HEURISTIC APPROACH TO FACILITY LAYOUT USING WEIGHT FACTORS

MR.BOONCHAROEN SIRINAOVAKUL

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE
DOCTOR OF ENGINEERING IN ELECTRICAL ENGINEERING
GRADUATE SCHOOL
KING MONGKUT'S INSTITUTE OF TECHNOLOGY LADKRABANG
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พ.ศ.	2538

บทคัดย่อ

วิทยานิพนธ์ฉบับนี้นำเสนอการประยุกต์ใช้ปัญญาประดิษฐ์ เพื่อช่วยการออกแบบผังโรงงาน ระบบนี้ประกอบด้วย ขบวนการวางผัง การค้นหาแบบฮิวริสติก และระบบผู้เชี่ยวชาญ การทำงานของระบบเริ่มจากขบวนการวางผังจะนำเอาพื้นที่ใช้งาน (facility area) มาสร้างแผนผัง (layout) แบบต่าง ๆ หลาย ๆ แบบ เพื่อเป็นแผนผังตัวเลือก (alternative layout) ออกมาจำนวนมาก จากนั้นการค้นหาแบบ ฮิวริสติก (heuristic search) จะค้นหาผังที่ดีจากแผนผังตัวเลือกที่สร้างขึ้น ในการเลือกผังที่ดีนั้นการ ค้นหาแบบฮิวริสติกจะอาศัยฮิวริสติกฟังก์ชันเป็น ผู้ตัดสินว่าแผนผังใดดีกว่าโดยพิจารณาจากระดับความสัมพันธ์ของความใกล้ชิด (closeness weight) ของพื้นที่ การกำหนดระดับความใกล้ชิดของ ที่มีค่าเป็นทั้งบวกและลบ ซึ่งยังไม่มีผู้นำเสนอมาก่อน ทำให้การพิจารณาการใช้งานของพื้นที่ต่าง ๆ ว่ามีความสัมพันธ์กันอย่างไร และควรวางใกล้ หรือห่างกันอย่างไร ได้ตรงกับความเป็นจริงมากยิ่งขึ้น ในการพิจารณาระดับความสัมพันธ์ของความใกล้ชิด จะอาศัยความชำนาญของผู้ที่วางผัง ในระบบที่นำเสนอนี้จะอาศัยระบบผู้เชี่ยวชาญ (expert system) เป็นระบบที่ทำหน้าที่สะสมความรู้ ต้นแบบของระบบดังกล่าวถูกสร้างขึ้นเพื่อการทดสอบ ผลของการทดสอบพบว่า ระบบนี้มีความสามารถในการแก้ปัญหาการวางผังงานที่ซับซ้อนได้ดี และตรงกับความเป็นจริงมากกว่าระบบที่เคยมีการนำเสนอมาแล้ว โดยเฉพาะอย่างยิ่งในกรณีที่มีพื้นที่ที่อาจมีอันตรายอยู่ในผังงาน

ระบบดังกล่าวนอกจากจะสามารถใช้กับการวางผังโรงงานแล้ว ระบบนี้ยังสามารถนำไปใช้กับการวางแพทเทิร์น (patterns) สำหรับการตัดโลหะ หรือผ้า (stock cutting) และการจัดวาง building blocks ในวงจรรวมขนาดใหญ่มาก (VLSI)

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ABSTRACT

This thesis presents a construction model of facility layout. A beam search technique has been used for solving the problems. The designed system consists of pattern allocation, beam search and knowledge base system. The system firstly generates the alternative layouts by using the pattern allocation. The heuristic search searches for the best layout from these generated alternatives. The heuristic function, or "closeness weight," is also used for directing the search process to the most profitable direction. This closeness weight may be both possitive and negative value, and is acquired from the knowledge base. For testing purpose, an experimental system is constructed based on the method. The results from the system show the potential applications on solving the complex facility layout problems and more realistic especially for the problem with practical limitation.

The system can be used not only with facility layout, but also for the pattern layout stock cutting and VLSI design applications.

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Mr. Booncharoen Sirinaovakul

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INTRODUCTION

One of the oldest activities of the industrial engineering is plant layout. It is the activity that deals with the design of an arrangement of the physical elements of an activity and has always been very closely related to the manufacturing industry, where the drawing of the resulting design was known as a plant layout. A good layout always involves the methods of handling material as it moves through the plant.

However, as the engineers broaden their outlook towards physical activity, they became aware that almost all meaningful activities require physical facilities. Most often such facilities should be planned and designed by following the same principles and procedures that had been using on plant layouts. In the layout design, the overall objective would be to consider what the appropriate inputs might be, and design an arrangement that would move them efficiently through the facility as the required activities are performed to achieve the desired outputs, such as products, orders of merchandise and so on.

In the facility design process, it may be considered as the machine layout design and the overall layout design. The machine layout design process considers the location of the machine or activity area in order to make it comfortable to workers and to minimize the working space required. In the overall design, the machine location or the activity area is represented as a floor plan or a to-be-located block. The solution of the overall layout is to optimize the overall area usage and to maximize the efficiency of area usage. Both machine layout and overall layout process also employ the area allocation technique, that is, the area having high leveled relationship must be located closely together. The relationship level is mostly considered from the rate of material flow in process and level of activity relation between the facility areas. For example, the receiving and shipping department must be located close to the storage department since the rate of material flow between these departments is high. In some special cases, the areas having high relationship level may be located apart. For instance, the welding department must theoretically be put closely to the chemical cleaning department in order to make it convenient to clean out all fluxes and dirt after the welding process. Unfortunately, this is not possible because spark from the arc welding may cause fire with the chemical cleaning solution. This special case is called *practical limitation* (Muther, R. 1973). The practical limitation in this sense means the additional restrictions considered for the layout, such as the company policy, labor union contract, community regulation and other related issues, that may affect the layout.

To justify the effective arrangement of facility areas, the following objectives should be satisfied (Apple 1977):

1. Facilitate the manufacturing process.
2. Minimize material handling.

3. Maintain flexibility of arrangement and of operations.

4. Maintain high turnover of work-in-process.

5. Provide for employee convenience, safety, and comfort in doing the work.

6. Fulfil the owner satisfaction.

In considering the effectiveness of the facility layout, the problem is concerned with the coordination of the product, process, schedule, and layout design decisions, as depicted in Figure 1.

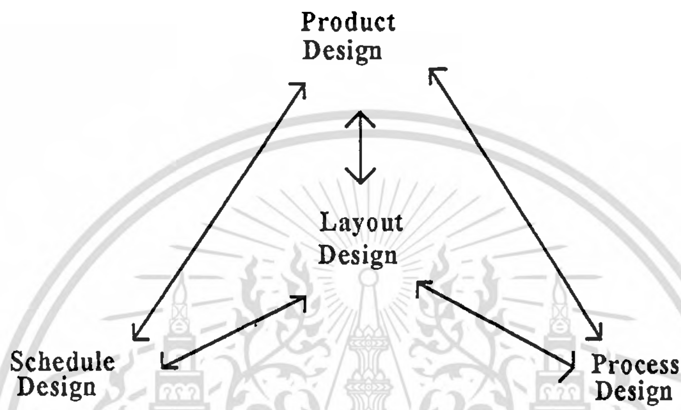


Figure 1 Communication links among product, process and layout design (Francis and White 1974)

1.1 Problem definition

The main functions of facility layout design are to allocate facilities under the facilities' interrelation-ship and to optimize their space requirements. The objective is to design an efficient arrangement of space required by a facility into an integrated whole, which is called area allocation. Area allocation technique has been studied not only in facility layout design but also in various contexts including stock cutting as well as VLSI design. In each context, problem formulation remains largely the same. Using an area allocation technique, the dimensions and properties of a facility are given to determine the interrelationship cost between all facility pairs. Satisfactory layout is then selected under the constraint of minimizing interrelationship costs. For a stock cutting problem, a set of patterns is fitted onto a plate to minimize scrap. For VLSI design, the problem is the location of electronic components onto a die to satisfy the component layout rules. In a facility layout problem, the objective is to arrange the facility areas to optimize the interrelationship among operating personnel, materials flow and information flow. This requires methods that meet the enterprise objectives efficiently, economically and safely.

1.2 Research background

Facility layout problems can occur in a large number of ways and can have significant effect on the overall effectiveness of the production system. Therefore, it is highly desirable that the optimum facility layout must be designed. Unfortunately, the magnitude of the problem is so great that true system optimization is beyond human current capabilities. The approach normally taken in solving the facility layout problem is to try to find a satisfactory solution by employing the heuristic approach. Therefore, the new approach must define the overall system as a collection of components or subsystems and must attempt to obtain optimum solutions for the subsystem. The resulting system will be a sub optimum solution, rather than an optimum solution. However, the solution is believed to be better than that which would otherwise be obtained.

In the early state of the facility layout, the problem was solved by manual. The Systematic Layout Planning (SLP) developed by Muther (1973) is the first pattern layout solving method that has received considerable publicity due to the success derived from its application in solving a large variety of layout problems.

Computerized layout techniques have been studied for many years. Most of the effort has been spent on quantitative techniques that rely on mathematical, statistical and modeling approaches for problem solving. Gilmore and Gomory (1961, 1963) proposed a method for solving the cutting stock problem by using a linear programming. It is the first computerized process for solving the pattern layout problem. At almost the same time, Buffa, Armour and Vollmann (1964) also present the first successful program, so called CRAFT, for solving the facility layout problem. The algorithm uses a heuristic approach to interchange facility locations. The initial layout is required before an improved solution based on material flow data can be found. The limitations of this algorithm are that CRAFT does not work without the initial layout and does not take any rating of relationships among activities into account. Alternative approaches, such as CORELAP (Lee and Moore 1967) and ALDEP (Seehof and Evans 1967) which do not start from initial layout, instead generate layout from scratch. They locate the activities according to the rating of the highest relationship activity. However, these algorithms also have limitations. They do not consider the exceptional conditions when the two departments must be separated for some reason. PLANET (Apple and Deisenroth 1972) accounts for these limitations by using the inter-department flow data and adding the "penalty" cost associated with separating departments. An another system, the DISCON (Drezner 1980), is formulated and solved by nonconvex mathematical programming using a procedure termed DISpersion CONcentration. This algorithm also takes the closeness weight into account. More recently, Tam and Li (1991) present a divide-and-conquer strategy for solving the problem. This strategy consists of three phases: cluster analysis, initial layout and layout refinement. This method produces the initial layout of each cluster that can then be refined by finding the positions of patterns to minimize the total force.

