 IS REMOVED FOR REPLACEMENT
 DEPARTMENT 2 IS SELECTED FOR DEPARTMENT 7
 SEARCHED MORE TO CONVERT TO SMALL
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 8 IS SELECTED FOR DEPARTMENT 7
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 7 HAS NO REPLACEMENT -PICK ANOTHER
 DEPARTMENT 8 IS REMOVED FOR REPLACEMENT
 DEPARTMENT 1 IS SELECTED FOR DEPARTMENT 8
 DUE TO UNACCEPTABLE SHAPE -
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 5 IS SELECTED FOR DEPARTMENT 8
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 10 IS SELECTED FOR DEPARTMENT 8
 DUE TO UNACCEPTABLE SHAPE -
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 12 IS SELECTED FOR DEPARTMENT 8
 DUE TO UNACCEPTABLE SHAPE -
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 8 HAS NO REPLACEMENT -PICK ANOTHER
 DUE TO NOISE -
 DEPARTMENT 3 IS REMOVED FOR REPLACEMENT

DEPARTMENT 5 IS SELECTED FOR DEPARTMENT 3
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 2 IS SELECTED FOR DEPARTMENT 3
 DUE TO UNACCEPTABLE SHAPE -
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 4 IS SELECTED FOR DEPARTMENT 3
 DUE TO UNACCEPTABLE SHAPE -
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 12 IS SELECTED FOR DEPARTMENT 3
 DUE TO UNACCEPTABLE SHAPE -
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 13 IS SELECTED FOR DEPARTMENT 3
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 3 HAS NO REPLACEMENT -PICK ANOTHER
 DEPARTMENT 3 IS REMOVED FOR REPLACEMENT
 DEPARTMENT 5 IS SELECTED FOR DEPARTMENT 3
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 2 IS SELECTED FOR DEPARTMENT 3
 DUE TO UNACCEPTABLE SHAPE -
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 4 IS SELECTED FOR DEPARTMENT 3
 DUE TO UNACCEPTABLE SHAPE -
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 12 IS SELECTED FOR DEPARTMENT 3
 DUE TO UNACCEPTABLE SHAPE -
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 13 IS SELECTED FOR DEPARTMENT 3
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 3 HAS NO REPLACEMENT -PICK ANOTHER
 DUE TO EXIT/DOOR -
 DEPARTMENT 12 IS REMOVED FOR REPLACEMENT
 DEPARTMENT 2 IS SELECTED FOR DEPARTMENT 12
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 5 IS SELECTED FOR DEPARTMENT 12
 DUE TO UNACCEPTABLE SHAPE -
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 11 IS SELECTED FOR DEPARTMENT 12
 SEARCHED MORE TO CONVERT TO SMALL
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 13 IS SELECTED FOR DEPARTMENT 12
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 12 HAS NO REPLACEMENT -PICK ANOTHER
 DUE TO COMP. AIR -
 DEPARTMENT 2 IS REMOVED FOR REPLACEMENT
 DEPARTMENT 1 IS SELECTED FOR DEPARTMENT 2
 DUE TO UNACCEPTABLE SHAPE -
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 4 IS SELECTED FOR DEPARTMENT 2
 DUE TO UNACCEPTABLE SHAPE -
 THE SUGGESTION IS REJECTED - BACKING UP

DEPARTMENT 6 IS SELECTED FOR DEPARTMENT 2

[LOCATION PATTERN AND STATISTICS AT ITERATION 6]

REMOVED DEPARTMENTS = 29 TRIAL SWITCH = 77

```

1 1 1 1 1 1 1 8 8 8 10 10 10 9 9 9
1 1 1 1 1 1 1 8 8 8 10 10 10 9 9 9
1 1 1 1 1 1 7 8 8 8 10 10 10 9 9 9
1 1 1 1 1 1 7 8 8 8 5 5 5 9 9 9
1 1 1 1 1 1 7 7 8 8 5 5 5 9 9 9
1 1 1 1 1 1 7 7 8 8 5 5 5 9 9 9
2 2 2 2 2 2 7 7 8 5 5 5 5 11 11 11
2 2 2 2 2 2 6 6 12 12 12 12 12 12 11 11
2 2 2 2 2 6 6 6 12 12 12 12 12 12 12 12
2 2 2 2 2 6 6 6 12 12 12 12 12 12 12 12
2 2 2 2 2 6 6 6 12 12 12 12 12 12 12 12
2 2 2 2 2 6 6 6 12 12 12 12 12 12 12 12
4 4 4 4 3 12 12 12 12 12 12 12 12 12 12 12
4 4 4 3 3 3 12 12 12 12 13 13 13 13 13 13
4 4 4 3 3 3 13 13 13 13 13 13 13 13 13 13
4 4 4 3 3 3 13 13 13 13 13 13 13 13 13 13
4 4 4 3 3 3 13 13 13 13 13 13 13 13 13 13

```

DESCRIPTION	VIOLATION	COEFCNT	SUM
MTL HANDLNG	114406.45	1	\$ 114406.45
USER PREFRC	0	2000.0	0.00
EXPANS PLAN	1	6000.0	6000.00
NOISE CNTRL	1	7000.0	7000.00
VIBRATION C	0	8000.0	0.00
EXPLOSION C	0	10000.0	0.00
DANGER-EQUIP	1	9000.0	9000.00
VENT. EQUIP	0	8000.0	0.00
AIR-COMPRES	3	4000.0	12000.00
POWER-FACIL	2	2000.0	4000.00
WATER-FACIL	0	6000.0	0.00
DOOR-EXIT C	1	6000.0	6000.00
HEAT CONTRL	0	3000.0	0.00
ENERGY CRDT	0	1000.0	0.00
OBJECTIVE FUNCTION			158406.45

THE SUGGESTION IS ACCEPTED

DUE TO DANGEROUS EQUIP. -

DEPARTMENT 7 IS REMOVED FOR REPLACEMENT

DEPARTMENT 1 IS SELECTED FOR DEPARTMENT 7

DUE TO UNACCEPTABLE SHAPE -
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 2 IS SELECTED FOR DEPARTMENT 7
 SEARCHED MORE TO CONVERT TO SMALL
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 6 IS SELECTED FOR DEPARTMENT 7

[LOCATION PATTERN AND STATISTICS AT ITERATION 7]
 REMOVED DEPARTMENTS = 30 TRIAL SWITCH = 80

```

1 1 1 1 1 1 1 8 8 8 10 10 10 9 9 9
1 1 1 1 1 1 1 8 8 8 10 10 10 9 9 9
1 1 1 1 1 1 6 8 8 8 10 10 10 9 9 9
1 1 1 1 1 1 6 8 8 8 5 5 5 9 9 9
1 1 1 1 1 1 6 6 8 8 5 5 5 9 9 9
1 1 1 1 1 1 6 6 8 8 5 5 5 9 9 9
2 2 2 2 2 2 6 6 8 5 5 5 5 11 11 11
2 2 2 2 2 2 6 6 12 12 12 12 12 11 11
2 2 2 2 2 7 7 6 12 12 12 12 12 12 12
2 2 2 2 2 7 7 7 12 12 12 12 12 12 12
2 2 2 2 2 7 7 7 12 12 12 12 12 12 12
4 4 4 4 3 12 12 12 12 12 12 12 12 12 12
4 4 4 3 3 3 12 12 12 12 13 13 13 13 13
4 4 4 3 3 3 13 13 13 13 13 13 13 13 13
4 4 4 3 3 3 13 13 13 13 13 13 13 13 13
4 4 4 3 3 3 13 13 13 13 13 13 13 13 13

```

DESCRIPTION	VIOLATION	COEFCNT	SUM
MTL HANDLNG	111774.36	1	\$ 111774.36
USER PREFRC	0	2000.0	0.00
EXPANS PLAN	1	6000.0	6000.00
NOISE CNTRL	1	7000.0	7000.00
VIBRATION C	0	8000.0	0.00
EXPLOSION C	0	10000.0	0.00
DANGER-EQUP	0	9000.0	0.00
VENT. EQUIP	0	8000.0	0.00
AIR-COMPRES	3	4000.0	12000.00
POWER-FACIL	2	2000.0	4000.00
WATER-FACIL	0	6000.0	0.00
DOOR-EXIT C	1	6000.0	6000.00
HEAT CONTRL	0	3000.0	0.00
ENERGY CRDT	0	1000.0	0.00
OBJECTIVE FUNCTION			146774.36

THE SUGGESTION IS ACCEPTED
 DUE TO NOISE -
 DEPARTMENT 3 IS REMOVED FOR REPLACEMENT
 DEPARTMENT 5 IS SELECTED FOR DEPARTMENT 3
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 2 IS SELECTED FOR DEPARTMENT 3
 DUE TO UNACCEPTABLE SHAPE -
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 4 IS SELECTED FOR DEPARTMENT 3
 DUE TO UNACCEPTABLE SHAPE -
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 12 IS SELECTED FOR DEPARTMENT 3
 DUE TO UNACCEPTABLE SHAPE -
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 13 IS SELECTED FOR DEPARTMENT 3
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 3 HAS NO REPLACEMENT -PICK ANOTHER
 DEPARTMENT 3 IS REMOVED FOR REPLACEMENT
 DEPARTMENT 5 IS SELECTED FOR DEPARTMENT 3
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 2 IS SELECTED FOR DEPARTMENT 3
 DUE TO UNACCEPTABLE SHAPE -
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 4 IS SELECTED FOR DEPARTMENT 3
 DUE TO UNACCEPTABLE SHAPE -
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 12 IS SELECTED FOR DEPARTMENT 3
 DUE TO UNACCEPTABLE SHAPE -
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 13 IS SELECTED FOR DEPARTMENT 3
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 3 HAS NO REPLACEMENT -PICK ANOTHER
 DUE TO EXIT/DOOR -
 DEPARTMENT 12 IS REMOVED FOR REPLACEMENT
 DEPARTMENT 5 IS SELECTED FOR DEPARTMENT 12
 DUE TO UNACCEPTABLE SHAPE -
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 6 IS SELECTED FOR DEPARTMENT 12
 DUE TO UNACCEPTABLE SHAPE -
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 7 IS SELECTED FOR DEPARTMENT 12
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 8 IS SELECTED FOR DEPARTMENT 12
 DUE TO UNACCEPTABLE SHAPE -
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 11 IS SELECTED FOR DEPARTMENT 12
 SEARCHED MORE TO CONVERT TO SMALL
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 13 IS SELECTED FOR DEPARTMENT 12

THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 12 HAS NO REPLACEMENT -PICK ANOTHER
 DUE TO EXPANSION -
 DEPARTMENT 2 IS REMOVED FOR REPLACEMENT
 DEPARTMENT 1 IS SELECTED FOR DEPARTMENT 2
 DUE TO UNACCEPTABLE SHAPE -
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 4 IS SELECTED FOR DEPARTMENT 2
 DUE TO UNACCEPTABLE SHAPE -
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 6 IS SELECTED FOR DEPARTMENT 2
 DUE TO UNACCEPTABLE SHAPE -
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 7 IS SELECTED FOR DEPARTMENT 2
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 2 HAS NO REPLACEMENT -PICK ANOTHER
 DUE TO COMP. AIR -
 DEPARTMENT 4 IS REMOVED FOR REPLACEMENT
 DEPARTMENT 4 HAS NO REPLACEMENT -PICK ANOTHER
 DUE TO COMP. AIR -
 DEPARTMENT 7 IS REMOVED FOR REPLACEMENT
 DEPARTMENT 7 HAS NO REPLACEMENT -PICK ANOTHER
 DUE TO MTL HDL COST -
 DEPARTMENT 1 IS REMOVED FOR REPLACEMENT
 DEPARTMENT 6 IS SELECTED FOR DEPARTMENT 1
 DUE TO UNACCEPTABLE SHAPE -
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 8 IS SELECTED FOR DEPARTMENT 1
 DUE TO UNACCEPTABLE SHAPE -
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 1 HAS NO REPLACEMENT -PICK ANOTHER
 DUE TO MTL HDL COST -
 DEPARTMENT 9 IS REMOVED FOR REPLACEMENT
 DEPARTMENT 5 IS SELECTED FOR DEPARTMENT 9
 DUE TO UNACCEPTABLE SHAPE -
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 10 IS SELECTED FOR DEPARTMENT 9
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 11 IS SELECTED FOR DEPARTMENT 9
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 9 HAS NO REPLACEMENT -PICK ANOTHER
 DEPARTMENT 6 IS REMOVED FOR REPLACEMENT
 DEPARTMENT 8 IS SELECTED FOR DEPARTMENT 6
 DUE TO UNACCEPTABLE SHAPE -
 THE SUGGESTION IS REJECTED - BACKING UP
 DEPARTMENT 6 HAS NO REPLACEMENT -PICK ANOTHER
 DUE TO MTL HDL COST -
 DEPARTMENT 5 IS REMOVED FOR REPLACEMENT
 DEPARTMENT 8 IS SELECTED FOR DEPARTMENT 5
 THE SUGGESTION IS REJECTED - BACKING UP

DEPARTMENT 10 IS SELECTED FOR DEPARTMENT 5
THE SUGGESTION IS REJECTED - BACKING UP
DEPARTMENT 11 IS SELECTED FOR DEPARTMENT 5
DUE TO UNACCEPTABLE SHAPE -
THE SUGGESTION IS REJECTED - BACKING UP
DEPARTMENT 5 HAS NO REPLACEMENT -PICK ANOTHER
DUE TO MTL HDL COST -
DEPARTMENT 11 IS REMOVED FOR REPLACEMENT
DEPARTMENT 11 HAS NO REPLACEMENT -PICK ANOTHER
FOUND NOTHING TO REMOVE