In using these conventional computerized techniques, there are two points to consider. First, conventional computerized techniques do not consider enough possible outcomes to arrive at the optimal solution, especially for the construction methods like CORELAP and ALDEP. Therefore, the improved methods, such as COL (Vollmann et al. 1968), COFAD (Tompkins and Reed 1976), etc., are presented to get a better solution, but the methods are still very sensitive to the initial layout.

Second, it is difficult to take the practical limitations of facility design problems such as the intangible factors, the human aspects of the layout and so on, into account. This is because any facility layout problem has multiple criteria in selecting the best layout and it is very specific in domain and problem. Thus, the flexibility of practical limitation considerations is very important.

Malakooti and Tsurushima(1989) commented that any facility layout is an ill-structured problem for three reasons. Firstly, there are multiple criteria. Secondly, it is hard to determine a problem space and thirdly there are many domain-specific and problem-specific constraints.

To cope with such ill-structured problems, artificial intelligence (AI) techniques for facility layout design have been formulated. Kumara, Kashyap and Moodie (1988) used an augmented transition network of natural language processing as the heuristic in an expert system to determine the practical limitations of the alternate layout, and WEB grammar to present the pattern allocation knowledge captured from the human expert. Malakooti and Tsurushima(1989) developed an expert system and multiple-criteria decision making. The expert system interacts with the decision maker(DM), and reflects the DM's preferences in the selection of rules and priorities. Abbou and Dutta(1990) developed an expert system approach to define appropriate layouts of machining facilities under specific combinations of manufacturing and material handling systems. The EXSYS Expert System shell and the relationship chart have been used to construct a knowledge base. Raoot and Rakshit(1991) presented the fuzzy set theory to solve a facility layout problem. The procedures for aggregating the experts' opinion, location, selection and placement of the facility, and for evaluating layout were presented. The major disadvantage of these presented systems is that they cannot handle some of the practical layout limitations.

It should be evident that solving the practical limitations of facility layout by using computerized technique is not as simple a matter as it may seem. Although there are many computerized techniques being proposed to solve the problem, they can still solve only one aspect of any problems. For instance, when the heavy load of flow material is considered, the hazard of facility is left unsolved. It is because of such relational characteristics that the layout facilities may be close together, a so-called "positive relationship." On the other hand, the layout facilities may be apart, a so-called "negative relationship." Most of the proposed methods solve the problem by assuming the relational characteristics of facilities have only a "positive relationship." This assumption makes most of the algorithms unable to solve some of the practical limitations of layout. Sirinaovakul and Thajchayapong (1991, 1991, 1993) also proposed a system using heuristic layout and heuristic search to solve these practical layout limitations. An expert system is also presented to help the heuristic search in assigning a closeness weight for the activity's relationship.

1.3 Research objective

The objective of this research is to apply artificial intelligence techniques for solving the plant layout problem. The research method will handle the problem of general facility layout and also covers the problem involved the practical limitation. The main objective of the research is to find a reasonable problem solving method. Therefore, the method of acquiring the layout knowledge will not be mentioned.

1.4 Scope of the research

To solve the layout problem, the research will consider the layout of new facilities, which starts from the initial state, that is the area allocation will be considered instead of the improvement of existing layout. The being located facilities are considered as the floor plan (or block). Therefore, only two dimensional rectangular patterns of facilities are considered in the research. The facilities with three dimensions, machine allocation and facility characteristics, such as door and window position, will not be included in this literature since the problem can be solved in the layout modification process. The result of this research is to propose the system for generating the first draft of facility layout. The modification process is also needed for improving the layout generated by the system and is left for further research.

The research emphasizes on problem solving method rather than the knowledge of layout justification. The implementation of the algorithm is tested on the rectangular patterns and the sample knowledge base is tested based on the work done by Muther.

1.5 Approach

The research attempts to utilize an expert system together with heuristic search to provide a sort of decision support system to make a selection on the best layouts. The problem solving method starts by the pattern allocation algorithm to generate the alternative layouts. The pattern allocation algorithm generates almost all possible layouts. Therefore, the problem space generated by the algorithm is very large. With these generated layouts, the heuristic search searches for the best layout with the assistance of the expert system. The heuristic search is a variation of best-first search, called beam search. The heuristic function of the heuristic search employs the potential energy model to define the cost of layout that is used for directing the search direction.

In the potential energy model, the stiffness coefficient is applied to explain the facility relationship level. This facility relationship level is defined by the facilities' characteristics in the same way as the stiffness coefficient is defined for the material characteristics. To assign the facility relationship level, the expert system is constructed to acquire the relationship knowledge from the plant layout expert. Moreover, the expert system also employs the Mycin's model to reduce the number of rules in representing the knowledge.

1.6 Contribution of the research

The research contributes several influential ideas of plant layout problem solving method. First, the research considers the practical limitation of plant layout in every aspect that have not been considered. Second, the research utilizes the advantage of the artificial intelligence technique. The heuristic search is used for reducing the size of the problem space and the expert system is designed to extract the knowledge from the human expert. This means that the problem solving method can handle both the larger numbers of layouts and more complexity of the problem. Lastly, the Mycin's CF model is also utilized to reduce the number of rules occurred in the knowledge base that is normally very massive.

The use of the designed system is not limited to the type of facility layout. It can be used for designing industrial plant, warehouse, office, retail store, and so on.

1.7 Research organization

The research objective general view has been presented in this chapter. Chapter 2 describes the type of the research that has been undertaken by scientists in the field of facility layout over the past several years. Chapter 3 is a description of the design system. The algorithms and the system development are also given in details. Chapter 4 is the programming design and its data structure. Finally, Chapter 5 contains concluding remarks and further research. An analysis and test out of algorithm are also given in Appendix I and Appendix II. Appendix III shows the illustrative case of knowledge.

Chapter 2
FACILITY LAYOUT DESIGN: AN OVERVIEW OF RESEARCH TRADITIONS AND APPROACHES

One of the main problems in facility layout happens to be in providing a reasonable layout of facility areas on a floor-plan. A placement may be referred to as reasonable if it enables the layout objectives and results in the total area being close to the possible minimum.

There are three main conditions involved in the computerized facility layout process: layout technique, search technique, and layout criteria. Consider the following two-step of facility layout process, i.e., facility allocation and the search for the best layout process. A typical approach to facility layout is first to allocate the facilities on to the floorplan. The relative positions of the facilities of partial layout or total area layouts are generated. The generated layout is refered to as a alternative layout. After the generation of several alternative layouts, the search process selects the best layout from these alternative layouts subjected to some cost measure (or layout criteria) such as relationship cost and material handling cost. For most of the layout algorithms, the search for the best layout process is embedded in the facility allocation process. The search process is invoked every time when the new alternative layouts are generated.

Facility allocation techniques can be categorized into two types, i.e., the construction allocation and iterative improvement. In most of the practical implementation, a constructive allocation algorithm is used for the partial layout generation and the result is iteratively improved until the complete layout is generated. In the construction allocation, there are several strategies such as matrix layout, planar graph, and pattern recognition. On the other hand, the iterative improvement algorithm refines an existing layout. Therefore, the initial layout is needed for this algorithm and then the interchanges among the facilities are considered. The techniques used for this algorithm are matrix layout and slicing graph.

In most of the search processes, the second step of facility layout consists of two parts: searching and selection criteria. It is intuitively clear that, to search for the best layout from the generated alternatives, the selection criteria direct the searching direction for the search process. This process is generally called the heuristic search and the selection criteria are generally called heuristic function. The examples of the heuristic search used in the layout problem are branch and bound, depth first, beam search and simulated annealing. The examples of selection criteria are material handling cost, relationship cost, and practical limitation cost.

To categorize the facility layout algorithms, the four main strategies are considered: traditional schematic technique, optimizing and heuristic approach, graph theory approach, artificial intelligence approach and simulated annealing approach. The major objective of this chapter is to present an overview of research and techniques used for solving the facility layout problem. In the following sections, some important facility layout techniques are reviewed.

2.1 Traditional schematic techniques

On the early development of the problem layout techniques, the layout of facility is done by manual. These techniques include operational process chart, flow diagrams, string diagram, template juggling and systematic layout planning (SLP). In the facility layout of this era, the process mostly starts by analyzing the process data. The allocation of facilities is done by hands according to the analyzed data. Not many layout alternatives are proposed and the selection of the layout alternatives is decided by the layout expert. Therefore, the generated layout of these techniques depended primarily on the decision, intuition and experience of the layout analyst.

2.1.1 Systematic Layout Planning (SLP)

The systematic layout planning is the most well known among these techniques. The technique has been developed by Muther (1955) and has received considerable publicity. The SLP technique is depicted graphically in Figure 2.

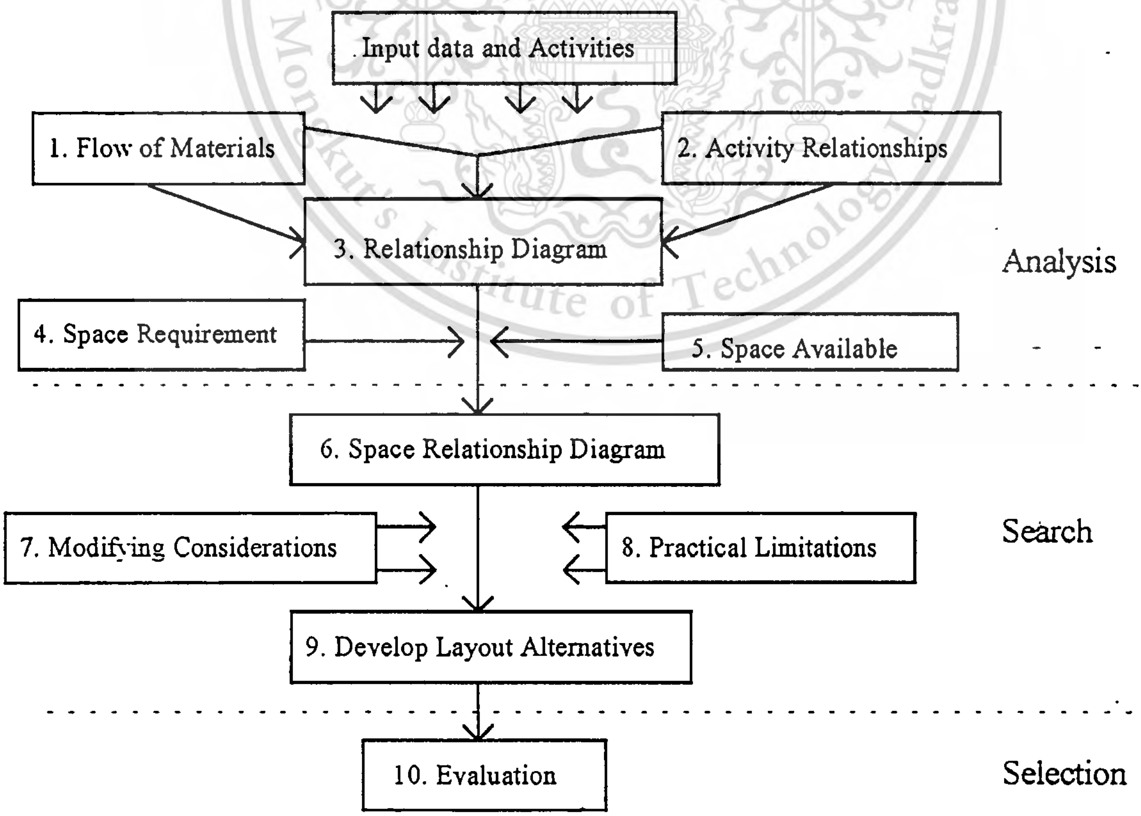


Figure 2 Systematic Layout Planning Procedure.

The SLP technique consists of three major processes, namely, analysis, search and selection. In the analysis process, once the appropriate information is gathered, a flow of material analysis can be combined with an activity relationship analysis to develop the relationship diagram. Space considerations, when combined with the relationship diagram, lead to the construction of the space-relationship diagram. On the basis of the space relationship diagram, modifying consideration and practical limitations, a number of alternative layouts are designed and evaluated.

With this technique, the data analysis process is analyzed systematically. Most of the factors concerned with the layout are considered. The facilities are allocated according to the result of analyzed data. The search and evaluation are done based on the judgment of the human expert.

2.1.2 Process chart

The process chart is another example of layout technique for the traditional schematic technique. It was proposed by Shubin, J. A. and Madeheim, H. (1965). The technique divides the manufacturing process into its separate operations and inspections by process analysis. The process chart consists of operation process chart, flow process chart, and flow diagram. The operation process chart indicates the points at which materials are introduced into the process and the sequence of all operations and inspections except those involved in material handling. The flow process chart is a graphic representation of all production activities occurring on the floor of the plant. It is an elaboration of the operation process chart to include transportation, storage, and delay. The flow diagram is an aid to visualization of the movement of material on the existing floor layout. Figure 3 shows an example of the flow process chart and the flow diagram.

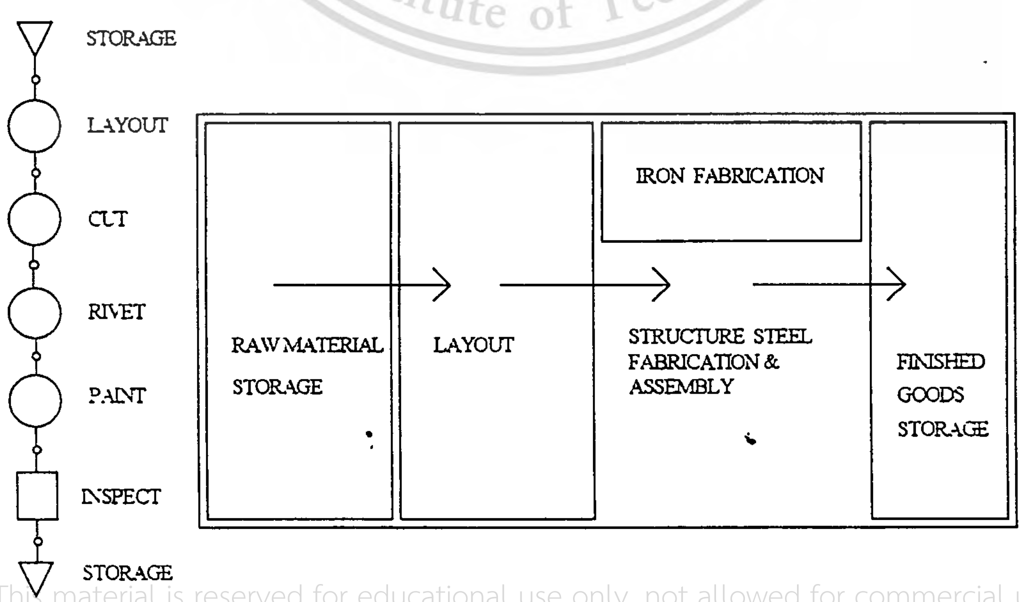


Figure 3 The flow process chart and flow diagram

To allocate the facility on to the plant, templates are used by locating and arranging the position of the templates on paper. After the templates are located in the desired arrangement, they are attached by Scotch tape and the final drawing of the layout can then be duplicated.

The proposed technique can handle both the layouts of new plant and the improvement of existing layout. For the layout of a new plant, the technique consists of operation process chart, flow process chart, and flow diagram. If the technique is used for improving the existing layout, the operation process chart is discarded.

2.2 Optimizing and heuristic approach

The computerized facility layout techniques of this approach are studied and researched in the early state. The area allocation algorithm uses the matrix area technique. The best layout is selected based on the material handling cost or relationship data. To solve this layout problem, the facility allocation is done during the search for the best layout process. The heuristic search methods are applied to help solve the problem. Examples of previous approaches include CRAFT (Buffa et al. 1964), CORELAP (Lee and Moore 1967) and ALDEP (Seehof and Evans 1967). The approaches can be classified as:

1. The iterative improvement technique.
2. The construction technique.
3. The multiple criteria technique.

The iterative improvement technique starts with an initial layout and attempting to improve it by a series of changes in the facilities' location. Among the improvement procedure, CRAFT is the most well known algorithm. Other examples of the improvement procedure are Vollmann, Nugent and Zartler procedure (1968), and the Hillier and Connors procedure (1966). The construction procedure generates the layout from the initial state. The procedure of this type generates partial layout alternatives by changing the facility locations and calculates the layout cost. The location of facility that gives the better layout cost is selected. The process of construction is stopped when the complete layout is generated. Of the construction algorithm, CORELAP (1967) is the well-known algorithm that generates layout by repeatedly selecting a facility for allocating and then determining where to place them. The layout and search techniques used for the heuristic approach are the same. They allocate the patterns by using the matrix and search for the best alternative by using branch and bound heuristic. The objective function that is used as a selection criterion is the material handling cost or relationship cost. The multiple criteria approaches are proposed for improving these layout algorithms. This approach combines the material handling cost and relationship cost as the multiple criteria.

2.2.1 Improvement technique

The CRAFT algorithm is considered to be the first successful computerized facility layout technique. The algorithm uses a heuristic approach to interchange facility locations. The initial layout is required before an improved solution based on material flow data can be solved. The facility allocation is processed during the layout improvement process. The algorithm computes the product of the flow, handling cost, and distance between center of facilities. Then it considers exchanges between locations. An exchange involving the greatest cost reduction is made. The new allocated facility is generated as a new layout and a new total cost is determined. The process is repeated until no significant cost reduction can be found.

CRAFT combines the facility allocation algorithm and the search for best layout algorithm as one process. The new allocation is occurred when the better cost is found. The program is path-oriented and not all possible exchanges are examined. The algorithm is a so called sub-optimum layout.

In term of data analysis, CRAFT used material flow data as the base for developing closeness relationship, the cost of moving, per unit move and per unit distance, and space requirements. In some special case, the cost of moving can be initialized by entering one for all cost. It can be seen from the algorithm that many data concerning the facility characteristic and relationship such as practical limitation and activity relation are discarded. Figure 4 shows an output example.

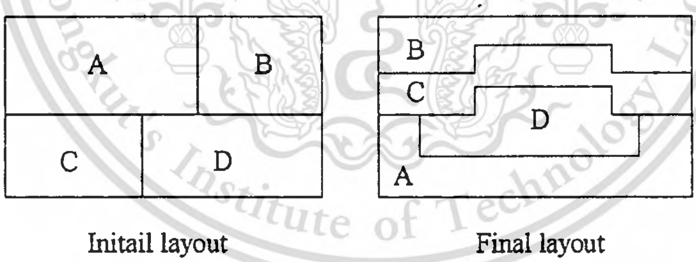


Figure 4 The output of CRAFT (Francis & White 1974)

2.2.2 Construction technique

CORELAP(Lee and Moore 1967) solves the layout problem by locating the most related activity, and then progressively adds other facilities, based on rated closeness desired, and in required size, until all facilities have been located.

In this algorithm, the level of closeness relationship of the facility must be given by layout analyst in the vowel-letter form. These closeness relationships are considered from a pair of facilities for every combination. The rated vowel-letters are described as:

A - closeness absolutely necessary,

E - closeness especially important,

I - closeness important,

O - ordinary closeness acceptable,

U - closeness unimportant, and

X - closeness not desirable.

The algorithm starts by calculating which of the facilities in the layout is the busiest or most widely related. Summation of the closeness weights for every facility related to other facilities are compared and the facility with the highest total is firstly located in the matrix. Next, a facility that must be closed should be selected and placed as near adjacent as possible. This facility is denoted as A. A search of remaining relationships for more A-related facilities is then made. These are placed, again as nearly adjacent as possible. When no A's are found, the same procedure is followed for E's, I's, O's, U's and X's relationships.

The facility allocation for CORELAP is to fill the matrix slot and the search process is the hill climbing. For the data analysis, CORELAP considers more details in the layout related information when comparing to CRAFT. However, the information is still judged and given by the human expert. CORELAP cannot rate the relationship for a pair of facility by itself.

Alternative approaches, such as ALDEP (Seehof and Evans 1967), MAT (Edwards et al. 1970), RMA I (Muther and McPherson 1970), PLANET (Apple and Deisenroth 1972), FRAT (Khalil 1973) and COFAD (Tomkins and Reed 1976) also locate the facility areas according to the rating of the highest relationship activity based on the relationship chart and accounts for the practical limitations by using the inter-department flow data. The *penalty* cost, associated with separating departments, is also considered. In this process the cost of facilities relationship and penalty cost are judged by an human expert. The system cannot determine this cost from the inter-department flow data by itself. The search techniques of these systems mostly involve branch and bound and hill climbing.