TOTAL DEPT REMOVAL = 41

DEPT SWITCH = 109

* CPU TIME = 21.110

APPENDIX C. PROGRAM LIST

```

C*****
C      FILE NAME : FLUKES                               Version 5.01
C*****
C      THIS PROGRAM CAN BE USED TO SOLVE BLOCK LAYOUT PROBLEMS
C      WITH PRACTICAL CONSTRAINTS AND OBJECTIVES IN CONSIDERATION.
C*****
C
C      - NIL: does not matter
C
C      [ DEPARTMENT ]
C      DEPT      : NUMBER OF DEPARTMENTS
C      SIZE(I)   : SIZE OF DEPARTMENT I (NUMBER OF UNITS)
C      MINSIDE(I) : MINIMUM WIDTH OR LENGTH OF DEPT. I
C      MAXSIDE(I) : MAXIMUM " SMALL DEPT.
C      NOSE(I)   : PRODUCE(1), AWAY(2), NIL(0)
C      VIBA(I)   : "
C      EXPO(I)   : EXPLOSIVE(1), FLAME(2), NIL(0)
C      DANG(I)   : DANGEROUS(1), AWAY(2), NIL(0)
C      HEAT(I)   : PRODUCE(1), REQUIRED(2), AWAY(3), NIL(0)
C      WGHT(I)   : HEAVY(1) OR NIL(0) (NIL = LIGHT)
C      EXIT(I)   : REQUIRED(1) OR NIL(0)
C      AIR(I)    : "
C      POWER(I)  : "
C      WATER(I)  : "
C      VENT(I)   : "
C      MOVE(I)   : HARD(1), NIL(0) (NIL = OKAY TO MOVE)
C      STATUS(I) : ASSIGNED(1), REMOVED(2), CANDIDATE(3),
C                  CHECKED(4), FIXED(5)
C      UAIR(I)   : SATISFIED(1) OR NIL(0)
C      UPOWER(I) : "
C      UWATER(I) : "
C      UEXIT(I)  : "
C      UVENT(I)  : "
C      CNTX(I)   : CENTROID OF DEPARTMENT I - X COORDINATE
C      CNTY(I)   : " - Y COORDINATE
C
C      [ FLOOR ]
C      LOAD(I,J) : LIGHT-ONLY(1) OR NIL(0)
C      FAIR(I,J) : AVAILABLE(1) OR NIL(0) (NOT AVAILABLE = NIL)
C      FPOWER(I,J) : "
C      FWATER(I,J) : "
C      FEXIT(I,J) : "
C      FVENT(I,J) : "
C      EXPN(I,J) : EXPANSION SIDE - YES(1) OR NIL(0)
C      ASSIGN(I,J) : NAME OF CURRENT ASSIGNED DEPARTMENT
C      ROW      : ROW INDEX
C      COL      : COLUMN INDEX

```

```

C
C [ FLOW DATA ]
C   DIST(I,J) : RECTILINEAR DISTANCE
C   QTY(I,J)  : AVERAGE NUMBER OF UNITS TO MOVE
C   COST(I,J) : UNIT COST FOR MOVING
C
C [ PREFERENCE ]
C   RELA(I,J) : RELATION - CLOSE(1), SEPARATE(2), NIL(0)
C   TYPE(I,J) : MUST(1), IP(2) -(IF POSSIBLE), NIL(0)
C
C [ TEMPORARY SAVING OF MEMORY ]
C   SAVASS(I,J) : NAME OF CURRENT ASSIGNED DEPARTMENT
C   SAVNBO(I,J) : DEPT. J IS NEIGHBOR OF DEPT. I - YES(1), NO(0)
C   SAVCTX(I)   : CENTROID OF DEPARTMENT I - X COORDINATE
C   SAVCTY(I)   :           "           - Y
C
C [ OTHERS ]
C   H COST      : THE HIGHEST MATERIAL-HANDLING COST
C   NBO(I,J)    : DEPT. J IS NEIGHBOR OF DEPT. I - YES(1), NO(0)
C   PAX         : X COORDINATE OF POINT A OF BIG DEPT.
C   PAY         : Y " " " A
C   PBX         : X " " " B
C   PBY         : Y " " " B
C   PCX         : X " " " C
C   PCY         : Y " " " C
C   PDX         : X " " " D
C   PDY         : Y " " " D
C   DIFX        : DIFFERENCE IN CENTROIDS OF BIG AND SMALL - X
C   DIFY        : " " " Y
C   BIG         : BIGGER DEPT. BETWEEN TWO
C   SMALL       : SMALLER DEPT. "
C   MHC         : MATERIAL HANDLING COST
C   NUP         : NUMBER OF USER PREFERENCE VIOLATION
C   NBK         : " " " BLOCKED UNIT TO EXPANSION PLAN
C   NNS         : " " " NOISE VIOLATION DEPT.
C   NVB         : " " " VIBRATION
C   NEX         : " " " EXPLOSION
C   NVT         : " " " VENTILATION
C   NDG         : " " " DANGEROUS EQUIPMENT
C   NAR         : " " " COMPRESSED-AIR
C   NPW         : " " " POWER SUPPLY
C   NWT         : " " " WATER-SEWER
C   NHT         : " " " HEAT CONTROL
C   NHS         : " " " HEAT SAVING
C   COEMHC      : COEFFICIENT OF MATERIAL HANDLING COST
C   COENUP      : " " " NUMBER OF USER PREFERENCE VIOLATION
C   COENBK      : " " " BLOCKED PIECE TO EXPANSION PLAN
C   COENNS      : " " " NOISE VIOLATION DEPT.
C   COENVB      : " " " VIBRATION
C   COENEX      : " " " EXPLOSION

```

```

C      COENV T      :      "      VENTILATION
C      COENDG      :      "      DANGEROUS EQUIPMENT
C      COENAR      :      "      COMPRESSED-AIR
C      COENPW      :      "      POWER SUPPLY
C      COENWT      :      "      WATER-SEWER
C      COENHT      :      "      HEAT CONTROL
C      COENHS      :      "      HEAT SAVING
C      TEMOBJ      : OBJECTIVE FUNCTION VALUE OF SUGGESTED LAYOUT
C      OBJECT      :      "      - CURRENT
C      BACK        : ADDRESS TO COME BACK TO THE POINT EXECUTED LAST
C      ITER        : NUMBER OF ITERATIONS
C      NREM        :      "      REMOVED DEPARTMENTS
C      NSWT        :      "      DEPT. TRIAL SWITCH
C
C*****
C*****
C
C ***   MAIN PROGRAM
C
C      DIMENSION MINSIDE(20),MOVE(20),LOAD(20,20),DIST(20,20)
C      DIMENSION SAVCTX(20),SAVCTY(20),MAXSIDE(20),NOSE(20)
C      DIMENSION QTY(20,20),COST(20,20),NBO(20,20)
C      DIMENSION CNTX(20),CNTY(20)
C
C      INTEGER SIZE(20),VIBA(20),EXPO(20),HEAT(20),WGHT(20),EXIT(20)
C      INTEGER AIR(20),POWER(20),WATER(20),FLAME(20),STATUS(20)
C      INTEGER UAIR(20),UPOWER(20),UWATER(20),UEXIT(20),UVENT(20)
C      INTEGER FAIR(20,20),FPOWER(20,20),FWATER(20,20),FEXIT(20,20)
C      INTEGER FVENT(20,20),SAVASS(20,20),SAVNBO(20,20),DANG(20)
C      INTEGER TYPE(20,20),EXPAN(20,20),RELA(20,20),ASSIGN(20,20)
C      INTEGER VENT(20)
C      INTEGER ROW,COL,DEPT,BACK,PAX,PAY,PBX,PBY,PCX,PCY,PDX,PDY
C      INTEGER * 4 CPUTIM, ICODE /2/
C
C      COMMON/MEM1/QTY,COST,NOSE,VIBA,DANG,EXPO,MOVE,HEAT,EXPAN,RELA,
1  TYPE,UAIR,UPOWER,UWATER,UEXIT,UVENT,TEMOBJ,OBJECT,ITER,NSWT,
2  AIR,POWER,WATER,EXIT,VENT,NREM,NP
C      COMMON/MEM2/DIST,ASSIGN,NBO,ROW,COL,DEPT,ID,JD,CNTX,CNTY,SIZE
C      COMMON/MEM3/FAIR,FPOWER,FWATER,FEXIT,FVENT
C
C      IRET1 = LIB$INIT_TIMER( )
C
C*****
C
C ***   DATA FILE READING
10  FORMAT(' ',3(I2,1X))
20  FORMAT(' ',4(I2,1X))
30  FORMAT(' ',10(I1,1X))
50  FORMAT(' ',20(I1,1X))
60  FORMAT(' ',20(I2,1X))

```

```

70      FORMAT(' ',10(F6.1,1X))
C
      READ(5,10) ROW,COL,DEPT
C
      DO 500 I = 1,DEPT
      READ(5,20) MINSIDE(I),SIZE(I),DANG(I),VENT(I)
      READ(5,30) NOSE(I),MOVE(I),VIBA(I),EXPO(I),HEAT(I),
+      WGHT(I),EXIT(I),AIR(I),POWER(I),WATER(I)
500     CONTINUE
C
      DO 510 I = 1,ROW
510     READ(5,50) (FAIR(I,J),J=1,COL)
C
      DO 511 I = 1,ROW
511     READ(5,50) (FPOWER(I,J),J=1,COL)
C
      DO 512 I = 1,ROW
512     READ(5,50) (FWATER(I,J),J=1,COL)
C
      DO 513 I = 1,ROW
513     READ(5,50) (FEXIT(I,J),J=1,COL)
C
      DO 8 I = 1,ROW
8       READ(5,50) (FVENT(I,J),J=1,COL)
C
      DO 514 I = 1,ROW
514     READ(5,50) (LOAD(I,J),J=1,COL)
C
      DO 515 I = 1,ROW
515     READ(5,50) (EXPN(I,J),J=1,COL)
C
      DO 516 I = 1,ROW
516     READ(5,60) (ASSIGN(I,J),J=1,COL)
C
      DO 517 I = 1,DEPT-1
517     READ(5,50) (RELA(I,J),J=I+1,DEPT)
C
      DO 520 I = 1,DEPT-1
520     READ(5,50) (TYPE(I,J),J=I+1,DEPT)
C
      IF(DEPT.GT.10) GO TO 540
C
      DO 530 I = 1,DEPT
530     READ(5,70) (QTY(I,J),J=1,DEPT)
C
      DO 535 I = 1,DEPT
535     READ(5,70) (COST(I,J),J=1,DEPT)
      GO TO 521
C
540     DO 550 I = 1,DEPT

```

```

      READ(5,70) (QTY(I,J),J=1,10)
550    READ(5,70) (QTY(I,J),J=11,DEPT)
      C
      DO 555 I = 1,DEPT
      READ(5,70) (COST(I,J),J=1,10)
555    READ(5,70) (COST(I,J),J=11,DEPT)
      C
      C ***    INITIALIZATION
521    ITER = 0
      NSW = 0
      NREM = 0
      NEXT = 0
      OBJECT = 9999999.

      C
      WRITE(*,*) 'DO YOU WANT TO REVIEW ALL INTERMEDIATE RESULTS?'
      WRITE(*,*) ' 1-YES      2-NO(SKIP)'
      READ(*,*) INTER

      C
      WRITE(*,*) 'DO YOU WANT TO PRINT ALL COMMENTS DURING LAYOUT?'
      WRITE(*,*) ' 1-YES      2-NO      3-PRINT ONLY INITIAL & FINAL'
      READ(*,*) NP

      C
      WRITE(*,*) 'ENTER INTEGER TO BE USED AS RANDOM NUMBER SEED'
      READ(*,*) NDOM

      C
      DO 526 I = 1,DEPT
526    STATUS(I) = 1
      WRITE(*,*) 'ANY DEPARTMENT TO BE FIXED ON THE POSITION?'
      WRITE(*,*) 'ENTER DEPT INDEX OR 0 IF NONE (NO MORE)'
      NOMO = 0
      DO 378 I = 1,DEPT
      READ(*,*) JJJ
      IF(JJJ.LT.1.OR.JJJ.GT.DEPT) GO TO 379
      STATUS(JJJ) = 5
      NOMO = 1
378    CONTINUE
      C
379    WRITE(*,*) 'ENTER DESIRED RATE FOR SHAPE (LESS THAN 1.0):'
      READ(*,*) FACT
      IF(FACT.GT.1.0) GO TO 379

      C
      C ***    WRITE TITLE OF THE REPORT
      WRITE(6,524)
524    FORMAT(/12X,'=== BLOCK PLAN LAYOUT BY FLUKES ===')
      WRITE(6,372) FACT
372    FORMAT(13X,'= ACCEPTABLE SHAPE ABOVE  ',F5.2,' =')
      IF(NOMO.NE.1) GO TO 373
      WRITE(6,*) 'FIXED POSITION DEPARTMENT:'
      DO 364 I = 1,DEPT
      IF(STATUS(I).NE.5) GO TO 364

```

```

        WRITE(6,365) I
364      CONTINUE
365      FORMAT(' ', 'DEPARTMENT ', I2)
C
C*****
C
C ***    UPDATE STATUS
373      CALL DISTANCE
        CALL NEIGHBOR
        CALL UTILITY
        IF(NP.EQ.3) NP = 4
        CALL OBJECTIV
        OBJECT = TEMOBJ
        ITER = 1
C
C ***    CHECK THE INITIAL LAYOUT WHETHER IT IS VIOLATING ANY
C ***    CONSTRAINTS
C
C ***    CHECK LOADING LIMIT
        DO 600 I = 1,DEPT
        IF(WGHT(I).EQ.0) GO TO 600
            DO 600 J = 1,ROW
                DO 600 K = 1,COL
                    IF(LOAD(J,K).EQ.0) GO TO 600
                    IF(ASSIGN(J,K).EQ.I) GO TO 650
600      CONTINUE
C
C ***    CHECK PREFERENCE
        DO 605 I = 1,DEPT-1
            DO 605 J = I+1,DEPT
C ***        CHECK CLOSE CASE
                IF(TYPE(I,J).NE.1) GO TO 605
                IF(RELA(I,J).NE.1) GO TO 602
                IF(NBO(I,J).EQ.0) GO TO 655
                GO TO 605
C ***        CHECK SEPARATE CASE
602      IF(RELA(I,J).NE.2) GO TO 605
                IF(NBO(I,J).EQ.1) GO TO 660
605      CONTINUE
        GO TO 100
C
C*****
C
C ***    WRITE MESSAGE ABOUT VIOLATION AND THEN STOP EXECUTION
650      WRITE(6,651) I,J,K
        GO TO 9999
655      WRITE(6,656) I,J
        GO TO 9999
660      WRITE(6,661) I,J
        GO TO 9999