The facility layout or improvement problem is considered to be a problem of assigning *n* facilities to *n* locations and is treated as a special case of the quadratic assignment and the traveling salesman problem. The algorithms have not been successful in solving real size problem.

2.2.3 Multiple criteria technique

Serveral approaches are proposed to enhance the above techniques by improving the objective function. Instead of using the product of flow, handling cost, and distances as an objective function, the multiple criteria approach add more objective function.

Rosenblatt (1979) proposed an algorithm called multi-goal approach. The algorithm combines quantitative and qualitative objectives. In the quantitative objective, the total material handling cost is considered and the objective is minimizing. In the qualitative objective, the measure of closeness rating is considered and the objective is maximizing.

The material handling cost of the system is calculated by the product of work flow and distance. The measure of closeness rating is supplied as a relationship chart (Muther 1973).

For any given layout, the material handling cost (C) and closeness rating (R) can be represented as a point (R, C) in figure 5.

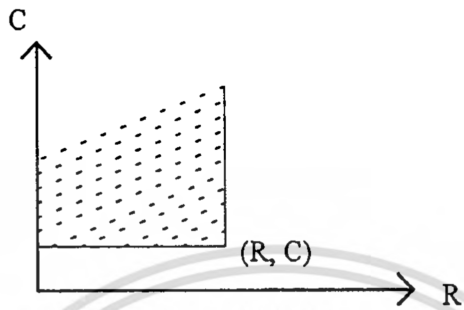


Figure 5 cost and closeness rating graph

Any point which is in the shaded area can be discarded. This is shown by the following equation.

$$\alpha_2 C_i - \alpha_1 R_i \le \alpha_2 C_j - \alpha_1 R_j$$

The α is the weight given to the equation. With the above equation, the total values of R and C of the layout can be calculated. The layout that gives the values of R and C outside the shaded area will be considered as an alternative. The layout that gives the values of R and C inside the shaded area will be discarded.

The strategy of this type uses the existing facility layout such as CRAFT and ALDEP for generating the layout and layout alternative.

The method of this strategy was further improved by Dutta and Sahu in 1982, by Fortenberry and Cox (1985) and Malakooti (1989) and Malakooti (1989).

2.2.4 Hierarchical approach

This approach is presented by Tam and Li. It consists of three phases, namely cluster analysis, initial layout and layout refinement. The cluster analysis is done based on the basis of similarities or dissimilarities by using the cost of material flow between facilities. The initial layout is then created based on the cluster. By using the potential energy function, the relative position of each facility in a cluster is calculated. The equation is:

$$f_{ij} = \frac{w_{ij} d_{ij}^2}{2} - \alpha \max\{0, d_{ij} - r_i - r_j\} \qquad (1)$$

f_{ij} is attractive force between two block i and j

w_{ij} is volume of material flows between blocks i and j

d_{ij} is distance between block i and j

α is degree of overlapping prohibition.

To refine the layout, the linear programming is used. The constraint equations are derived from x and y axis projection, aspect ratio and orientation data, and site dimension. The x and y axis projection is the data used for checking the overlapping of patterns. The aspect ratio and orientation data represent the boundary of block sides and site dimension represents the boundary of layout. These constraint equations are subjected to the objective equation(1).

2.3 Graph theory approach

Graph approach generates the layout by using graph theory. There are two kinds of facility placement using graph theory: slicing and non-slicing. A slicing floorplan is a floorplan which can be obtained by recursively cutting a rectangle into two parts by either a vertical or a horizontal line. The initial layout is required for this algorithm. The examples of this approach such as optimal aspect ratio proposed by Wimer, Koren and Cederbaum (1989) and cutting point interchange proposed by Tam (1992). A non-slicing floorplan is a floorplan which is not a slicing floorplan. The algorithm starts by allocating the facilities from the initial state. The examples for this algorithm such as maximal planar graph proposed by Seppanen and Moore (1970) and Detahedron heuristic proposed by Fould and Robinson (1978). The searching for the best layout process of these algorithms is depth first search. The objective function is relationship cost. Graph theory is used for constructing the facility layout process. Along the way, the relationship weights are used as the criteria for selecting the best layout. The layout alternative generation is done by allocating the unallocated facility at every position that makes the layout to be the planar graph. The position that gives the largest total relationship weight is selected. There are three important approaches to solve the facility layout by using graph theory, i.e., planar graph, optimal aspect ratio and cutting point interchange.

2.3.1 Planar graph approaches

The concept of using graph theory for solving the facility layout problem was first proposed by Seppanen and Moore since 1970 and the algorithm for solving the problem was proposed in 1975 by Moore. It utilizes the properties of planar graph. The facility areas, in this algorithm, are considered as the vertices of the planar graph. To construct the layout, the dual graph is created from this planar graph. The algorithm consists of three steps. First, the algorithm creates the maximal spanning tree of the facilities from the given relationship weights. Second, the high relationship weight edges are added to the maximal spanning tree to construct the maximal planar graph. Lastly, the dual graph is constructed from this maximal planar graph. This dual graph is considered to be the output of the facility design.

For ease of discussion, the illustrative problem is presented. Seven facilities, a through g, are arranged. The relationship weights are given as follows:

A Absolutely necessary: ac

E Extremely important: ce, dg, fg.

I Important: ae, be, cd.

O Ordinary closeness: ab, ad, af, ag, bc, bf, bg, cf, cg.

U Unimportant: de, df, ef, eg.

X Undesirable: db.

To construct the maximal spanning tree, we choose the edge which has the largest relationship weight and does not form a closed loop with those already selected from the edges which are not yet part of the tree. Figure 6 shows the maximal spanning tree constructed by the algorithm.

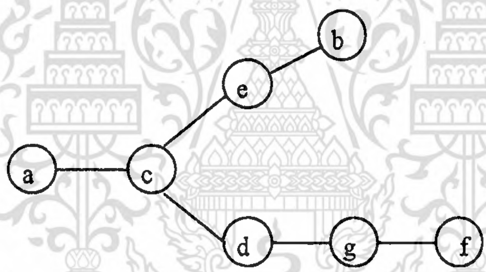


Figure 6 Maximal spanning tree

In order to construct the planar graph, the edge addition heuristic is used. The edge from one vertex to another vertex is considered by relationship weight. Figure 7 shows the maximal planar graph constructed from figure 6. The dashed lines are the additional edges and the solid lines are the original edges.

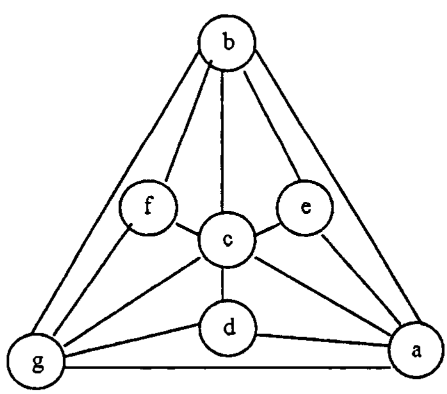


Figure 7 The constructed planar graph

The number of edges in the planar is calculated from Euler's formula, that is, number of vertices (V) - number of edges (E) + number of faces (F) = 2. Since every face of maximal planar graph has exactly three edges, the formula becomes:

$$E_{max} = 3V - 6.$$

Combining figure 8 with area requirement, the algorithm will issue the final layout.

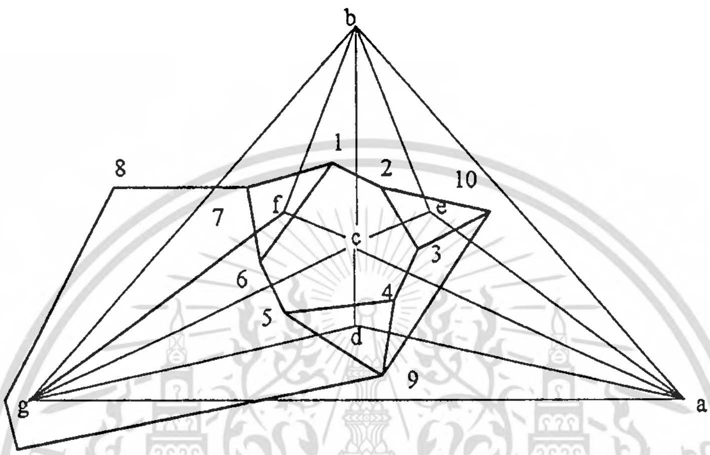


Figure 8 Dual graph constructed from the planar graph

In stead of constructing the maximal planar tree, Fould, Gibbon and Giffin (1985), Fould and Giffin (1985) and Fould and Robinson (1978) proposed a method called Detahedron Heuristic. The heuristic chooses the four most promising facilities and constructs the planar graph. From this planar graph, the next facility is selected and inserted in a triangle of the planar graph that causes the largest increase in weight of the graph. The process is repeated until no facility can be inserted. Figure 9 shows the facility insertion process.

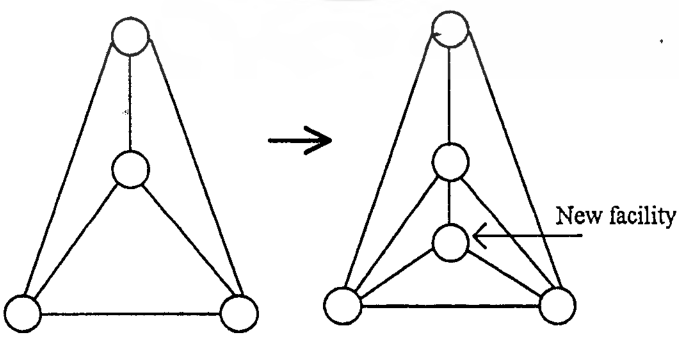


Figure 9 The facility insertion process

Hassan and Hogg (1991) also developed an algorithm using the planar graph. The method solves the problem of maximal planar limitation. In maximal planar graph, a face must have exactly three vertices but in the layout problem a face may contain more or less than three vertices. Graph in figure 10 is an example of this problem. Vertex F of figure 10 (b) has four edges and point 1 of figure 10(a) has four facilities meetings.

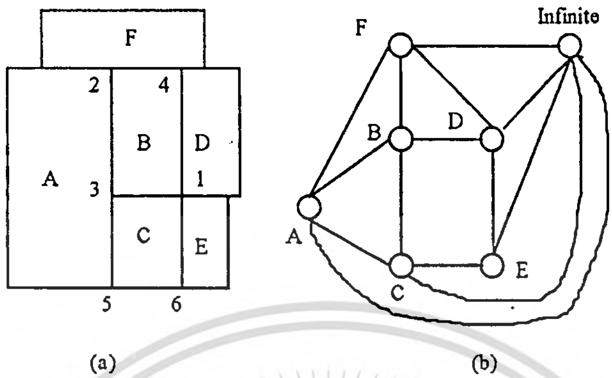


Figure 10 Non-maximal planar graph.

To solve these problems, the algorithm constructed the layout by using the layout matrix instead of dual graph. The layout matrix is expressed in unit squares and assumed to be very large. The partial layout developed at each iteration is considered to have four sides, plus any corner that may occur. The sides that contain the dual point(s) and the corner(s) are the candidate locations where a facility may be placed (see figure 11). The facilities are divided into two groups, exterior facility and interior facility group. The interior facilities are considered first. For each unplaced facility, the total flow with the placed facilities at each side that contains a dual point(s), and at a corner of the partial layout is calculated. The dual point for this algorithm is defined as a meeting point of the pattern in the planar graph. The movement cost, defined by the product of flow and distance between facilities, for a candidate facility is calculated at each candidate location. If the location with the minimum cost is the same location with which the candidate facility has the largest total flow, then the facility may be selected and placed at this location. The algorithm repeats the above steps until all facilities are placed. After the facilities allocation process is finished, the facility location and facility dimension adjustment processes are proceeded.

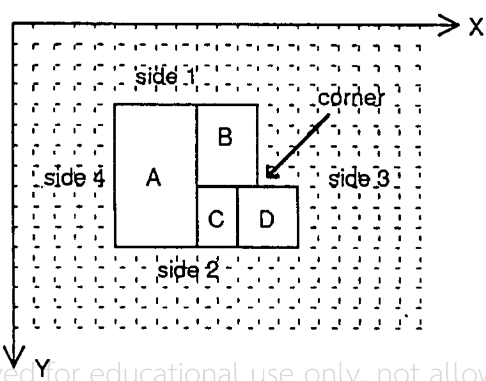


Figure 11 No dual point in side 3 & 4.

2.3.2 Optimal Aspect Ratio Approach

The approach uses the slicing technique to solve the pattern allocation problem. By using this technique, the initial layout is needed for considering the dual polar graph and then this initial layout can then be improved. In the graph theory, the floorplan can be represented as dual polar graph, G(U,E) and H(V,F), which are used for representing the vertical line segments and horizontal line segments respectively. Figure 12(a) shows a floorplan whose vertical line segments are denoted by u_1 through u_5 and horizontal line segments are denoted by v_1 - v_6. Figure 12(b) shows the corresponding dual polar graphs. Figure 12(c) is the decomposition tree of the floorplan.

The dual polar graph represents the paths of one segment line to other segment lines through the blocks from left to right and top to bottom.

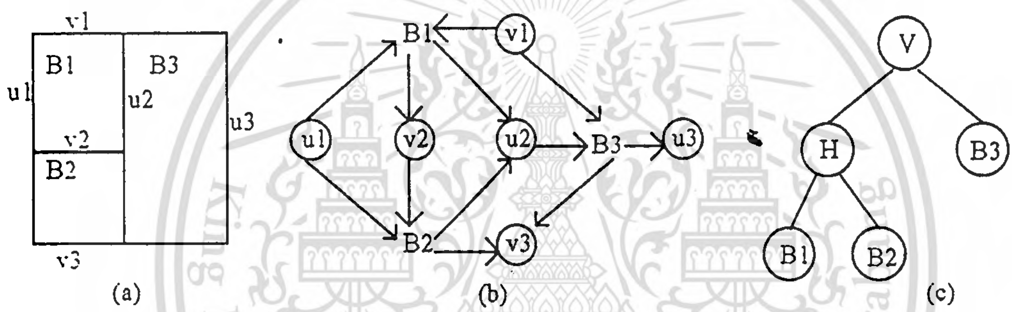


Figure 12 (a)Floorplan (b)Representation graph (c) Decomposition tree

The decomposition tree represents the way of block composition. The parent node shows how the leaf nodes are composed, horizontal or vertical manner, to be the super block (Wimer et al. 1989).

The algorithm, proposed by Wimer, Koren and Cederbaum (1989) and Cederbaum (1992) is about the problem of selecting an optimal implementation for each building block so that the area of the final layout is minimized. The algorithm suggests a branch and bound that proves to be very efficient and can handle successfully large general non-slicing floorplans. The high efficiency of the algorithm steams from the branching strategy and the bounding function employed in the search procedure. The branch and bound algorithm is supplemented by a heuristic minimization procedure that further prunes the search. It is computationally efficient and does not prevent achieving a global minimum. The algorithm also shows how the non-slicing and the slicing algorithms can be combined to handle efficiently very large general floorplans.

By using the algorithm, all possible dimensions of each pattern are given. The objective is to assign the dimensions to the patterns so that the total area is minimized. Figure 13 shows the Search tree of the floorplan in figure 12.

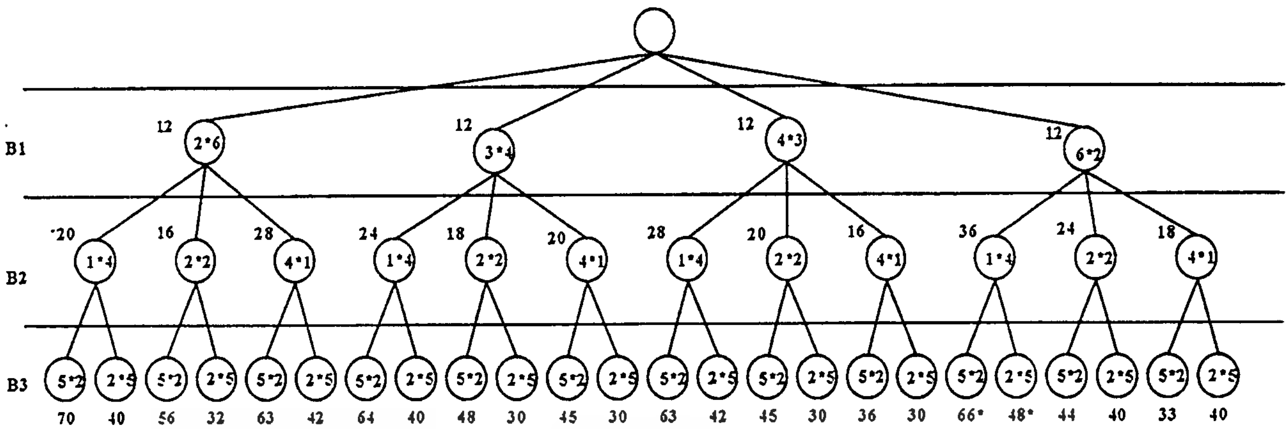


Figure 13 Search tree

From figure 13, the root node represents no located pattern. The daughters of the root node represent the possible layout for pattern B1 and its costs are calculated from the area of B1. In level 3, the values in the nodes represent the possible dimensions of B2. The costs are calculated from the total area of B1 and B2 when B1 is stacked on the top of B2. The leaf nodes represent the possible dimensions of B3 and its costs are calculated from the total area of B1, B2 and B3. From the layout, B1 is stacked on the top of B2 and B3 located on the left hand side of B1 and B2. In calculating for the layout costs, the location for each pattern can be considered from its representation graph (see Figure 12c).

To start the algorithm, the search tree (as shown in Figure 13) must be created and then the branch and bound algorithm is applied to search for the best layout from the constructed tree. The idea of the proposed is that the algorithm considers the best dimensions of the patterns to minimize the total area. The change of locations and properties of the patterns are not considered by the algorithm.

2.3.3 Cutting Point Interchange Approach

Instead of using dual polar graph, the approach (proposed by Tam, K.Y. in 1992) uses four operators to represent the slicing structure. The four operators are defined as:

"L" : left cut

"R" : right cut

"U" : up cut

"B" : bottom cut

Each operator is explained in figure 14a-d.

To represent the slicing structure, the approach considers the slicing structure as construction of super block from the combination of blocks. The parent node represents the way of leaf nodes constructing to be a super block. Figure 15 shows the slicing structure and its slicing tree. The leaf node is called "operand" and another node is called "operator." From figure 14, the slicing tree can be represented is short form as 65U4L32U1BR. The representation of this form is similar to the way operators and operands are stated in post order arithmetic expressions.