```



```

651     FORMAT(' ', 'DEPT', I2, ' MUST NOT BE ON FLOOR(' ', I2, ' ', ' ', I2, ' ')/)
656     FORMAT(' ', 'DEPT', I2, ' AND ', I2, ' MUST BE PLACED CLOSE'/)
661     FORMAT(' ', 'DEPT', I2, ' AND ', I2, ' MUST BE SEPARATE'/)
C
C*****
C
C ***   DEPARTMENT REMOVAL STAGE
C
100     ITER = ITER + 1
C
C ***   UPDATE UTILITY ASSIGNMENT STATUS OF THOSE DEPARTMENTS
        CALL UTILITY
C
C ***   IF ANY NEIGHBORING DEPARTMENT TO THE DEPARTMENT WITH FLAME
C ***   HAS EXPLOSIVE MATERIAL, REMOVE THE DEPARTMENT.
        DO 775 I = 1, DEPT
        IF(EXPO(I).NE.1) GO TO 775
        IF(STATUS(I).NE.1) GO TO 775
            DO 775 J = 1, DEPT
            IF(I.EQ.J) GO TO 775
            IF(NBO(I,J).NE.1) GO TO 775
            IF(FLAME(J).NE.1) GO TO 775
            ID = I
            IF(STATUS(J).EQ.1) NEXT = J
            IF(STATUS(J).EQ.1.AND.RAN(NDOM).GT.0.5) ID = J
            IF(STATUS(J).EQ.1.AND.RAN(NDOM).GT.0.5) NEXT = I
            IF(NP.EQ.1) WRITE(6,*)'DUE TO EXPLOSION -'
            GO TO 990
775     CONTINUE
C
C ***   IF ANY NEIGHBORING DEPARTMENT TO THE DEPARTMENT WITH
C ***   DANGEROUS EQUIPMENT HAS MANY PEOPLE, REMOVE THE DEPARTMENT.
        DO 723 I = 1, DEPT
        IF(DANG(I).NE.1) GO TO 723
        IF(STATUS(I).NE.1) GO TO 723
            DO 723 J = 1, DEPT
            IF(I.EQ.J) GO TO 723
            IF(NBO(I,J).NE.1) GO TO 723
            IF(DANG(J).NE.2) GO TO 723
            ID = I
            IF(STATUS(J).EQ.1) NEXT = J
            IF(STATUS(J).EQ.1.AND.RAN(NDOM).GT.0.5) ID = J
            IF(STATUS(J).EQ.1.AND.RAN(NDOM).GT.0.5) NEXT = I
            IF(NP.EQ.1) WRITE(6,*)'DUE TO DANGEROUS EQUIP. -'
            GO TO 990
723     CONTINUE
C
C ***   IF ANY NEIGHBORING DEPARTMENT TO THE DEPARTMENT MAKING
C ***   VIBRATION NEEDS TO BE AWAY, REMOVE THE DEPARTMENT.
        DO 772 I = 1, DEPT

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IF(VIBA(I).NE.1) GO TO 772
IF(STATUS(I).NE.1) GO TO 772
  DO 772 J = 1,DEPT
    IF(I.EQ.J) GO TO 772
    IF(NBO(I,J).NE.1) GO TO 772
    IF(VIBA(J).NE.2) GO TO 772
    ID = I
    IF(STATUS(J).EQ.1) NEXT = J
    IF(STATUS(J).EQ.1.AND.RAN(NDOM).GT.0.5) ID = J
    IF(STATUS(J).EQ.1.AND.RAN(NDOM).GT.0.5) NEXT = I
    IF(NP.EQ.1) WRITE(6,*)'DUE TO VIBRATION -'
  GO TO 990
772  CONTINUE
C
C ***  IF ANY NEIGHBORING DEPARTMENT TO THE DEPARTMENT MAKING
C ***  NOISE NEEDS TO BE AWAY, REMOVE THE DEPARTMENT.
DO 773 I = 1,DEPT
  IF(NOSE(I).NE.1) GO TO 773
  IF(STATUS(I).NE.1) GO TO 773
    DO 773 J = 1,DEPT
      IF(I.EQ.J) GO TO 773
      IF(NBO(I,J).NE.1) GO TO 773
      IF(NOSE(J).NE.2) GO TO 773
      ID = I
      IF(STATUS(J).EQ.1) NEXT = J
      IF(STATUS(J).EQ.1.AND.RAN(NDOM).GT.0.5) ID = J
      IF(STATUS(J).EQ.1.AND.RAN(NDOM).GT.0.5) NEXT = I
      IF(NP.EQ.1) WRITE(6,*)'DUE TO NOISE -'
    GO TO 990
773  CONTINUE
C
C ***  IF VENT REQUIRED DEPARTMENT IS NOT ASSIGNED TO ANY FLOOR
C ***  BLOCKS WITH VENTILATION EQUIP., REMOVE THE DEPARTMENT.
DO 744 I = 1,DEPT
  IF(VENT(I).NE.1) GO TO 744
  IF(STATUS(I).NE.1) GO TO 744
  ID = I
  IF(UVENT(ID).NE.1.AND.NP.EQ.1)WRITE(6,*)'DUE TO VENT -'
  IF(UVENT(ID).NE.1) GO TO 990
744  CONTINUE
C
C ***  IF DOOR REQUIRED DEPARTMENT IS NOT ASSIGNED TO ANY FLOOR
C ***  BLOCKS WITH DOOR, REMOVE THE DEPARTMENT.
DO 749 I = 1,DEPT
  IF(EXIT(I).NE.1) GO TO 749
  IF(STATUS(I).NE.1) GO TO 749
  ID = I
  IF(UEXIT(ID).NE.1.AND.NP.EQ.1) WRITE(6,*)'DUE TO EXIT/DOOR -'
  IF(UEXIT(ID).NE.1) GO TO 990
749  CONTINUE

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```

C
C *** IF A WATER REQUIRED DEPARTMENT IS NOT ASSIGNED ON THE FLOOR
C *** WITH WATER, REMOVE THE DEPARTMENT.
      DO 770 I = 1,DEPT
      IF(WATER(I).NE.1) GO TO 770
      IF(STATUS(I).NE.1) GO TO 770
      ID = I
      IF(UWATER(ID).NE.1.AND.NP.EQ.1)WRITE(6,*)'DUE TO WATER EQP -'
      IF(UWATER(ID).NE.1) GO TO 990
770  CONTINUE
C
C *** IF A HEAVY DEPARTMENT IS ASSIGNED ON ANY ONE OF THE BLOCKS
C *** PLANNED AS EXPANSION SIDE, REMOVE THE DEPARTMENT.
      DO 750 J = 1,ROW
          DO 750 K = 1,COL
              NAME = ASSIGN(J,K)
              IF(STATUS(NAME).NE.1) GO TO 750
              IF(MOVE(NAME).NE.1) GO TO 750
              IF(EXPN(J,K).NE.1) GO TO 750
              ID = NAME
              IF(NP.EQ.1) WRITE(6,*)'DUE TO EXPANSION -'
              GO TO 990
750  CONTINUE
C
C *** IF A COMPRESSED-AIR REQUIRED DEPARTMENT IS NOT ASSIGNED ON
C *** THE FLOOR WITH COMPRESSED-AIR, REMOVE THE DEPARTMENT.
      DO 760 I = 1,DEPT
      IF(AIR(I).NE.1) GO TO 760
      IF(STATUS(I).NE.1) GO TO 760
      ID = I
      IF(UAIR(ID).NE.1.AND.NP.EQ.1) WRITE(6,*)'DUE TO COMP. AIR -'
      IF(UAIR(ID).NE.1) GO TO 990
760  CONTINUE
C
C *** IF A POWER REQUIRED DEPARTMENT IS NOT ASSIGNED ON THE FLOOR
C *** WITH POWER, REMOVE THE DEPARTMENT.
      DO 765 I = 1,DEPT
      IF(POWER(I).NE.1) GO TO 765
      IF(STATUS(I).NE.1) GO TO 765
      ID = I
      IF(UPOWER(ID).NE.1.AND.NP.EQ.1)WRITE(6,*)'DUE TO POWER EQP -'
      IF(UPOWER(ID).NE.1) GO TO 990
765  CONTINUE
C
C *** IF ANY NEIGHBORING DEPARTMENT TO THE DEPARTMENT REQUIRING
C *** HEAT REQUIRES HEAT CONTROL, REMOVE THE DEPARTMENT.
      DO 780 I = 1,DEPT
      IF(HEAT(I).NE.1) GO TO 780
      IF(STATUS(I).NE.1) GO TO 780
          DO 780 J = 1,DEPT

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        IF(I.EQ.J) GO TO 780
        IF(NBO(I,J).NE.1) GO TO 780
        IF(HEAT(J).NE.3) GO TO 780
        ID = I
        IF(STATUS(J).EQ.1) NEXT = J
        IF(STATUS(J).EQ.1.AND.RAN(NDOM).GT.0.5) ID = J
        IF(STATUS(J).EQ.1.AND.RAN(NDOM).GT.0.5) NEXT = I
        IF(NP.EQ.1) WRITE(6,*)'DUE TO HEAT CONTROL -'
        GO TO 990
780      CONTINUE
C
C ***      IF USER WANTED TO PLACE TWO DEPARTMENTS CLOSE IF
C ***      POSSIBLE AND THE TWO DEPARTMENTS ARE NOT, REMOVE
C ***      EITHER ONE OF THE DEPARTMENTS.
        DO 785 I = 1,DEPT-1
        IF(STATUS(I).NE.1) GO TO 785
            DO 785 J =I+1,DEPT
            IF(TYPE(I,J).NE.2) GO TO 785
            IF(RELA(I,J).NE.1) GO TO 785
            IF(NBO(I,J).EQ.1) GO TO 785
            ID = I
            IF(STATUS(J).EQ.1) NEXT = J
            IF(STATUS(J).EQ.1.AND.RAN(NDOM).GT.0.5) ID = J
            IF(STATUS(J).EQ.1.AND.RAN(NDOM).GT.0.5) NEXT = I
            IF(NP.EQ.1) WRITE(6,*)'DUE USER PREF. CLOSE -'
            GO TO 990
785      CONTINUE
C
C ***      IF USER WANTED TO PLACE TWO DEPARTMENTS SEPARATE IF
C ***      POSSIBLE AND THE TWO DEPARTMENTS ARE NOT, REMOVE
C ***      EITHER ONE OF THE DEPARTMENTS.
        DO 787 I = 1,DEPT-1
        IF(STATUS(I).NE.1) GO TO 787
            DO 787 J =I+1,DEPT
            IF(TYPE(I,J).NE.2) GO TO 787
            IF(RELA(I,J).NE.2) GO TO 787
            IF(NBO(I,J).EQ.0) GO TO 787
            ID = I
            IF(STATUS(J).EQ.1) NEXT = J
            IF(STATUS(J).EQ.1.AND.RAN(NDOM).GT.0.5) ID = J
            IF(STATUS(J).EQ.1.AND.RAN(NDOM).GT.0.5) NEXT = I
            IF(NP.EQ.1) WRITE(6,*)'DUE USER PREF. SEPARATE -'
            GO TO 990
787      CONTINUE
C
C ***      IF ANY NEIGHBORING DEPARTMENT TO THE DEPARTMENT REQUIRING
C ***      HEAT DOES NOT PRODUCE HEAT, REMOVE EITHER ONE OF THE
C ***      DEPARTMENTS.
        DO 781 I = 1,DEPT
        IF(HEAT(I).EQ.1) GO TO 784