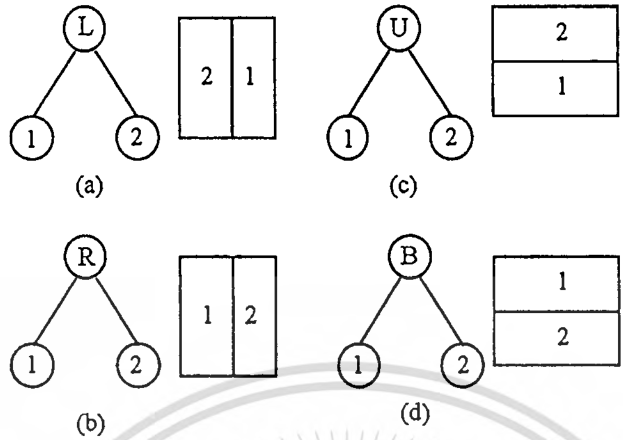


Figure 14 the operators of slicing structure

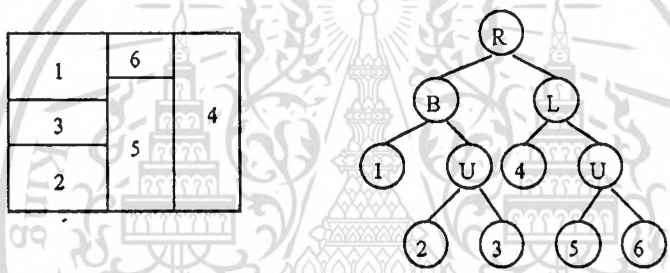


Figure 15 the slicing structure and its slicing tree

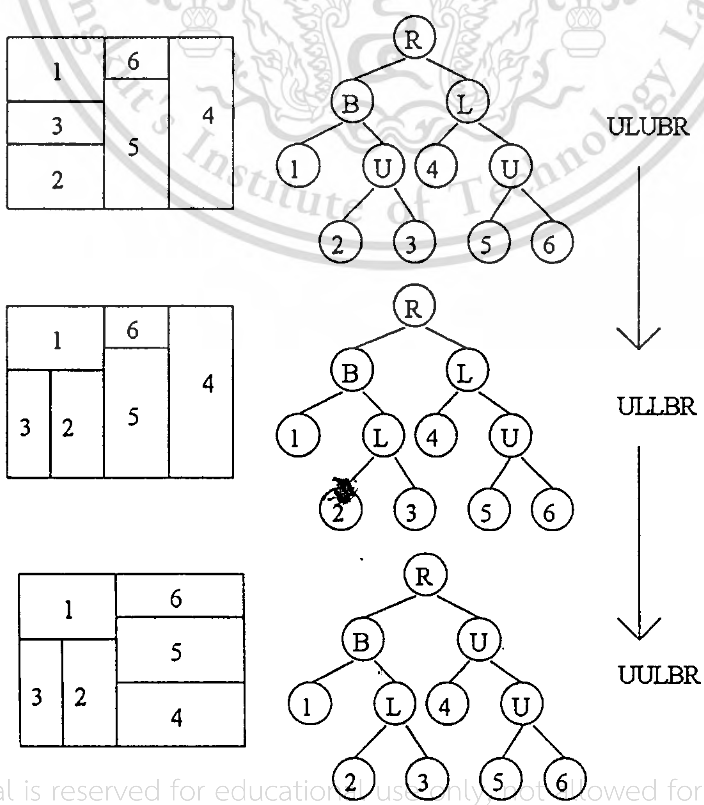


Figure 16 the slicing tree transformations

The algorithm relocates the facilities by changing the two opposite operators along each dimension (e.g. "L" and "R", "U" and "B"). The change of operator means that the facility location is relocated. From Figure 14a, the operator of the root node is "L". When the operator is changed to be "R", as shown in Figure 14b, facilities "1" and "2" are relocated. The similar way of interchange is also occurred in Figure 14c and d. Therefore, the operator nodes of the slicing tree can be changed in the same way as explained above as long as the space is available.

By using the changing of operator technique, the facilities are relocated without changing the position of operands in the slicing tree. Therefore, the string 65U4L32U1BR can be written as ULUBR and the string can be changed to relocate the facilities in the layout. The possible outcome of alternative layouts proposed by this algorithm is 4^{n-1} where n is the number of facilities. Figure 15 shows some of the slicing tree transformations.

With this technique the aspect ratio and the space allocation are considered before transforming the slicing structure. The objective function is based mainly on the traffic volumes between facilities. The facilities with large volumes are placed in close proximity while satisfying the area and shape constrains (aspect ratios) of individual facility.

To search for the best layout, the algorithm uses the simulated annealing in which more details will be discussed in the next section.

2.4 Artificial intelligence approach

Artificial intelligence approach allocates the facilities by using the information analyzed by artificial intelligence. The approach of facility layout by using artificial intelligence was first presented by Fisher and Nof (1984). They introduce the first prototype expert system for solving the facility layout problem, called FADES. The system not only solves the facility layout problem, but also helps the selection of equipment and economic investment analysis. Other approaches are the expert system approach proposed by Kumara et al. (1988), and Malakooti and Tsurushima (1989), and the fuzzy approach proposed by Raoot and Rakshit (1991). There are many types of search process for these algorithms. The algorithm proposed by Kumara et al. uses the expert system rule in both selecting the best layout and the multiple criteria. The algorithm proposed by Malakooti and Tsurushima use a depth first search as the search process and knowledge base as multiple criteria.

2.4.1 Expert system approaches

Kumara et. al. (1988) presented a module, called IFLAPS, for solving the facility layout problem by using artificial intelligence. The module consists of expert system and pattern recognition system. In the expert system, the augmented transition network is used to represent the facility layout knowledge, such as area dimension, required facilities, function, relationship weight, noise index and so on. With this knowledge and actual data of the facilities, the positions of the facilities are assigned via the expert rules. This expert rule defines the position of the facility as immediate, adjacency and non-adjacency assignment.

The pattern recognition system generates the production rules by capturing the expert rule above. This production rule, a so called facility layout grammar, is used for generating the facility layout and is represented by using web grammar. The layout process starts by allocating the first facility on to a grid of matrix. Then, a next facility to be inserted is selected and allocated according to the inferring result of the production rule. In the production rule the facility and its associated location are defined by comparing to the other facility. Figure 17 shows the example of production rule in web grammar. The locations of facility are defined as left, right, top and bottom. In rule 1, it states that MC is located next to the right of R. In rule 2, MF is located at the right of R and MC is located at the bottom of R. The above steps are repeated until all facilities are considered. After the position of all facilities is defined, the aspect ratio of all facilities is adjusted to fit with the layout.

P1: R → (R → MC)
P2: R → (R → MF
            ↓
            MC)
P3: MC → Metal Cutting.
P4: MF → Metal Forming.
P5: R → Raw Material.

Figure 17 the example of production rule.

The block diagram of IFLAPS system is shown in figure 18. The system consists of two major processes, facility layout process and pattern recognition. The facility layout process produces the expert rules while pattern recognition generates the layout result.

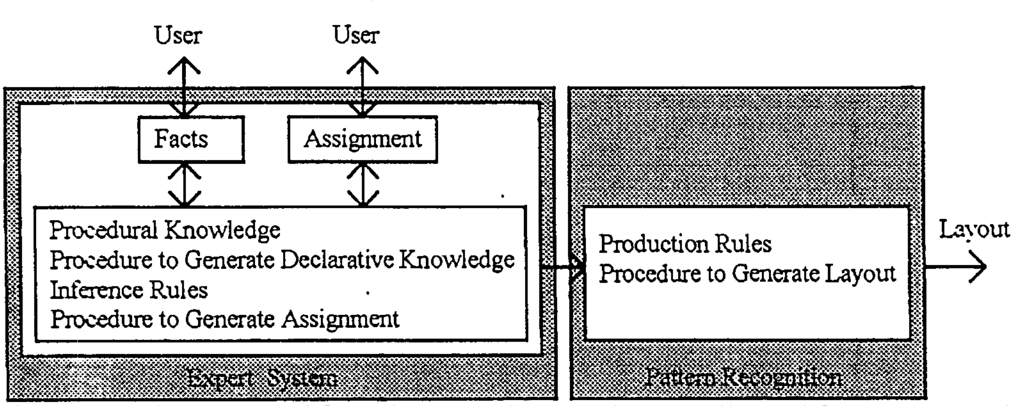


Figure 18 IFLAPS system block diagram

Malakooti and Tsurushima (1989) proposed a system which consists of:

(1) Data base, which expresses the problem to be solved. The data are department, site and constraint.

(2) Knowledge base, which stores domain-specific problem-solving knowledge. Knowledge base represents the problem solving knowledge in the form of IF-THEN rules.

(3) Priority base, which contains priorities for rules, adjacency, departments and sites. The priorities are ranged from A to O (vowel system). The highest priority is ranged as A and the lowest priority is ranged as U.

(4) Inference engine, which controls the problem-solving procedure.

(5) Decision marker (DM), which generates the optional layouts by changing the priorities. The best layout is selected by DM.

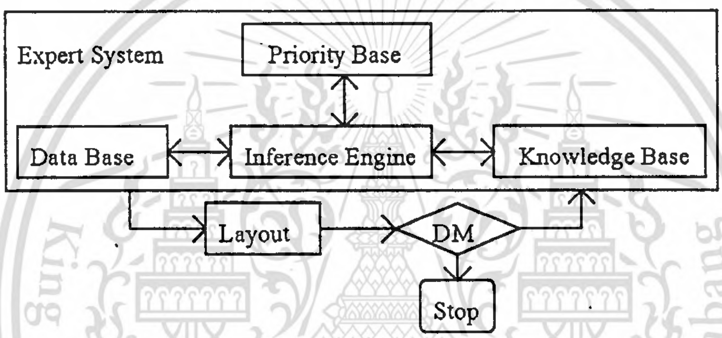


Figure 19 Block diagram of the system

Figure 19 shows the overall structure of the system. To start the process, the inference engine investigates the priority of rules, adjacency (or relationship chart), department and site for setting the sequence of operations. If the rule priority is the highest (which is normal), the inference engine will start the system by inferring the rules. The result from the rule inferring is to assign the department to the site such as "assign drilling department to site 2" and so on. If two or more departments are assigned to the same site, the adjacency relationship is used to help the system in assigning the department to the site. The DM is finally asked to confirm the result. If the result is disagreed by DM, the priorities of the system are adjusted.

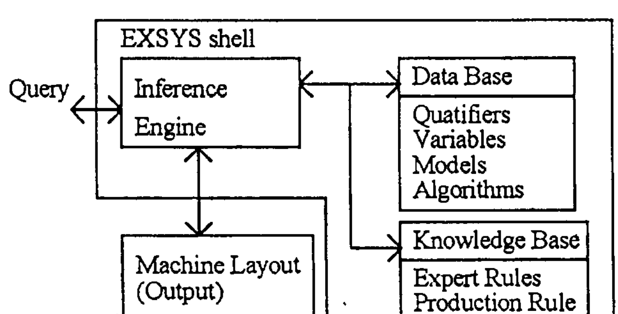


Figure 20 Block diagram of Abdou's system

In 1990, Abdou and Dutta proposed an integrated approach to facility layout using expert system. The proposed system is shown in figure 20. It uses EXSYS expert system shell to develop the machine layout system.

The developed system consists of three subsystems, namely data base, knowledge base and inference engine. The system starts by query the user for the information about the machine to be laid out. This information is stored under the quantifiers and variables. The models in data base subsystem contain the criteria for selecting the material handling equipment and the algorithm contains the criteria for selecting CORELAP and ALDEP layout algorithm. With the query information, the inference engine selects the material handling equipment and layout algorithm by using rules in the knowledge base.

This system selects the proper layout algorithm, CORELAP or ALDEP, under the specific criteria. The purpose is to exploit the advantage of the suitable algorithm.