```

```

781  CONTINUE
      GO TO 783
784  DO 782 I = 1,DEPT
      IF(HEAT(I).NE.2) GO TO 782
      IF(STATUS(I).NE.1) GO TO 782
          DO 782 J = 1,DEPT
          IF(I.EQ.J) GO TO 782
          IF(NBO(I,J).NE.1) GO TO 782
          IF(HEAT(J).EQ.1) GO TO 782
          ID = I
          IF(STATUS(J).EQ.1) NEXT = J
          IF(STATUS(J).EQ.1.AND.RAN(NDOM).GT.0.5) ID = J
          IF(STATUS(J).EQ.1.AND.RAN(NDOM).GT.0.5) NEXT = I
          IF(NP.EQ.1) WRITE(6,*) 'DUE TO ENERGY SAVING -'
          GO TO 990
782  CONTINUE
C
C *** IF MATERIAL HANDLING COST BETWEEN TWO DEPARTMENTS IS THE
C *** HIGHEST ONE, REMOVE EITHER ONE OF THE DEPARTMENTS.
783  H COST = 0.
      ID = 0
      JD = 0
      DO 790 I = 1,DEPT-1
      IF(STATUS(I).NE.1) GO TO 790
          DO 790 J = I+1,DEPT
          HAND = DIST(I,J)*QTY(I,J)*COST(I,J)+
+          DIST(I,J)*QTY(J,I)*COST(J,I)
          IF(HAND.LE.H COST) GO TO 790
          H COST = HAND
          ID = I
          IF(STATUS(J).EQ.1) NEXT = J
          IF(STATUS(J).EQ.1.AND.RAN(NDOM).GT.0.5) ID = J
          IF(STATUS(J).EQ.1.AND.RAN(NDOM).GT.0.5) NEXT = I
790  CONTINUE
      IF(H COST.NE.0..AND.NP.EQ.1)WRITE(6,*) 'DUE TO MTL HDL COST -'
      IF(H COST.NE.0.) GO TO 990
      IF(NP.EQ.1) WRITE(6,*) 'FOUND NOTHING TO REMOVE'
      GO TO 9999
C
C *****
C
C *** CHANGE THE STATUS OF THE REMOVED DEPARTMENT TO 'REMOVED'
990  STATUS(ID)=2
      NREM = NREM+1
      IF(NP.EQ.1) WRITE(6,993) ID
993  FORMAT(' ','DEPARTMENT ',I2,' IS REMOVED FOR REPLACEMENT')
C
C *****
C
C *** FIND A DEPT. FOR REPLACEMENT AMONG SAME SIZED DEPTS.

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1011 DO 1010 J = 1,DEPT
      IF(J.EQ.ID) GO TO 1010
      IF(SIZE(ID).NE.SIZE(J)) GO TO 1010
      IF(STATUS(J).NE.1) GO TO 1010
      JD = J
      IF(ID.EQ.IDOLD.AND.JD.EQ.JDOLD) GO TO 1010
      IF(ID.EQ.JDOLD.AND.JD.EQ.IDOLD) GO TO 1010
      STATUS(JD) = 3
      BACK = 2
      GO TO 1500
1010 CONTINUE
C
C *** FIND A DEPARTMENT FOR REPLACEMENT AMONG NEIGHBORING
C *** DEPARTMENTS
1001 DO 1000 J = 1,DEPT
      IF(J.EQ.ID) GO TO 1000
      IF(NBO(ID,J).NE.1) GO TO 1000
      IF(STATUS(J).NE.1) GO TO 1000
      JD = J
      IF(ID.EQ.IDOLD.AND.JD.EQ.JDOLD) GO TO 1000
      IF(ID.EQ.JDOLD.AND.JD.EQ.IDOLD) GO TO 1000
      STATUS(JD) = 3
      BACK = 1
      GO TO 1500
1000 CONTINUE
C
C *** IF NO REPLACEMENT FOUND, RETURN TO THE REMOVAL STAGE
      DO 1023 I = 1,DEPT
1023 IF(STATUS(I).EQ.3) STATUS(I) = 1
      STATUS(ID) = 4
      IF(NP.EQ.1) WRITE(6,1024) ID
1024 FORMAT(' ', 'DEPARTMENT ', I2, ' HAS NO REPLACEMENT -',
+ 'PICK ANOTHER')
      IF(NEXT.EQ.0) GO TO 100
      ID = NEXT
      NEXT = 0
      GO TO 990
C
C *****
C
C *** EXAMINE THE SWITCH-SUGGESTION OF DEPARTMENT ID AND JD
C
1500 IF(NP.EQ.1) WRITE(6,132) JD, ID
132  FORMAT(' DEPARTMENT ', I2, ' IS SELECTED FOR DEPARTMENT ', I2)
C
C *** CHECK LOADING LIMIT VIOLATION AND RETURN TO THE PREVIOUS
C *** PHASE FOR REST OF THEM
      IF(WGHT(ID).EQ.0.AND.WGHT(JD).EQ.0) GO TO 1515
      DO 1510 I = 1,ROW
        DO 1510 J = 1,COL

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                IF(LOAD(I,J).EQ.0) GO TO 1510
                IF(ASSIGN(I,J).EQ.ID.AND.WGHT(JD).EQ.1) GO TO 727
                IF(ASSIGN(I,J).EQ.JD.AND.WGHT(ID).EQ.1) GO TO 727
1510      CONTINUE
C
C ***      CHECK USER HARD PREFERENCE - CLOSE
1515      DO 1520 J = 1,DEPT
                IF(ID.EQ.J.OR.JD.EQ.J) GO TO 1520
                IF(TYPE(ID,J).NE.1.AND.TYPE(J,ID).NE.1) GO TO 1144
                IF((RELA(ID,J).EQ.1.OR.RELA(J,ID).EQ.1).AND.
+ (NBO(JD,J).NE.1.AND.NBO(J,JD).NE.1)) GO TO 727
                GO TO 1520
1144      IF(TYPE(JD,J).NE.1.AND.TYPE(J,JD).NE.1) GO TO 1520
                IF((RELA(JD,J).EQ.1.OR.RELA(J,JD).EQ.1).AND.
+ (NBO(ID,J).NE.1.AND.NBO(J,ID).NE.1)) GO TO 727
1520      CONTINUE
C
C ***      SEPARATE
                DO 1525 J = 1,DEPT
                IF(ID.EQ.J.OR.JD.EQ.J) GO TO 1525
                IF(TYPE(ID,J).NE.1.AND.TYPE(J,ID).NE.1) GO TO 1145
                IF((NBO(ID,J).EQ.1.OR.NBO(J,ID).EQ.1).AND.
+ (RELA(J,JD).EQ.2.OR.RELA(JD,J).EQ.2)) GO TO 727
                GO TO 1525
1145      IF(TYPE(JD,J).NE.1.AND.TYPE(J,JD).NE.1) GO TO 1525
                IF((NBO(JD,J).EQ.1.OR.NBO(J,JD).EQ.1).AND.
+ (RELA(J,ID).EQ.2.OR.RELA(ID,J).EQ.2)) GO TO 727
1525      CONTINUE
                NSWT = NSWT + 1
C
C*****
C
C ***      SAVE THE CURRENT CONFIGURATION TO USE IF SUGGESTION IS NOT
C ***      ACCEPTED
                DO 1623 I = 1,ROW
                        DO 1623 J = 1,COL
1623          SAVASS(I,J) = ASSIGN(I,J)
                DO 1624 I = 1,DEPT
                SAVCTX(I) = CNTX(I)
                SAVCTY(I) = CNTY(I)
                        DO 1624 J = 1,DEPT
                SAVNBO(I,J) = NBO(I,J)
1624      CONTINUE
C
C*****
C
C ***      PHYSICALLY SWITCH DEPARTMENT POSITIONS AND UPDATE STATUS
C
C ***      CHANGE THE POSITION OF TWO DEPARTMENTS
C ***      IF THE SIZE OF TWO DEPARTMENTS ARE NOT SAME, WRITE SMALL ONE

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C ***   ON THE OTHER END OF BIG ONE AND THEN CHANGE SMALL TO BIG ONE
        IF(SIZE(ID).EQ.SIZE(JD)) GO TO 3100
        BIG = JD
        SMALL = ID
        IF(SIZE(ID).GT.SIZE(JD)) BIG = ID
        IF(SIZE(ID).GT.SIZE(JD)) SMALL = JD

C
C ***   CALCULATE MAXIMUM LENGTH OF SMALL DEPARTMENT
        TEM = SIZE(SMALL)/MINSIDE(SMALL)
        MAXSIDE(SMALL) = INT(TEM)

C
C ***   FIND COORDINATE OF 4 EXTREME POINTS OF BIG DEPARTMENT
        PAX = COL
        PAY = ROW
        PBX = 1
        PBY = ROW
        PCX = COL
        PCY = 1
        PDX = 1
        PDY = 1
        DO 3000 I = 1,ROW
            DO 3000 J = 1,COL

C
C ***   WRITE INDEX '99' ON SMALL DEPT.
        IF(ASSIGN(I,J).EQ.SMALL) ASSIGN(I,J) = 99
        IF(ASSIGN(I,J).NE.BIG) GO TO 3000

C
C ***   POINT A
        IF(I.GT.PAY) GO TO 3010
        PAY = I
        IF(J.GE.PAX) GO TO 3010
        PAX = J

C
C ***   POINT B
3010    IF(I.GT.PBY) GO TO 3020
        PBY = I
        IF(J.LE.PBX) GO TO 3020
        PBX = J

C
C ***   POINT C
3020    IF(I.LT.PCY) GO TO 3030
        PCY = I
        IF(J.GE.PCX) GO TO 3030
        PCX = J

C
C ***   POINT D
3030    IF(I.LT.PDY) GO TO 3000
        PDY = I
        IF(J.LE.PDX) GO TO 3000
        PDX = J

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3000    CONTINUE
C
C ***    COMPARE THE CENTROID OF BIG AND SMALL AND DECIDE WHERE TO
C ***    BEGIN WRITING ON BIG
C
C ***    CASE A
          IF((CNTX(BIG).LE.CNTX(SMALL)).AND.(CNTY(BIG).LE.CNTY(SMALL)))
+        GO TO 3050
C
C ***    CASE B
          IF((CNTX(BIG).GE.CNTX(SMALL)).AND.(CNTY(BIG).LE.CNTY(SMALL)))
+        GO TO 3060
C
C ***    CASE C
          IF((CNTX(BIG).LE.CNTX(SMALL)).AND.(CNTY(BIG).GE.CNTY(SMALL)))
+        GO TO 3070
C
C ***    CASE D
          IF((CNTX(BIG).GE.CNTX(SMALL)).AND.(CNTY(BIG).GE.CNTY(SMALL)))
+        GO TO 3080
C
C ***    MOVE SMALL DEPT TO THE POINT A OF BIG DEPT
3050    NBLOCK = 0
          NX = PBX - PAX + 1
          NY = PCY - PAY + 1
          IF(NY.LT.NX) GO TO 3056
          IF(NX.GT.MAXSIDE(SMALL)) GO TO 3054
C
C ***    IF NX IS SMALLER THAN MAXSIDE OF SMALL ONE
          DO 3057 I = PAY,ROW
              DO 3057 J = PAX,COL
                  IF(ASSIGN(I,J).NE.BIG) GO TO 3057
                  ASSIGN(I,J) = SMALL
                  NBLOCK = NBLOCK+1
                  IF(NBLOCK.EQ.SIZE(SMALL)) GO TO 3287
3057    CONTINUE
          GO TO 9996
C
C ***    IF NX IS BIGGER THAN MAXSIDE OF SMALL ONE
3054    DO 3055 I = PAY,ROW
          DO 3055 J = PAX,PAX+MAXSIDE(SMALL)
              IF(ASSIGN(I,J).NE.BIG) GO TO 3055
              ASSIGN(I,J) = SMALL
              NBLOCK = NBLOCK+1
              IF(NBLOCK.EQ.SIZE(SMALL)) GO TO 3287
3055    CONTINUE
          GO TO 9996
C
C ***    IF NY IS SMALLER THAN NX
3056    IF(NY.GT.MAXSIDE(SMALL)) GO TO 21

```

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C
C *** IF NY IS SMALLER THAN MAXSIDE OF SMALL ONE
DO 19 I = PAX,COL
      DO 19 J = PAY,ROW
      IF(ASSIGN(J,I).NE.BIG) GO TO 19
      ASSIGN(J,I) = SMALL
      NBLOCK = NBLOCK+1
      IF(NBLOCK.EQ.SIZE(SMALL)) GO TO 3287
19    CONTINUE
      GO TO 9996

C
C *** IF NY IS BIGGER THAN MAXSIDE OF SMALL ONE
21    DO 29 I = PAX,COL
      DO 29 J = PAY,PAY+MAXSIDE(SMALL)
      IF(ASSIGN(J,I).NE.BIG) GO TO 29
      ASSIGN(J,I) = SMALL
      NBLOCK = NBLOCK+1
      IF(NBLOCK.EQ.SIZE(SMALL)) GO TO 3287
29    CONTINUE
      GO TO 9996

C
C *** MOVE SMALL DEPT TO THE POINT B OF BIG DEPT
3060  NBLOCK = 0
      NX = PBX - PAX + 1
      NY = PDY - PBY + 1
      IF(NY.LT.NX) GO TO 66
      IF(NX.GT.MAXSIDE(SMALL)) GO TO 67

C
C *** NX IS SMALLER THAN MAXSIDE OF SMALL ONE
DO 68 I = PBY,ROW
      DO 68 J = PBX,1,-1
      IF(ASSIGN(I,J).NE.BIG) GO TO 68
      ASSIGN(I,J) = SMALL
      NBLOCK = NBLOCK+1
      IF(NBLOCK.EQ.SIZE(SMALL)) GO TO 3287
68    CONTINUE
      GO TO 9996

C
C *** NX IS BIGGER THAN MAXSIDE OF SMALL ONE
67    DO 3065 I = PBY,ROW
      DO 3065 J = PBX,PBX-MAXSIDE(SMALL),-1
      IF(ASSIGN(I,J).NE.BIG) GO TO 3065
      ASSIGN(I,J) = SMALL
      NBLOCK = NBLOCK+1
      IF(NBLOCK.EQ.SIZE(SMALL)) GO TO 3287
3065  CONTINUE
      GO TO 9996

C
C *** NY IS SMALLER THAN NX
66    IF(NY.GT.MAXSIDE(SMALL)) GO TO 69

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C
C ***  NY IS SMALLER THAN MAXSIDE OF SMALL ONE
DO 71 I = PBX,1,-1
      DO 71 J = PBX,ROW
      IF(ASSIGN(J,I).NE.BIG) GO TO 71
      ASSIGN(J,I) = SMALL
      NBLOCK = NBLOCK+1
      IF(NBLOCK.EQ.SIZE(SMALL)) GO TO 3287
71    CONTINUE
      GO TO 9996

C
C ***  NY IS BIGGER THAN MAXSIDE OF SMALL ONE
69    DO 73 I = PBX,1,-1
      DO 73 J = PBX,PBX+MAXSIDE(SMALL)
      IF(ASSIGN(J,I).NE.BIG) GO TO 73
      ASSIGN(J,I) = SMALL
      NBLOCK = NBLOCK+1
      IF(NBLOCK.EQ.SIZE(SMALL)) GO TO 3287
73    CONTINUE
      GO TO 9996

C
C ***  MOVE SMALL DEPT TO THE POINT C OF BIG DEPT
3070  NBLOCK = 0
      NX = PDX - PCX + 1
      NY = PCY - PAY + 1
      IF(NY.LT.NX) GO TO 137
      IF(NX.GT.MAXSIDE(SMALL)) GO TO 139

C
C ***  NX IS SMALLER THAN MAXSIDE OF SMALL ONE
DO 138 I = PCY,1,-1
      DO 138 J = PCX,COL
      IF(ASSIGN(I,J).NE.BIG) GO TO 138
      ASSIGN(I,J) = SMALL
      NBLOCK = NBLOCK+1
      IF(NBLOCK.EQ.SIZE(SMALL)) GO TO 3287
138   CONTINUE
      GO TO 9996

C
C ***  NX IS BIGGER THAN MAXSIDE OF SMALL ONE
139   DO 3075 I = PCY,1,-1
      DO 3075 J = PCX,PCX+MAXSIDE(SMALL)
      IF(ASSIGN(I,J).NE.BIG) GO TO 3075
      ASSIGN(I,J) = SMALL
      NBLOCK = NBLOCK+1
      IF(NBLOCK.EQ.SIZE(SMALL)) GO TO 3287
3075  CONTINUE
      GO TO 9996

C
C ***  NY IS SMALLER THAN NX
137   IF(NY.GT.MAXSIDE(SMALL)) GO TO 234

```

```

C
C ***  NY IS SMALLER THAN MAXSIDE OF SMALL ONE
DO 237 I = PCX, COL
      DO 237 J = PCY, 1, -1
      IF(ASSIGN(J, I).NE.BIG) GO TO 237
      ASSIGN(J, I) = SMALL
      NBLOCK = NBLOCK+1
      IF(NBLOCK.EQ.SIZE(SMALL)) GO TO 3287
237   CONTINUE
      GO TO 9996