2.4.2 Fuzzy approach

Raoot and Rakshit (1991) proposed a system based on the general framework of ' fuzzy' and 'linguistic pattern'. The research describes the quantitative and qualitative factors that affect the facility relationship. The problem solving strategy consists of (1) the aggregation of the experts' opinions; (2) a strategy for locating facilities; (3) a strategy for resolving location conflicts; (4) a heuristic for facility selection; (5) a facility placement procedure; and (6) a strategy for evaluating the layout.

The basic input to the model is the opinion of experts on the facility relationship between a facility pair. The maximal mean evaluation method is used to aggregate these opinions and each type of facility relationship is treated separately. This aggregated value of the facility relationship is used in the location strategy.

(1) if PROD-LINK = VERY HIGH
then DISTANCE = VERY CLOSE.
(2)if SERV-LINK = ESSENTIAL
then DISTANCE = CLOSE.
(3) if ORG-LINK = DIRECT
then DISTANCE = NEAR BY.

Figure 21 The example of rules.

The locating facility strategy is done based on the value of their relationships. The strategy is expressed in linguistic patterns in the form of if-then rules. Figure 21 shows the example of rules for facility locating strategy and table 1 is the linguistic variables and their associated values.

Linguistic variable	Associated values	Explanation
PRO-LINK	Very low, low, medium, high, very high	Production relationship
SERV-LINK	Negligible, considerable, essential	Service relationship
ORGN-LINK	Independent, Indirect, Direct	Organizational relationship
ENVR-LINK	Safe, unsafe, hazardous, very hazardous	Environmental relationship
DISTANCE	Very close, close, near by, far, very far	Distance between facilities

Table 1 The linguistic variables and their associated values.

By using the rules in figure 21 and the facility relationship values from step 1, the recommended distance is provided. This location strategy may give different recommendations for the location of a facility pair when there is more than one type of relationship between the facilities. This result in location conflicts which are resolved by aggregating the recommended distance values. The aggregation is done on the basis of the *maximum sum of truth values* of each of the recommended distances with respect to each of the values of the linguistic variable DISTANCE.

The selection of facilities is based on the recommended distances between different facility in pair. From the distances, the truth value of each distance is calculated with respect to the proposition VERY CLOSE and truth value matrix is constructed. This truth value gives the total degree of closeness. From this total degree of closeness, the next facility to be inserted is deleted.

The placement of facility of this algorithm is done based on the spiral technique (Gaston 1984).

2.5 Simulated annealing approaches

Simulated annealing [Kirkpatrick et al 1983] is a variation of hill climbing in which, at the beginning of the process, some downhill moves may be made. The idea is to do enough exploration of the whole space early on so that the final solution is relatively insensitive to the starting state. This should lower the chances of getting caught at a local maximum, a plateau, or a ridge.

Simulated annealing as a computational process is patterned after the physical process of annealing, in which physical substances such as metals are melted and then gradually cooled until some solid state is reaches. The goal of this process is to produce a minimal-energy final state. Thus this process is one of valley descending in which the objective function is the energy level. Physical substances usually move from energy configurations to the lower ones, so the valley descending occurs naturally. There is some probability that a transition to the higher energy state will occur. This probability is given by the function

$$p = e^{-\Delta E/kT}$$

where ΔE is the positive change in the energy level,
T is the temperature, and
k is Boltzmann's constant.

Simulated annealing algorithms provide just such a hill-climbing mechanism. Moves that worsen the current solution by an amount, E, are accepted with probability. T is a new control parameter analogous to temperature in the annealing of physical systems. In an optimization framework, we anneal a placement by performing standard iterative improvement steps, but now accept some worsen solutions according to this temperature rule. Central to any annealing algorithm is the need to evaluate many moves. During initial annealing, T is large; in this hot regime, most uphill moves are accepted. As the iterative improvement proceeds, the temperature T is slowly reduced. Near the end of annealing, T is small; in this cold regime, few uphill moves are accepted. The change in the fraction of moves accepted at each temperature is often referred to informally as the statistics of the annealing process. The examples of facility layout using simulated annealing are CLASS and the approach proposed by Tam (1992).

Another system named CLASS is proposed by S. Jajodia, I. Minis, G. Harhalakis and J. M. Proth (1992). The proposed system defines energy level (E) as the product of the number of pallet transfer and the distance between them. The initial temperature (t) of the system is determined by identifying the lowest value at which at least 80 per cent of a certain number of random configuration changes are accepted. The temperature can also be specified by the user. The annealing temperature is reduced by the temperature reduction factor (k: Boltzmann's constant) which has value less than unity. The algorithm is as follows:

```
Procedure:
Place (at random) of all k entities on k*k grid.
Compute the total value of E and set value of t.
While (temperature steps < 100) or
(layout configuration can be changed)do
begin   while (configuration changes = 100*k) or
        (successful configuration changes = 10*k) do
        begin  Select (at random) candidate positions p1, p2 and
               compute DE.
               If DE<0 then change the configuration (p1, p2) else
        begin  Generate random number (ran) and 0 <ran< 1
               If ran < exp(DE/t) then change the configuration
               t = k*t
        end
        end
end
```

The approach uses matrix as the layout process and the search process is done by simulated annealing.

The approach proposed by Tam uses cutting point interchange of graph theory in the layout process and uses simulated annealing for searching for the best layout. The algorithm of simulated annealing is the same as CLASS.

2.6 Conclusions

The layout techniques explained in this chapter are categorized as:

1. Traditional schematic approach,
2. Optimizing and heuristic approach,
3. Graph theory approach,
4. Artificial intelligence approach and
5. Heuristic search approach.

Traditional schematic approach allocates the facility by manual. The advantage of this approach is that the conditions concerned with facility layout are considered. The disadvantages are that the approach is time consuming and not many alternatives are generated. To overcome the time consuming and the alternative generation problems, The computerized facility layout algorithms are designed. The optimizing and heuristic approach are among the first approach presented. It employs the computer speed to solve the problem. Although the approach may reduce the time consuming and the alternative generation problem, it lefts the conditions concerned with facility layout to be unsolved. At about the same time, graph theory approach is presented. The problems of layout are still the same. However, the emphasis of this approach is to improve the pattern layout process. The artificial intelligence approach is designed to solve the conditions concerned with facility layout problem which is considered to be the ill-structured problem. In the facility layout process, the alternative generation is considered to be the NP complete problem. Therefore, the heuristic search approach may be a good candidate to deliver a satisfiable solution in a reasonable time.

Chapter 3
THE PROPOSED PROBLEM SOLVING METHOD

For solving the layout problem, the number, dimension and properties of the facility areas are given at the initial state. The goal is to decide where each facility area should be located to minimize the overall cost. Figure 22 is the proposed diagram of the problem solving technique.

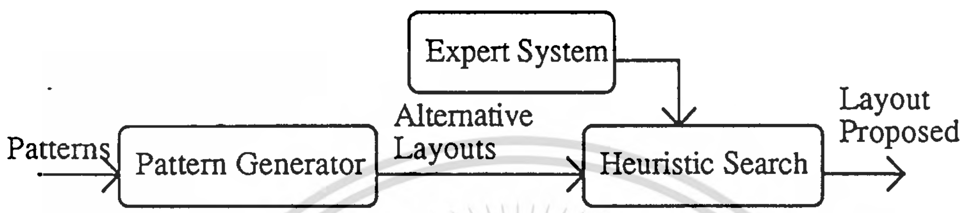


Figure 22 Structure of the Problem Solving Technique.

There are three major processes in the system; the pattern generator, the heuristic search and the expert system. The pattern generator constructs the alternative layouts. The heuristic search searches for a set of low cost layouts among these constructed alternatives. This heuristic search has dual functions. First, the so-called heuristic function calculates cost of layout, which is used as a criterion of selection. Second, the system selects a set of low cost layouts. The expert system is used in helping the system to calculate the layout cost. It works as a tool to increase the flow of information concerning facilities to the heuristic function.

To start the procedure (see also figure 23), the pattern generator selects a pair of activity areas or patterns having the highest W value and locates them. The output from the pattern generator is alternative layouts. To select the best layout out of these alternatives, the system uses a heuristic search technique. Distances are calculated. Frequencies of traveling are put in by the user and the closeness weights are assigned by the expert system. In assigning the closeness weight, the functional characteristic, interrelationship among the facilities, material flow condition and practical limitation of facility layout are taken into account by the knowledge base of the expert system. Using distance, frequency of traveling and closeness weight, the costs of layout are calculated. Using these layout costs, the heuristic search selects a set of low cost layouts as layout candidates. The system then searches for the next pattern to be located. If there are no further patterns then the system uses the layout candidates as the proposed layouts. If further patterns exist, the system selects the next pattern to be located on the basis of its W-value and locates it around the selected layout. Alternative layouts are generated again and costed. The system repeats the above process until there are no further patterns to be located. The details of each process are discussed below.