C
C ***  NY IS BIGGER THAN MAXSIDE OF SMALL ONE
234   DO 239 I = PCX, COL
      DO 239 J = PCY, PCY+MAXSIDE(SMALL), -1
      IF(ASSIGN(J, I).NE.BIG) GO TO 239
      ASSIGN(J, I) = SMALL
      NBLOCK = NBLOCK+1
      IF(NBLOCK.EQ.SIZE(SMALL)) GO TO 3287
239   CONTINUE
      GO TO 9996

C
C ***  MOVE SMALL DEPT TO THE POINT D OF BIG DEPT
3080  NBLOCK = 0
      NX = PDX - PCX + 1
      NY = PDY - PBY + 1
      IF(NY.LT.NX) GO TO 5361
      IF(NX.GT.MAXSIDE(SMALL)) GO TO 5366

C
C ***  NX IS SMALLER THAN MAXSIDE OF SMALL ONE
DO 5421 I = PDY, 1, -1
      DO 5421 J = PDX, 1, -1
      IF(ASSIGN(I, J).NE.BIG) GO TO 5421
      ASSIGN(I, J) = SMALL
      NBLOCK = NBLOCK+1
      IF(NBLOCK.EQ.SIZE(SMALL)) GO TO 3287
5421  CONTINUE
      GO TO 9996

C
C ***  NX IS BIGGER THAN MAXSIDE OF SMALL ONE
5366  DO 3085 I = PDY, 1, -1
      DO 3085 J = PDX, PDX-MAXSIDE(SMALL), -1
      IF(ASSIGN(I, J).NE.BIG) GO TO 3085
      ASSIGN(I, J) = SMALL
      NBLOCK = NBLOCK+1
      IF(NBLOCK.EQ.SIZE(SMALL)) GO TO 3287
3085  CONTINUE
      GO TO 9996

C
C ***  NY IS SMALLER THAN NX
5361  IF(NY.GT.MAXSIDE(SMALL)) GO TO 6931

```

```

C
C *** NY IS SMALLER THAN MAXSIDE OF SMALL ONE
DO 4421 I = PDX,1,-1
      DO 4421 J = PDY,1,-1
      IF(ASSIGN(J,I).NE.BIG) GO TO 4421
      ASSIGN(J,I) = SMALL
      NBLOCK = NBLOCK+1
      IF(NBLOCK.EQ.SIZE(SMALL)) GO TO 3287
4421  CONTINUE
      GO TO 9996
C
C *** NY IS BIGGER THAN MAXSIDE OF SMALL ONE
6931  DO 6937 I = PDX,1,-1
      DO 6937 J = PDY,PDY-MAXSIDE(SMALL),-1
      IF(ASSIGN(J,I).NE.BIG) GO TO 6937
      ASSIGN(J,I) = SMALL
      NBLOCK = NBLOCK+1
      IF(NBLOCK.EQ.SIZE(SMALL)) GO TO 3287
6937  CONTINUE
C
C *** SWITCH MORE INDICES FROM BIG TO SMALL
9996  IF(NP.EQ.1) WRITE(6,*) 'SEARCHED MORE TO CONVERT TO SMALL'
      MANUAL = 1
      DO 9994 I = 1,ROW
        DO 9994 J = 1,COL
        IF(ASSIGN(I,J).NE.BIG) GO TO 9994
        IF(J.EQ.COL) GO TO 8003
        IF(ASSIGN(I,J+1).EQ.SMALL) GO TO 8009
8003  IF(J.EQ.1) GO TO 8005
        IF(ASSIGN(I,J-1).EQ.SMALL) GO TO 8009
8005  IF(I.EQ.1) GO TO 8007
        IF(ASSIGN(I-1,J).EQ.SMALL) GO TO 8009
8007  IF(I.EQ.ROW) GO TO 9994
        IF(ASSIGN(I+1,J).EQ.SMALL) GO TO 8009
        GO TO 9994
8009  ASSIGN(I,J) = SMALL
        NBLOCK = NBLOCK+1
        IF(NBLOCK.EQ.SIZE(SMALL)) GO TO 3287
9994  CONTINUE
      IF(INTER.NE.1) GO TO 3233
      DO 8010 I = 1,ROW
        DO 8010 J = 1,COL
        IF(ASSIGN(I,J).NE.BIG) GO TO 8010
        ASSIGN(I,J) = SMALL
        NBLOCK = NBLOCK+1
        IF(NBLOCK.EQ.SIZE(SMALL)) GO TO 3287
8010  CONTINUE
      WRITE(6,*) '*** ERROR AT DEPT. CONVERSION TO SMALL'
      GO TO 9999
C

```

```

C *** SWITCH DEPT INDEX 99 TO BIG
3287 DO 8888 I = 1,ROW
      DO 8888 J = 1,COL
8888     IF(ASSIGN(I,J).EQ.99) ASSIGN(I,J) = BIG
      MEMO = SMALL
C
C *** CHECK THE SHAPE OF TWO DEPARTMENTS
5500 XL = COL
      XH = 1
      YL = ROW
      YH = 1
      DO 4010 I = 1,ROW
        DO 4010 J = 1,COL
        IF(ASSIGN(I,J).NE.MEMO) GO TO 4010
        IF(I.GT.YH) YH = I
        IF(I.LT.YL) YL = I
        IF(J.GT.XH) XH = J
        IF(J.LT.XL) XL = J
4010 CONTINUE
C
C ** CALCULATE THE SIZE OF RECTANGLE THAT INCLUDES THE DEPT
      RATE = SIZE(MEMO)/((YH-YL+1)*(XH-XL+1))
      IF(RATE.LT.FACT.AND.NP.EQ.1) WRITE(6,*)
+ 'DUE TO UNACCEPTABLE SHAPE -'
      IF(RATE.LT.FACT) GO TO 3233
      IF(MEMO.EQ.BIG) GO TO 5555
      MEMO = BIG
      GO TO 5500
C
C *** THE SIZE OF TWO DEPARTMENTS ARE SAME, SO JUST SWITCH NAMES
3100 DO 3200 I = 1,ROW
      DO 3200 J = 1,COL
      IF(ASSIGN(I,J).EQ.ID) ASSIGN(I,J) = 99
      IF(ASSIGN(I,J).EQ.JD) ASSIGN(I,J) = ID
3200     IF(ASSIGN(I,J).EQ.99) ASSIGN(I,J) = JD
C
C *** ASK USERS WHETHER MODIFICATION IS NECESSARY
5555 IF(INTER.NE.1) GO TO 3230
      IF(MANUAL.NE.1) GO TO 3230
      DO 3297 I = 1,ROW
3297     WRITE(*,3298) (ASSIGN(I,J),J=1,COL)
3298     FORMAT(' ',20(I2,1X)//)
      WRITE(*,*)' '
C
      WRITE(*,*) 'DO YOU WANT TO CHANGE ANY? 1-YES, 2-NO'
      READ(*,*) NSER
      IF(NSER.NE.1) GO TO 3230
      WRITE(*,*) 'ENTER A BLOCK COORDINATES SEPARATED BY SPACE'
      READ(*,*) IX,IY
      WRITE(*,*) 'ENTER OTHER BLOCK COORDINATES SEPARATED BY SPACE'

```

```

      READ(*,*) JX,JY
      NAME = ASSIGN(IX,IY)
      ASSIGN(IX,IY) = ASSIGN(JX,JY)
      ASSIGN(JX,JY) = NAME
      GO TO 5555
C
C ***   CALCULATE OBJECTIVE FUNCTION VALUE
3230    MANUAL = 0
        CALL DISTANCE
        CALL NEIGHBOR
        CALL UTILITY
        CALL OBJECTIV
        IF(OBJECT.GE.TEMOBJ) GO TO 3231
C
C ***   RETURN TO THE VALUE TO ORIGINAL
3233    IF(NP.EQ.1) WRITE(6,*) 'THE SUGGESTION IS REJECTED
      +   - BACKING UP'
        DO 6623 I = 1,ROW
            DO 6623 J = 1,COL
16623        ASSIGN(I,J) = SAVASS(I,J)
        DO 6624 I = 1,DEPT
            CNTX(I) = SAVCTX(I)
            CNTY(I) = SAVCTY(I)
            DO 6624 J = 1,DEPT
                NBO(I,J) = SAVNBO(I,J)
16624    CONTINUE
        CALL UTILITY
727     IF(BACK.EQ.1) GO TO 1001
        IF(BACK.EQ.2) GO TO 1011
C
C ***   BEGIN TO FIND VIOLATION AGAIN
3231    IF(NP.EQ.1) WRITE(6,*) 'THE SUGGESTION IS ACCEPTED'
        OBJECT = TEMOBJ
C
C ***   RENEW THE STATUS OF DEPT. TO CONTINUE LAYOUT PROCESS
        DO 3333 I = 1,DEPT
            IF(STATUS(I).EQ.5) GO TO 3333
            STATUS(I) = 1
3333    CONTINUE
        IDOLD = ID
        JDOLD = JD
        GO TO 100
C
9999    IF(NP.NE.3) GO TO 9993
        NP = 2
        ITER = ITER - 1
        CALL DISTANCE
        CALL NEIGHBOR
        CALL UTILITY
        CALL OBJECTIV

```

```

9993  WRITE(6,196) NREM,NSWT
196   FORMAT(// ' TOTAL DEPT REMOVAL =',I5,10X,'DEPT SWITCH =',I5)
      IRET2 = LIB$STAT_TIMER(ICODE,CPUTIM)
      WRITE(6,341) CPUTIM/100.
341   FORMAT(// ' * CPU TIME =',F10.3)
      STOP
      END

C
C*****
C*****
C
C ***   CALCULATE OBJECTIVE FUNCTION VALUE FOR COMPARISON WITH OLD
C ***   ONE
C       SUBROUTINE OBJECTIV
C
C       DIMENSION DIST(20,20),QTY(20,20),COST(20,20),NBO(20,20)
C       DIMENSION NOSE(20),MOVE(20)
C
C       INTEGER HEAT(20),EXPN(20,20),RELA(20,20),TYPE(20,20),DANG(20)
C       INTEGER UAIR(20),UPOWER(20),UWATER(20),UEXIT(20),UVENT(20)
C       INTEGER EXPO(20),AIR(20),POWER(20),WATER(20),EXIT(20)
C       INTEGER VIBA(20),ASSIGN(20,20),VENT(20),DEPT,ROW,COL
C
C       REAL MHC
C
C       COMMON/MEM1/QTY,COST,NOSE,VIBA,DANG,EXPO,MOVE,HEAT,EXPN,RELA,
1      TYPE,UAIR,UPOWER,UWATER,UEXIT,UVENT,TEMOBJ,OBJECT,ITER,NSWT,
2      AIR,POWER,WATER,EXIT,VENT,NREM,NP
C       COMMON/MEM2/DIST,ASSIGN,NBO,ROW,COL,DEPT,ID,JD
C
C*****
C
C ***   MATERIAL HANDLING COST
C       MHC = 0.
C       DO 100 I = 1,DEPT-1
C           DO 100 J = I+1,DEPT
C               MHC = MHC+QTY(I,J)*COST(I,J)*DIST(I,J)+
+           QTY(J,I)*COST(J,I)*DIST(I,J)
100      CONTINUE
C
C ***   USER PREFERENCE - CLOSE
C       NUP = 0
C       DO 200 I = 1,DEPT-1
C           DO 200 J = I+1,DEPT
C               IF(TYPE(I,J).NE.2) GO TO 200
C               IF(RELA(I,J).NE.1) GO TO 200
C               IF(NBO(I,J).EQ.0) NUP = NUP+1
200      CONTINUE
C
C ***   USER PREFERENCE - SEPARATE

```



```

DO 300 I = 1,DEPT-1
    DO 300 J = I+1,DEPT
        IF(TYPE(I,J).NE.2) GO TO 300
        IF(RELA(I,J).NE.2) GO TO 300
        IF(NBO(I,J).EQ.1) NUP = NUP+1
300    CONTINUE
C
C ***    FUTURE EXPANSION PLAN
        NBK = 0
        DO 400 K = 1,DEPT
            IF(MOVE(K).NE.1) GO TO 400
            NID = 0
                DO 400 I = 1,ROW
                    DO 400 J = 1,COL
                        IF(ASSIGN(I,J).NE.K) GO TO 400
                        IF(NID.EQ.1) GO TO 400
                        IF(EXPN(I,J).NE.1) GO TO 400
                        NBK = NBK+1
                        NID = 1
400    CONTINUE
C
C ***    HEALTH/SAFETY
        NNS = 0
        NVB = 0
        NEX = 0
        NDG = 0
        DO 205 I = 1,DEPT-1
            DO 205 J = I+1,DEPT
                IF(NBO(I,J).NE.1) GO TO 205
C
C ***    COUNT NOISE VIOLATION
                IF((NOSE(I).EQ.1.AND.NOSE(J).EQ.2).OR.
+                (NOSE(I).EQ.2.AND.NOSE(J).EQ.1)) NNS = NNS+1
C
C ***    COUNT DANGEROUS EQUIPMENT VIOLATION
                IF((DANG(I).EQ.1.AND.DANG(J).EQ.2).OR.
+                (DANG(I).EQ.2.AND.DANG(J).EQ.1)) NDG = NDG+1
C
C ***    COUNT VIBRATION VIOLATION
                IF((VIBA(I).EQ.1.AND.VIBA(J).EQ.2).OR.
+                (VIBA(I).EQ.2.AND.VIBA(J).EQ.1)) NVB = NVB+1
C
C ***    COUNT EXPLOSION VIOLATION
                IF((EXPO(I).EQ.1.AND.EXPO(J).EQ.2).OR.
+                (EXPO(I).EQ.2.AND.EXPO(J).EQ.1)) NEX = NEX+1
205    CONTINUE
C
C ***    UTILITY & DOOR
        NAR = 0
        NPW = 0

```

```

NWT = 0
NDO = 0
NVT = 0
DO 206 I = 1,DEPT
  IF(AIR(I).EQ.1.AND.UAIR(I).EQ.0) NAR = NAR+1
  IF(POWER(I).EQ.1.AND.UPOWER(I).EQ.0) NPW = NPW+1
  IF(EXIT(I).EQ.1.AND.UEXIT(I).EQ.0) NDO = NDO+1
  IF(WATER(I).EQ.1.AND.UWATER(I).EQ.0) NWT = NWT+1
206 IF(VENT(I).EQ.1.AND.UVENT(I).EQ.0) NVT = NVT+1
C
C *** ENERGY
NHT = 0
NHS = 0
DO 2070 I = 1,DEPT-1
  DO 2070 J = I+1,DEPT
    IF(NBO(I,J).NE.1) GO TO 2070
    IF((HEAT(I).EQ.1.AND.HEAT(J).EQ.3).OR.
      + (HEAT(I).EQ.3.AND.HEAT(J).EQ.1)) NHT = NHT+1
    IF((HEAT(I).EQ.1.AND.HEAT(J).EQ.2).OR.
      + (HEAT(I).EQ.2.AND.HEAT(J).EQ.1)) NHS = NHS+1
2070 CONTINUE
  IF(COEMHC.EQ.1.) GO TO 337
C
C *** COMPUTE NEW OBJECTIVE FUNCTION VALUE
C *** READ IN COEFFICIENT OF EACH COUNTER
COEMHC = 1.
READ(5,*) COENUP
READ(5,*) COENBK
READ(5,*) COENNS
READ(5,*) COENVB
READ(5,*) COENEX
READ(5,*) COENDG
READ(5,*) COENVT
READ(5,*) COENAR
READ(5,*) COENPW
READ(5,*) COENDO
READ(5,*) COENWT
READ(5,*) COENHT
READ(5,*) COENHS
337 TEMOBJ = MHC*COEMHC + NUP*COENUP + NBK*COENBK + NNS*COENNS +
1 NVB*COENVB + NEX*COENEX + NAR*COENAR + NPW*COENPW +
2 NWT*COENWT + NHT*COENHT - NHS*COENHS + NDO*COENDO +
3 NDG*COENDG + NVT*COENVT
C
C *** REPORT CALCULATION RESULTS IF NEW
IF(OBJECT.LT.TEMOBJ) GO TO 444
IF(NP.EQ.3) GO TO 444
IF(NP.EQ.4) NP = 3
WRITE(6,902) ITER,NREM,NSWT
CALL REPORT

```

```

WRITE(6,904)
WRITE(6,950)
WRITE(6,952)
WRITE(6,951)
WRITE(6,954) MHC,MHC
TEM=NUP*COENUP
WRITE(6,956) NUP,COENUP,TEM
TEM=NBK*COENBK
WRITE(6,958) NBK,COENBK,TEM
TEM=NNS*COENNS
WRITE(6,960) NNS,COENNS,TEM
TEM=NVB*COENVB
WRITE(6,962) NVB,COENVB,TEM
TEM=NEX*COENEX
WRITE(6,964) NEX,COENEX,TEM
TEM=NDG*COENDG
WRITE(6,965) NDG,COENDG,TEM
TEM=NVT*COENVT
WRITE(6,966) NVT,COENVT,TEM
TEM=NAR*COENAR
WRITE(6,967) NAR,COENAR,TEM
TEM=NPW*COENPW
WRITE(6,968) NPW,COENPW,TEM
TEM=NWT*COENWT
WRITE(6,970) NWT,COENWT,TEM
TEM=NDO*COENDO
WRITE(6,972) NDO,COENDO,TEM
TEM=NHT*COENHT
WRITE(6,974) NHT,COENHT,TEM
TEM=NHS*COENHS
WRITE(6,976) NHS,COENHS,TEM
WRITE(6,951)
WRITE(6,978) TEMOBJ
WRITE(6,950)
IF(NP.EQ.3) WRITE(6,953)
IF(NP.EQ.3) WRITE(6,953)
902  FORMAT(// ' [ LOCATION PATTERN AND STATISTICS AT ITERATION',
+    I3,'] ' / ' REMOVED DEPARTMENTS =',I4,5X,'TRIAL SWITCH =',I4)
904  FORMAT(/)
953  FORMAT(////)
950  FORMAT(' ',56(' -'))
951  FORMAT(' ', '| ',54(' -'), '| ')
952  FORMAT(' | DESCRIPTION | VIOLATION | COEFCNT | SUM',
+    12X, '| ')
954  FORMAT(' | MTL HANDLNG | ',F12.2,' | ',7X,'1 | $',F13.2,' | ')
956  FORMAT(' | USER PREFRC | ',9X,I3,' | ',F8.1,' | ',F15.2,' | ')
958  FORMAT(' | EXPANS PLAN | ',9X,I3,' | ',F8.1,' | ',F15.2,' | ')
960  FORMAT(' | NOISE CNTRL | ',9X,I3,' | ',F8.1,' | ',F15.2,' | ')
962  FORMAT(' | VIBRATION C | ',9X,I3,' | ',F8.1,' | ',F15.2,' | ')
964  FORMAT(' | EXPLOSION C | ',9X,I3,' | ',F8.1,' | ',F15.2,' | ')

```

```

965  FORMAT('  DANGER-EQUIP  ',9X,I3,' ',F8.1,' ',F15.2,' ')
966  FORMAT('  VENT. EQUIP   ',9X,I3,' ',F8.1,' ',F15.2,' ')
967  FORMAT('  AIR-COMPRES  ',9X,I3,' ',F8.1,' ',F15.2,' ')
968  FORMAT('  POWER-FACIL  ',9X,I3,' ',F8.1,' ',F15.2,' ')
970  FORMAT('  WATER-FACIL  ',9X,I3,' ',F8.1,' ',F15.2,' ')
972  FORMAT('  DOOR-EXIT C  ',9X,I3,' ',F8.1,' ',F15.2,' ')
974  FORMAT('  HEAT CONTRL  ',9X,I3,' ',F8.1,' ',F15.2,' ')
976  FORMAT('  ENERGY CRDT ',9X,I3,' ',F8.1,' ',F15.2,' ')
978  FORMAT('  OBJECTIVE FUNCTION ',15X,' ',F15.2,' ')
444  RETURN
      END

```

C

C*****

C*****

C

```

C ***  CALCULATE RECTILINEAR DISTANCE BETWEEN TWO DEPARTMENTS
        SUBROUTINE DISTANCE

```

C

```

        DIMENSION CNTX(20),CNTY(20),DIST(20,20),NBO(20,20)

```

C

```

        INTEGER ASSIGN(20,20),SIZE(20),DEPT,ROW,COL

```

C

```

        COMMON/MEM2/DIST,ASSIGN,NBO,ROW,COL,DEPT,ID,JD,CNTX,CNTY,SIZE

```

C

C*****

C

```

        DO 100 I = 1,DEPT
          CNTX(I) = 0.
100      CNTY(I) = 0.
          DO 200 J = 1,ROW
            DO 200 J = 1,COL
              CNTX(ASSIGN(I,J)) = CNTX(ASSIGN(I,J))+J
200          CNTY(ASSIGN(I,J)) = CNTY(ASSIGN(I,J))+I
          DO 300 I = 1,DEPT
            CNTX(I) = CNTX(I)/SIZE(I)-.5
300          CNTY(I) = CNTY(I)/SIZE(I)-.5

```

C

```

C ***  CALCULATE RECTILINEAR DISTANCE BETWEEN TWO DEPARTMENTS

```

```

        DO 400 I = 1,DEPT-1
          DO 400 J = I+1,DEPT
400          DIST(I,J) = 0.
          DO 500 I = 1,DEPT-1
            DO 500 J = I+1,DEPT
              DIFX = CNTX(I) - CNTX(J)
              DIFX = ABS(DIFX)
              DIFY = CNTY(I) - CNTY(J)
              DIFY = ABS(DIFY)
500          DIST(I,J) = DIFX+DIFY

```

```

        RETURN

```

```

        END

```

```

C
C*****
C*****
C
C ***   FIND NEIGHBOR OF EACH DEPARTMENT
        SUBROUTINE NEIGHBOR
C
        DIMENSION CNTX(20),CNTY(20),DIST(20,20),NBO(20,20)
C
        INTEGER ASSIGN(20,20),SIZE(20),DEPT,ROW,COL
C
        COMMON/MEM2/DIST,ASSIGN,NBO,ROW,COL,DEPT,ID,JD,CNTX,CNTY,SIZE
C*****
C
        DO 100 I = 1,DEPT
            DO 100 J = 1,DEPT
100          NBO(I,J) = 0
            DO 200 I = 1,ROW
                DO 200 J = 1,COL
                    IF((I.EQ.ROW).OR.(J.EQ.COL)) GO TO 250
                    IF(ASSIGN(I,J).NE.ASSIGN(I,J+1))
+                     NBO(ASSIGN(I,J),ASSIGN(I,J+1)) = 1
                    IF(ASSIGN(I,J).NE.ASSIGN(I+1,J))
+                     NBO(ASSIGN(I,J),ASSIGN(I+1,J)) = 1
                    GO TO 200
250          IF(I.EQ.ROW.AND.J.EQ.COL) GO TO 200
                IF(I.EQ.ROW) GO TO 270
                IF(ASSIGN(I,J).NE.ASSIGN(I+1,J))
+                 NBO(ASSIGN(I,J),ASSIGN(I+1,J)) = 1
                GO TO 200
270          IF(ASSIGN(I,J).NE.ASSIGN(I,J+1))
+                 NBO(ASSIGN(I,J),ASSIGN(I,J+1)) = 1
200          CONTINUE
            DO 300 I = 1,DEPT
                DO 300 J = 1,DEPT
                    IF(I.EQ.J) GO TO 300
                    IF(NBO(I,J).EQ.1) NBO(J,I) = 1
300          CONTINUE
            RETURN
        END
C
C*****
C*****
C
C ***   REPORT THE LATEST LAYOUT CONFIGURATION
        SUBROUTINE REPORT
C
        DIMENSION CNTX(20),CNTY(20),DIST(20,20),NBO(20,20)
C

```

```

      INTEGER ASSIGN(20,20),SIZE(20),DEPT,ROW,COL
C
      COMMON/MEM2/DIST,ASSIGN,NBO,ROW,COL,DEPT,ID,JD,CNTX,CNTY,SIZE
C
C*****
C
C      WRITE THE CURRENT LAYOUT CONFIGURATION
C
      WRITE(6,300)
      DO 100 I = 1,ROW
100    WRITE(6,200) (ASSIGN(I,J),J=1,COL)
200    FORMAT(' ',20(I2,1X)//)
300    FORMAT(//)
      RETURN
      END
C
C*****
C*****
C
C ***      UPDATE UTILITY ASSIGNMENT STATUS OF DEPARTMENTS
      SUBROUTINE UTILITY
C
      DIMENSION DIST(20,20),QTY(20,20),COST(20,20),NBO(20,20)
      DIMENSION NOSE(20),MOVE(20)
C
      INTEGER AIR(20),POWER(20),WATER(20),EXIT(20),VENT(20)
      INTEGER UAIR(20),UPOWER(20),UWATER(20),UEXIT(20),UVENT(20)
      INTEGER FAIR(20,20),FPOWER(20,20),FWATER(20,20),FEXIT(20,20)
      INTEGER ASSIGN(20,20),FVENT(20,20),DEPT,ROW,COL
      INTEGER HEAT(20),EXPN(20,20),RELA(20,20),TYPE(20,20),DANG(20)
      INTEGER EXPO(20),VIBA(20)
C
      COMMON/MEM1/QTY,COST,NOSE,VIBA,DANG,EXPO,MOVE,HEAT,EXPN,RELA,
1     TYPE,UAIR,UPOWER,UWATER,UEXIT,UVENT,TEMOBJ,OBJECT,ITER,NSWT,
2     AIR,POWER,WATER,EXIT,VENT
      COMMON/MEM2/DIST,ASSIGN,NBO,ROW,COL,DEPT
      COMMON/MEM3/FAIR,FPOWER,FWATER,FEXIT,FVENT
C
C*****
      DO 701 I = 1,DEPT
      UAIR(I) = 0
      UPOWER(I) = 0
      UWATER(I) = 0
      UEXIT(I) = 0
701    UVENT(I) = 0
C
C ***      IF A COMPRESSED-AIR REQUIRED DEPARTMENT IS ASSIGNED ON THE
C ***      FLOOR WITH AIR, CHANGE THE INDEX TO 1 - SATISFIED
      DO 700 J = 1,ROW
          DO 700 K = 1,COL

```

```

NAME = ASSIGN(J,K)
IF(AIR(NAME).NE.1) GO TO 700
IF(UAIR(NAME).EQ.1) GO TO 700
IF(FAIR(J,K).EQ.1) UAIR(NAME) = 1
700    CONTINUE
C
C ***    IF A POWER REQUIRED DEPARTMENT IS ASSIGNED ON THE FLOOR
C ***    WITH POWER SUPPLY, CHANGE THE INDEX TO 1 - SATISFIED
DO 705 J = 1,ROW
      DO 705 K = 1,COL
        NAME = ASSIGN(J,K)
        IF(POWER(NAME).NE.1) GO TO 705
        IF(UPOWER(NAME).EQ.1) GO TO 705
        IF(FPOWER(J,K).EQ.1) UPOWER(NAME) = 1
705    CONTINUE
C
C ***    IF A WATER/SEWER REQUIRED DEPARTMENT IS ASSIGNED ON THE
C ***    FLOOR WITH WATER FACILITY, CHANGE THE INDEX TO 1 -
C ***    SATISFIED
DO 710 J = 1,ROW
      DO 710 K = 1,COL
        NAME = ASSIGN(J,K)
        IF(WATER(NAME).NE.1) GO TO 710
        IF(UWATER(NAME).EQ.1) GO TO 710
        IF(FWATER(J,K).EQ.1) UWATER(NAME) = 1
710    CONTINUE
C
C ***    IF AN EXIT/DOOR REQUIRED DEPARTMENT IS ASSIGNED ON THE
C ***    FLOOR WITH EXIT, CHANGE THE INDEX TO 1 - SATISFIED
DO 717 J = 1,ROW
      DO 717 K = 1,COL
        NAME = ASSIGN(J,K)
        IF(EXIT(NAME).NE.1) GO TO 717
        IF(UEXIT(NAME).EQ.1) GO TO 717
        IF(FEXIT(J,K).EQ.1) UEXIT(NAME) = 1
717    CONTINUE
C
C ***    IF A VENTILATION REQUIRED DEPARTMENT IS ASSIGNED ON THE
C ***    FLOOR WITH VENTILATION, CHANGE THE INDEX TO 1 -
C ***    SATISFIED
DO 703 J = 1,ROW
      DO 703 K = 1,COL
        NAME = ASSIGN(J,K)
        IF(VENT(NAME).NE.1) GO TO 703
        IF(UVENT(NAME).EQ.1) GO TO 703
        IF(FVENT(J,K).EQ.1) UVENT(NAME) = 1
703    CONTINUE
      RETURN
      END
C

```

```

C*****
C*****
C
C ***  RANDOM NUMBER GENERATOR
C ***  Z SUB(I)=(7**5)Z SUB(I-1))(MOD 2**31 - 1)
C ***  P227 LAW&KELTON
      FUNCTION RAN(IX)
      INTEGER A,P,IX,B15,B16,XHI,XALO,LEFTLO,FHI,K
      DATA A/16807/,B15/32768/,B16/65536/,P/2147483647/
      XHI = IX/B16
      XALO = (IX-XHI*B16)*A
      LEFTLO = XALO/B16
      FHI = XHI*A+LEFTLO
      K = FHI/B15
      IX = (((XALO-LEFTLO*B16)-P)+(FHI-K*B15)*B16)+K
      IF(IX.LT.0) IX=IX+P
      RAN = FLOAT(IX)*4.656612875E-10
      RETURN
      END

```


APPENDIX D. DATA FILE GENERATION PROGRAM LIST

```

C*****
C      FILE NAME : DATA.FOR                                vs 2.53
C*****
C      THIS PROGRAM CAN BE USED TO GENERATE DATA FILE FOR FLUKES.
C*****
C
C      [ DEPARTMENT ]
C      DEPT      : NUMBER OF DEPARTMENTS
C      SIZE(I)   : SIZE OF DEPARTMENT I IN UNIT NUMBER
C      MINSIDE(I) : MINIMUM WIDTH OR LENGTH OF DEPT. I
C      NOSE(I)   : PRODUCE(1), CONTROL(2), NIL(0)
C      VIBA(I)   :      "
C      EXPO(I)   : EXPLOSIVE(1), FLAME(2), NIL(0)
C      HEAT(I)   : PRODUCE(1), REQUIRED(2), CONTROL(3), NIL(0)
C      WGHT(I)   : HEAVY(1) OR NIL(0) (NIL = LIGHT)
C      EXIT(I)   : REQUIRED(1) OR NIL(0)
C      AIR(I)    :      "
C      POWER(I)  :      "
C      WATER(I)  :      "
C      MOVE(I)   : HARD(1), NIL(0) (NIL = OKAY TO MOVE)
C
C      [ FLOOR ]
C      LOAD(I,J) : LIGHT(1) OR NIL(0) ( HEAVY = NIL )
C      FAIR(I,J) : YES(1) OR NIL(0) (NOT AVAILABLE = NIL)
C      FPOWER(I,J) :      "
C      FWATER(I,J) :      "
C      FEXIT(I,J) :      "
C      EXPN(I,J) : EXPANSION SIDE - YES(1) OR NIL(0)
C      ASSIGN(I,J) : NAME OF CURRENT ASSIGNED DEPARTMENT
C      ROW      : ROW INDEX
C      COL      : COLUMN INDEX
C
C      [ FLOW ]
C      QTY(I,J)  : NUMBER OF AVERAGE UNITS
C      COST(I,J) : UNIT COST FOR MOVING
C
C      [ PREFERENCE ]
C      RELA(I,J) : RELATION - CLOSE(1), APART(2), NIL(0)
C      TYPE(I,J) : MUST(1), IP(2) (IF POSSIBLE), NIL(0)
C*****
C
C      ***      MAIN PROGRAM
C
C      DIMENSION MINSIDE(20),MOVE(20),LOAD(20,20),NOSE(20)
C      DIMENSION QTY(20,20),COST(20,20)
C

```

```

INTEGER SIZE(20),VIBA(20),EXPO(20),HEAT(20),WGHT(20),EXIT(20)
INTEGER AIR(20),POWER(20),WATER(20),FLAME(20),DANG(20)
INTEGER FAIR(20,20),FPOWER(20,20),FWATER(20,20),FEXIT(20,20)
INTEGER EXPN(20,20),ASSIGN(20,20),RELA(20,20),TYPE(20,20)
INTEGER VENT(20),FVENT(20,20),ROW,COL,DEPT

```

C

C*****

C

```

10  FORMAT(' ','ENTER THE SIZE OF DEPARTMENT ',I2)
15  FORMAT(' ','ENTER THE MINIMUM LENGTH OF DEPARTMENT ',I2)
20  FORMAT(' ','DOES DEPARTMENT ',I2,' MAKE OR AWAY FROM NOISE?'
+  '/' ' ',' 0-NO PROBLEM  1-PRODUCE  2-NEED CONTROL')
23  FORMAT(' ','DOES DEPT.',I2,' HAS DANG. EQUIP. OR AWAY FROM IT?'
+  '/' ' ',' 0-NO PROBLEM  1- DANGER EQUIP.  2-NEED AWAY FROM IT')
24  FORMAT(' ','DOES DEPT.',I2,' NEED VENTILATION EQUIPMENT?'
+  '/' ' ',' 0-NO PROBLEM  1- REQUIRED')
25  FORMAT(' ','IS DEPARTMENT ',I2,' HARD TO MOVE?'
+  '/' ' ',' 0-NO PROBLEM  1-HARD TO MOVE')
30  FORMAT(' ','DOES DEPARTMENT ',I2,' MAKE OR AWAY FROM
+  VIBRATION?/' ' ',' 0-NO PROBLEM  1-PRODUCE  2-NEED CONTROL')
35  FORMAT(' ','DOES DEPARTMENT ',I2,' HAVE EXPLOSIVE THING OR
+  FLAME?/' ' ',' 0-NO PROBLEM  1-EXPLOSIVE  2-FLAME')
40  FORMAT(' ','DOES DEPARTMENT ',I2,' PRODUCE HEAT OR NEED
+  CONTROL?/' ' ',' 0-NO PROBLEM  1-PRODUCE  2-REQUIRED
+  3-CONTROL')
50  FORMAT(' ','IS DEPARTMENT ',I2,' HEAVY FOR LIGHT ONLY
+  FLOOR?/' ' ',' 0-NO PROBLEM  1-HEAVY')
55  FORMAT(' ','DOES DEPARTMENT ',I2,' NEED TO HAVE DOOR OR
+  EXIT?/' ' ',' 0-NO PROBLEM  1-REQUIRED')
60  FORMAT(' ','DOES DEPARTMENT ',I2,' NEED TO HAVE COMPRESSED-
+  AIR?/' ' ',' 0-NO PROBLEM  1-REQUIRED')
65  FORMAT(' ','DOES DEPARTMENT ',I2,' NEED TO HAVE POWER
+  SUPPLY?/' ' ',' 0-NO PROBLEM  1-REQUIRED')
70  FORMAT(' ','DOES DEPARTMENT ',I2,' NEED TO HAVE WATER
+  SUPPLY?/' ' ',' 0-NO PROBLEM  1-REQUIRED')
110 FORMAT(' ','DOES FLOOR(',I2,',',I2,') HAVE COMPRESSED-AIR?'
+  '/' ' ',' 0-NO  1-YES')
115 FORMAT(' ','DOES FLOOR(',I2,',',I2,') HAVE POWER SUPPLY?'
+  '/' ' ',' 0-NO  1-YES')
120 FORMAT(' ','DOES FLOOR(',I2,',',I2,') HAVE WATER SUPPLY?'
+  '/' ' ',' 0-NO  1-YES')
125 FORMAT(' ','IS FLOOR(',I2,',',I2,') ON EXPANSION SIDE?'
+  '/' ' ',' 0-NO  1-YES')
130 FORMAT(' ','DOES FLOOR(',I2,',',I2,') CANNOT HAVE HEAVY
+  DEPT.?/' ' ',' 0-NO PROBLEM  1-LIGHT ONLY')
133 FORMAT(' ','DOES FLOOR(',I2,',',I2,') HAS DOOR ON IT?'
+  '/' ' ',' 0-NO  1-YES')
135 FORMAT(' ','ENTER DEPT. INDEX ASSIGNED ON FLOOR (',I2,',',
+  I2,')')
136 FORMAT(' ','DOES FLOOR(',I2,',',I2,') HAS VENT. EQUIP. ON IT?'

```

```

+ /' ',' 0-NO 1-YES')
210 FORMAT(' ','WHAT IS THE RELATION OF DEPT.','I2,' AND ','I2
+ /' ',' 0-DOES NOT MATTER 1-CLOSE 2-APART')
215 FORMAT(' ','WHAT IS THE RELATION TYPE OF DEPT.','I2,' AND ',
+ I2,/' ',' 0-DOES NOT MATTER 1-MUST 2-IF POSSIBLE')
225 FORMAT(' ','WHAT IS UNIT MOVING COST BETWEEN DEPT.','I2,
+ ' AND ','I2,?')
230 FORMAT(' ','NUMBER OF UNIT MOVING BETWEEN DEPT.','I2,
+ ' AND ','I2,?')
410 FORMAT(' ',3(I2,1X))
420 FORMAT(' ',4(I2,1X))
430 FORMAT(' ',10(I1,1X))
440 FORMAT(' ',20(I1,1X))
450 FORMAT(' ',20(I2,1X))
460 FORMAT(' ',10(F6.1,1X))
470 FORMAT(' ','DO YOU WANT TO CHANGE ANY? 1-YES 0-NO')
480 FORMAT(' ','ENTER ROW & COLUMN INDEX OF FLOOR WHICH')
490
C
C*****
C
C *** DATA READING
5 WRITE(*,*) 'ENTER THE NUMBER OF ROW COLUMN AND DEPTS'
  READ(*,*) ROW,COL,DEPT
  WRITE(*,480)
  READ(*,*) NSER
  IF(NSER.NE.0) GO TO 5
C
DO 100 I = 1,DEPT
  WRITE(*,10) I
  READ(*,*) SIZE(I)
  WRITE(*,15) I
  READ(*,*) MINSIDE(I)
  WRITE(*,20) I
  READ(*,*) NOSE(I)
  WRITE(*,23) I
  READ(*,*) DANG(I)
  WRITE(*,24) I
  READ(*,*) VENT(I)
  WRITE(*,25) I
  READ(*,*) MOVE(I)
  WRITE(*,30) I
  READ(*,*) VIBA(I)
  WRITE(*,35) I
  READ(*,*) EXPO(I)
  WRITE(*,40) I
  READ(*,*) HEAT(I)
  WRITE(*,50) I
  READ(*,*) WGHT(I)
  WRITE(*,55) I
  READ(*,*) EXIT(I)

```

```

WRITE(*,60) I
READ(*,*) AIR(I)
WRITE(*,65) I
READ(*,*) POWER(I)
WRITE(*,70) I
READ(*,*) WATER(I)
100 CONTINUE
C
101 WRITE(*,480)
    READ(*,*) NSER
    IF(NSER.NE.1) GO TO 199
    WRITE(*,*) 'WHAT DO YOU WANT TO CHANGE?  ENTER THE NUMBER'
    WRITE(*,*)
    WRITE(*,*) ' 1. DEPT. SIZE      2. MINIMUM SIDE      3. NOISE'
    WRITE(*,*) ' 4. DEPT MOVING    5. VIBRATION          6. EXPLOSION'
    WRITE(*,*) ' 7. HEAT              8. WEIGHT OF DEPT    9. EXIT'
    WRITE(*,*) '10. POWER           11. COMPRESSED-AIR 12. WATER'
    WRITE(*,*) '13. DANG. EQUIP. 14. VENTILATION'
    WRITE(*,*)
    READ(*,*) NSER
    WRITE(*,*) 'ENTER DEPARTMENT INDEX :'
    READ(*,*) ID
    IF(NSER.EQ.1) WRITE(*,10) ID
    IF(NSER.EQ.1) READ(*,*) SIZE(ID)
    IF(NSER.EQ.2) WRITE(*,15) ID
    IF(NSER.EQ.2) READ(*,*) MINSIDE(ID)
    IF(NSER.EQ.3) WRITE(*,20) ID
    IF(NSER.EQ.3) READ(*,*) NOSE(ID)
    IF(NSER.EQ.4) WRITE(*,25) ID
    IF(NSER.EQ.4) READ(*,*) MOVE(ID)
    IF(NSER.EQ.5) WRITE(*,30) ID
    IF(NSER.EQ.5) READ(*,*) VIBA(ID)
    IF(NSER.EQ.6) WRITE(*,35) ID
    IF(NSER.EQ.6) READ(*,*) EXPO(ID)
    IF(NSER.EQ.7) WRITE(*,40) ID
    IF(NSER.EQ.7) READ(*,*) HEAT(ID)
    IF(NSER.EQ.8) WRITE(*,50) ID
    IF(NSER.EQ.8) READ(*,*) WGHT(ID)
    IF(NSER.EQ.9) WRITE(*,55) ID
    IF(NSER.EQ.9) READ(*,*) EXIT(ID)
    IF(NSER.EQ.10) WRITE(*,65) ID
    IF(NSER.EQ.10) READ(*,*) POWER(ID)
    IF(NSER.EQ.11) WRITE(*,60) ID
    IF(NSER.EQ.11) READ(*,*) AIR(ID)
    IF(NSER.EQ.12) WRITE(*,70) ID
    IF(NSER.EQ.12) READ(*,*) WATER(ID)
    IF(NSER.EQ.13) WRITE(*,23) ID
    IF(NSER.EQ.13) READ(*,*) DANG(ID)
    IF(NSER.EQ.14) WRITE(*,24) ID
    IF(NSER.EQ.14) READ(*,*) VENT(ID)

```

```

GO TO 101
C
199 DO 200 I = 1,ROW
      DO 200 J = 1,COL
      WRITE(*,135) I,J
      READ(*,*) ASSIGN(I,J)
      FAIR(I,J) = 0
      FPOWER(I,J) = 0
      FWATER(I,J) = 0
      FEXIT(I,J) = 0
      EXPN(I,J) = 0
200   LOAD(I,J) = 0
C
      MAX = ROW*COL
      WRITE(*,490)
      WRITE(*,*) 'HAS COMPRESSED-AIR ON IT.  ENTER 0 0 IF NO MORE'
      DO 602 I = 1,MAX
      READ(*,*) NROW,NCOL
      IF(NROW.EQ.0.OR.NCOL.EQ.0) GO TO 604
602   FAIR(NROW,NCOL) = 1
C
604   WRITE(*,490)
      WRITE(*,*) 'HAS POWER FACILITY ON IT.  ENTER 0 0 IF NO MORE'
      DO 606 I = 1,MAX
      READ(*,*) NROW,NCOL
      IF(NROW.EQ.0.OR.NCOL.EQ.0) GO TO 608
606   FPOWER(NROW,NCOL) = 1
C
608   WRITE(*,490)
      WRITE(*,*) 'HAS WATER-SEWER ON IT.  ENTER 0 0 IF NO MORE'
      DO 610 I = 1,MAX
      READ(*,*) NROW,NCOL
      IF(NROW.EQ.0.OR.NCOL.EQ.0) GO TO 609
610   FWATER(NROW,NCOL) = 1
C
609   WRITE(*,490)
      WRITE(*,*) 'HAS VENT EQUIP. ON IT.  ENTER 0 0 IF NO MORE'
      DO 611 I = 1,MAX
      READ(*,*) NROW,NCOL
      IF(NROW.EQ.0.OR.NCOL.EQ.0) GO TO 612
611   FVENT(NROW,NCOL) = 1
C
612   WRITE(*,490)
      WRITE(*,*) 'HAS DOOR-EXIT ON IT.  ENTER 0 0 IF NO MORE'
      DO 614 I = 1,MAX
      READ(*,*) NROW,NCOL
      IF(NROW.EQ.0.OR.NCOL.EQ.0) GO TO 616
614   FEXIT(NROW,NCOL) = 1
C
616   WRITE(*,490)

```

```

WRITE(*,*) 'CANNOT HAVE HEAVY DEPT.  ENTER 0 0 IF NO MORE'
DO 618 I = 1,MAX
READ(*,*) NROW,NCOL
IF(NROW.EQ.0.OR.NCOL.EQ.0) GO TO 620
618 FEXIT(NROW,NCOL) = 1
C
620 TEM = ROW/6
NR = INT(TEM)
IF(NR.EQ.0) NR = 1
TEM = COL/6
NC = INT(TEM)
IF(NC.EQ.0) NC = 1
C
WRITE(*,*)
WRITE(*,*) 'WHAT IS THE FUTURE EXPANSION SIDE?'
WRITE(*,*) ' 1-LEFT SIDE   2-RIGHT SIDE   3-UPPER   4-BOTTOM'
WRITE(*,*) 'ENTER THE NUMBER ONE BY ONE.  ENTER 0 IF NO MORE'
C
DO 630 I = 1,4
READ(*,*) NSER
IF(NSER.EQ.0) GO TO 201
IF(NSER.NE.1) GO TO 634
DO 632 J = 1,ROW
DO 632 K = 1,NC
632 EXPN(J,K) = 1
GO TO 630
C
634 IF(NSER.NE.2) GO TO 638
DO 636 J = 1,ROW
DO 636 K = COL, COL-NC, -1
636 EXPN(J,K) = 1
GO TO 630
C
638 IF(NSER.NE.3) GO TO 642
DO 640 J = 1,NR
DO 640 K = 1,COL
640 EXPN(J,K) = 1
GO TO 630
C
642 IF(NSER.NE.4) GO TO 620
DO 644 J = ROW, ROW-NR, -1
DO 644 K = 1,COL
644 EXPN(J,K) = 1
630 CONTINUE
C
201 WRITE(*,480)
READ(*,*) NSER
IF(NSER.NE.1) GO TO 299
WRITE(*,*)
WRITE(*,*) 'WHAT DO YOU WANT TO CHANGE?  ENTER THE NUMBER'

```

```

WRITE(*,*) '1. AIR      2. POWER    3. WATER    4. EXPANSION'
WRITE(*,*) '5. LOADING  6. EXIT     7. ASSIGNED DEPARTMENT'
WRITE(*,*) '8. VENTILATION'
READ(*,*) NSER
WRITE(*,*) 'ENTER ROW AND COLUMN INDEX : '
READ(*,*) ID,JD
IF(NSER.EQ.1) WRITE(*,110) ID,JD
IF(NSER.EQ.1)READ(*,*) FAIR(ID,JD)
IF(NSER.EQ.2) WRITE(*,115) ID,JD
IF(NSER.EQ.2)READ(*,*) FPOWER(ID,JD)
IF(NSER.EQ.3) WRITE(*,120) ID,JD
IF(NSER.EQ.3)READ(*,*) FWATER(ID,JD)
IF(NSER.EQ.4) WRITE(*,125) ID,JD
IF(NSER.EQ.4)READ(*,*) EXPN(ID,JD)
IF(NSER.EQ.5) WRITE(*,130) ID,JD
IF(NSER.EQ.5)READ(*,*) LOAD(ID,JD)
IF(NSER.EQ.6) WRITE(*,133) ID,JD
IF(NSER.EQ.6)READ(*,*) FEXIT(ID,JD)
IF(NSER.EQ.7) WRITE(*,135) ID,JD
IF(NSER.EQ.7)READ(*,*) ASSIGN(ID,JD)
IF(NSER.EQ.8) WRITE(*,136) ID,JD
IF(NSER.EQ.8)READ(*,*) FVENT(ID,JD)
GO TO 201

```

C

299

```

WRITE(*,*)
MAX = DEPT*DEPT
WRITE(*,*) 'ANY TWO DEPTS. NEED TO BE PLACED SPECIALLY?'
WRITE(*,*) 'ENTER THE INDEX OF TWO DEPARTMENTS'
WRITE(*,*) 'RELATION      1-CLOSE      2-APART'
WRITE(*,*) 'AND TYPE      1-MUST BE    2-IF POSSIBLE.'
WRITE(*,*) 'ENTER 0 0 0 0 IF NO MORE'
DO 702 I = 1,MAX
READ(*,*) NDT1,NDT2,NREL,NTYP
IF(NDT1.EQ.0.OR.NDT2.EQ.0) GO TO 710
REL(NDT1,NDT2) = NREL
702 TYPE(NDT1,NDT2) = NTYP

```

C

710

```

DO 700 I = 1,DEPT
  DO 700 J = 1,DEPT
    COST(I,J) = 0.
700 QTY(I,J) = 0.

```

C

```

WRITE(*,*)
WRITE(*,*) 'ENTER THE INDEX OF TWO DEPARTMENTS'
WRITE(*,*) 'UNIT QUANTITY AND COST'
WRITE(*,*) 'ENTER 0 0 0 0 IF NO MORE'

```

C

```

DO 722 I = 1,MAX
READ(*,*) NDT1,NDT2,VAR1,VAR2
IF(NDT1.EQ.0.OR.NDT2.EQ.0) GO TO 301

```

```

722      QTY(NDT1,NDT2) = VAR1
C      COST(NDT1,NDT2) = VAR2
301      WRITE(*,480)
      READ(*,*) NSER
      IF(NSER.NE.1) GO TO 399
      WRITE(*,*) 'WHAT DO YOU WANT TO CHANGE?  ENTER THE NUMBER'
      WRITE(*,*) '1. RELATION    2. TYPE OF RELATION'
      WRITE(*,*) '3. COST        4. QUANTITY'
      READ(*,*) NSER
      WRITE(*,*) 'ENTER TWO DEPARTMENT INDEX :'
      READ(*,*) ID,JD
      IF(NSER.EQ.1) WRITE(*,210) ID,JD
      IF(NSER.EQ.1) READ(*,*) RELA(ID,JD)
      IF(NSER.EQ.2) WRITE(*,215) ID,JD
      IF(NSER.EQ.2) READ(*,*) TYPE(ID,JD)
      IF(NSER.EQ.3) WRITE(*,225) ID,JD
      IF(NSER.EQ.3) READ(*,*) COST(ID,JD)
      IF(NSER.EQ.4) WRITE(*,230) ID,JD
      IF(NSER.EQ.4) READ(*,*) QTY(ID,JD)
      GO TO 301

C
399      WRITE(*,*) 'ENTER PENALTY TO USER PREFERENCE VIOLATION :'
      READ(*,*) IUPV
      WRITE(*,*) 'ENTER PENALTY TO EXPANSION PLAN VIOLATION :'
      READ(*,*) IEPV
      WRITE(*,*) 'ENTER PENALTY TO NOISE PROBLEM :'
      READ(*,*) INCV
      WRITE(*,*) 'ENTER PENALTY TO VIBRATION PROBLEM :'
      READ(*,*) IVBP
      WRITE(*,*) 'ENTER PENALTY TO EXPLOSION PROBLEM :'
      READ(*,*) IEXP
      WRITE(*,*) 'ENTER PENALTY TO DANGER-EQUIPMENT PROBLEM :'
      READ(*,*) IDAP
      WRITE(*,*) 'ENTER PENALTY TO VENTILATION PROBLEM :'
      READ(*,*) IVTP
      WRITE(*,*) 'ENTER PENALTY TO COMPRESSED-AIR PROBLEM :'
      READ(*,*) ICAP
      WRITE(*,*) 'ENTER PENALTY TO POWER FACILITY PROBLEM :'
      READ(*,*) IPFP
      WRITE(*,*) 'ENTER PENALTY TO WATER-SEWER PROBLEM :'
      READ(*,*) IWSP
      WRITE(*,*) 'ENTER PENALTY TO DOOR-EXIT PROBLEM :'
      READ(*,*) IDEP
      WRITE(*,*) 'ENTER PENALTY TO HEAT CONTRL VIOLATION :'
      READ(*,*) IHCV
      WRITE(*,*) 'ENTER CREDIT FOR ENERGY SAVING :'
      READ(*,*) ICES

C
      WRITE(*,*) ' 1. USER PREFERENCE VIOLATION =',IUPV

```



```

WRITE(*,*) ' 2. EXPANSION PLAN VIOLATION      =', IEPV
WRITE(*,*) ' 3. NOISE PROBLEM                  =', INCV
WRITE(*,*) ' 4. VIBRATION PROBLEM              =', IVBP
WRITE(*,*) ' 5. EXPLOSION PROBLEM              =', IEXP
WRITE(*,*) ' 6. DANGER-EQUIPMENT PROBLEM       =', IDAP
WRITE(*,*) ' 7. VENTILATION PROBLEM            =', IVTP
WRITE(*,*) ' 8. COMPRESSED-AIR PROBLEM         =', ICAP
WRITE(*,*) ' 9. POWER FACILITY PROBLEM        =', IPFP
WRITE(*,*) '10. WATER-SEWER PROBLEM            =', IWSP
WRITE(*,*) '11. DOOR-EXIT PROBLEM             =', IDEP
WRITE(*,*) '12. HEAT CONTRL VIOLATION         =', IHCV
WRITE(*,*) '13. CREDIT FOR ENERGY SAVING     =', ICES

C
402  WRITE(*,480)
      READ(*,*) NSER
      IF(NSER.NE.1) GO TO 401
      WRITE(*,*) 'ENTER THE NUMBER TO CHANGE : '
      READ(*,*) NSER
      WRITE(*,*) 'ENTER CORRECT VALUE : '
      READ(*,*) ITEM
      IF(NSER.EQ.1) IUPV = ITEM
      IF(NSER.EQ.2) IEPV = ITEM
      IF(NSER.EQ.3) INCV = ITEM
      IF(NSER.EQ.4) IVBP = ITEM
      IF(NSER.EQ.5) IEXP = ITEM
      IF(NSER.EQ.6) IDAP = ITEM
      IF(NSER.EQ.7) IVTP = ITEM
      IF(NSER.EQ.8) ICAP = ITEM
      IF(NSER.EQ.9) IPFP = ITEM
      IF(NSER.EQ.10) IWSP = ITEM
      IF(NSER.EQ.11) IDEP = ITEM
      IF(NSER.EQ.12) IHCV = ITEM
      IF(NSER.EQ.13) ICES = ITEM
      GO TO 402

C
C*****
C
C ***   DATA FILE WRITING
401  WRITE(6,410) ROW,COL,DEPT
C
      DO 500 I = 1,DEPT
      WRITE(6,420) MINSIDE(I),SIZE(I),DANG(I),VENT(I)
      WRITE(6,430) NOSE(I),MOVE(I),VIBA(I),EXPO(I),HEAT(I),
+      WGHT(I),EXIT(I),AIR(I),POWER(I),WATER(I)
500  CONTINUE
C
      DO 510 I = 1,ROW
510  WRITE(6,450) (FAIR(I,J),J=1,COL)
C
      DO 511 I = 1,ROW

```

```

511      WRITE(6,450) (FPOWER(I,J),J=1,COL)
C
      DO 512 I = 1,ROW
512      WRITE(6,450) (FWATER(I,J),J=1,COL)
C
      DO 513 I = 1,ROW
513      WRITE(6,450) (FEXIT(I,J),J=1,COL)
C
      DO 8 I = 1,ROW
8        WRITE(6,450) (FVENT(I,J),J=1,COL)
C
      DO 514 I = 1,ROW
514      WRITE(6,450) (LOAD(I,J),J=1,COL)
C
      DO 515 I = 1,ROW
515      WRITE(6,450) (EXPN(I,J),J=1,COL)
C
      DO 516 I = 1,ROW
516      WRITE(6,460) (ASSIGN(I,J),J=1,COL)
C
      DO 517 I = 1,DEPT-1
517      WRITE(6,450) (RELA(I,J),J=I+1,DEPT)
C
      DO 520 I = 1,DEPT-1
520      WRITE(6,450) (TYPE(I,J),J=I+1,DEPT)
C
      IF(DEPT.GT.10) GO TO 540
C
      DO 530 I = 1,DEPT
530      WRITE(6,470) (QTY(I,J),J=1,DEPT)
C
      DO 535 I = 1,DEPT
535      WRITE(6,470) (COST(I,J),J=1,DEPT)
      GO TO 560
C
540      DO 550 I = 1,DEPT
      WRITE(6,470) (QTY(I,J),J=1,10)
550      WRITE(6,470) (QTY(I,J),J=11,DEPT)
C
      DO 555 I = 1,DEPT
      WRITE(6,470) (COST(I,J),J=1,10)
      WRITE(6,470) (COST(I,J),J=11,DEPT)
555      CONTINUE
C
560      WRITE(6,*) IUPV
      WRITE(6,*) IEPV
      WRITE(6,*) INCV
      WRITE(6,*) IVBP
      WRITE(6,*) IEXP
      WRITE(6,*) IDAP

```

```
WRITE(6,*) IVTP  
WRITE(6,*) ICAP  
WRITE(6,*) IPFP  
WRITE(6,*) IWSP  
WRITE(6,*) IDEP  
WRITE(6,*) IHCV  
WRITE(6,*) ICES  
STOP  
END
```