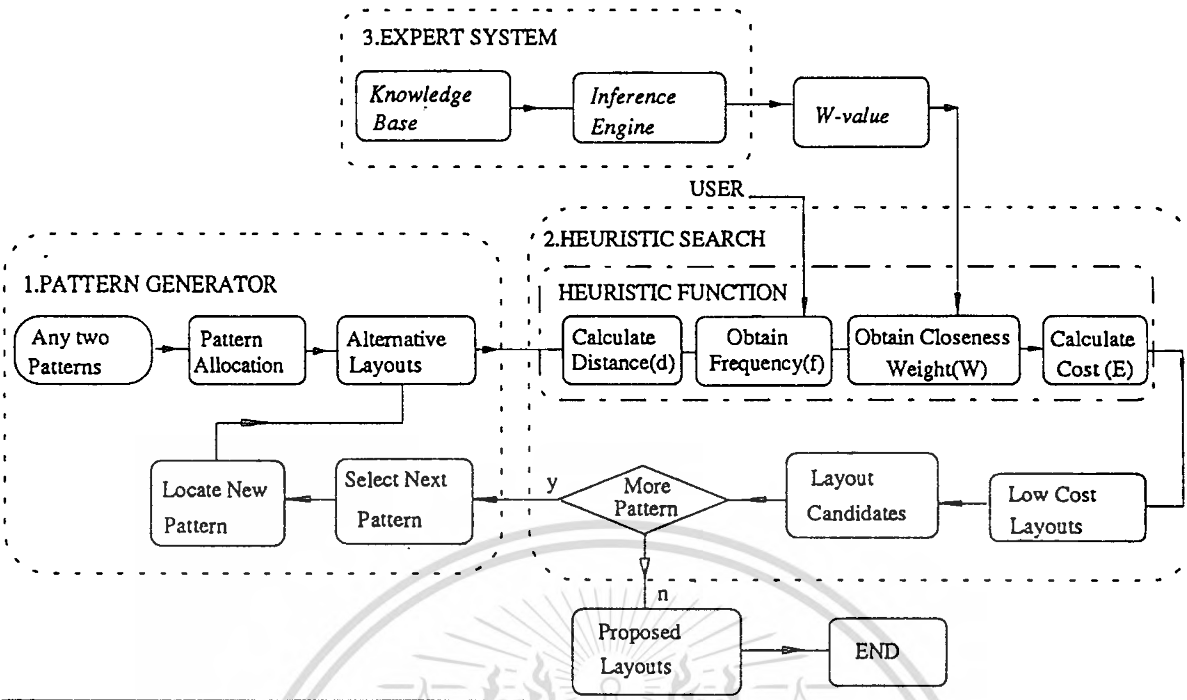


Figure 23 The flow diagram of the proposed process

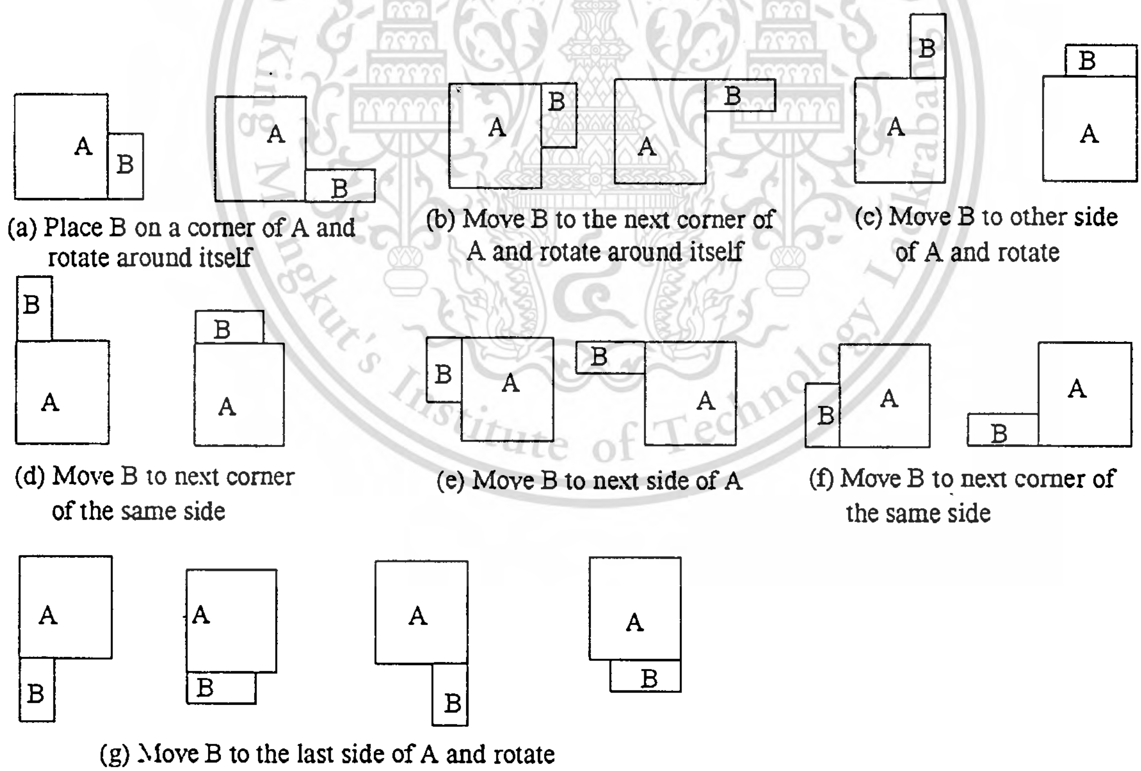
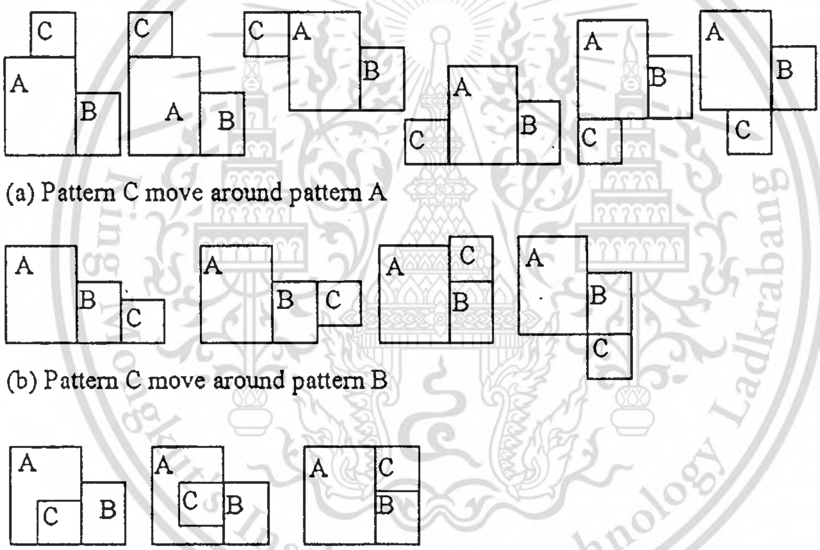


Figure 24 Some generated alternatives of two patterns.

3.1 Pattern generator

The proposed pattern generator is adapted from the heuristic approach to two-dimensional stock cutting problems proposed by Dagli et al(1987). The process starts with a pair of facility areas, namely A and B. The pattern B is put onto a side of the pattern A so that the sides of A and B adjoin. This combined area, A and B, is proposed as the first alternative. Next, the pattern B is rotated around itself and placed so that its perpendicular side adjoins the same side of A and this combined area is also proposed as an alternative. The pattern B is then moved to the next corner of A and rotated around itself. The pattern B is then moved to the perpendicular side of the pattern A after all sides of B are adjoined onto all corners of a side of pattern A. In generating the alternatives, the overlapping of the combined area is checked. If the patterns overlap, the alternative is rejected. The method repeats the above procedures until all possible combinations of patterns A and B have been considered and all facility areas are located.

Figure 24 shows the alternative layouts generated by patterns A and B and Figure 25 shows the generated alternatives of three patterns. Pattern C is allocated onto the selected layout of patterns A and B (upper-left most pattern of Figure 24).



(a) Pattern C move around pattern A

(b) Pattern C move around pattern B

(c) The patterns are overlapped

Figure 25 Some generated alternatives of pattern A, B and C.

3.1.1 Next Pattern

For the allocation of more than two facility areas, the process is similar but some additional steps are included. Assuming C is the next pattern to be inserted onto the generated alternatives, AB. With the same algorithm, the system locates C onto A and B respectively. All generated non-overlapped patterns are selected as the alternatives.

Figure 25 shows some of the generated alternatives of pattern AB and pattern C. From the figure 25, only the non-overlapped patterns are shown. Figure 25(a) shows pattern C allocated around A and figure 25(b) shows pattern C allocated around pattern B.

For generating the alternatives of pattern A, B and C, pattern C has to be allocated on to every combination of pattern A and B. Therefore, all the combinations of pattern A and B in figure 24 have to be combined with pattern C as shown in figure 25.

The algorithms also do the same way for four or more patterns. That is the next pattern to be located will be placed on to the generated pattern, ABC of the figure 25. The pseudo code of the above procedure is:

```
Program AlternativeGeneration(q:number of patterns);
No.ofPatterns: q>2;
Pattern: P1, P2, P3, ....Pq;
Integer: x,y;
Procedure Allocation(input AB : Pattern);
Angle: Pattern A: A1, A2, A3, ... An
          Pattern B: B1, B2, B3, ... NB;
No.ofSides: PatternA: m, PatternB: n;
Integer:  i,j,k,l,m,n;
CallProcedure: OVERLAP
Begin
(For i = 1 to m;
 (For j = 1 to n;
  k = i;
  l = j;
  (Repeat the following steps 2 times;
  if i=m then i+1=1;
  if j=n then j+1=1;
  Adjoin side BjBj+1 with side AiAi+1 by
  adjoining the angle Bl with Ak;
  if the adjoined pattern NOT_OVERLAP with other patterns
    Then (Assign this adjoined pattern as an alternative;
      if l=n then l=1 else l=l+1;
      if k=m then k=1 else k=k+1;)
    else (if l=n then l=1 else l=l+1;
        if k=m then k=1 else k=k+1;) )
 Next j;) Next i;)
End;
Begin{Main Program}
(For x=2 to q-1;
 (For y=1 to x-1;
  Allocation(Py,Px);
  Next y;)
Next x;)
End.
```

Observing the ordering of next pattern to be inserted, If P1, P2, P3, ..., Pn are the patterns being located, then the pairs of pattern generation are considered as follows.

(P1P2), ((P1P3)(P2P3)), ... ((P1Pn)(P2Pn)...(Pn-1Pn))

From the equation above, if we locate patterns P1, P2 P3 and P4, then the ordering of the pattern to be located are as follows:

(P1 P2)
(P1 P3) (P2 P3)
((P1 P4) (P3 P4)) ((P2 P4) (P3 P4))

3.1.2 The Number of Generated Alternatives

Obviously, the number of generated alternatives from the above algorithm is exponentially increased when the number of facility areas is increased. Let $a_1, a_2, a_3, \ldots, a_n$ be the number of sides of pattern $A_1, A_2, A_3, \ldots, A_n$. The maximum number of generated alternatives of pattern A_1 and A_2 are $2*a_1*a_2$. If only one side of two patterns is reduced by the adjoined sides, then the alternatives for 3 patterns are $2^2*a_1*a_2*a_3(a_1+a_2-1)$. With the same assumption, the maximum number of generated alternatives for n patterns is:

$$2*a_1*a_2 \qquad \text{for } n = 2 \qquad (1)$$

$$2^{n-1}*a_1*a_2*a_3 \ldots a_n*(a_1+a_2-1)*(a_1+a_2+a_3-2)\ldots*(a_1+a_2+\ldots a_{n-1}-(n-2)) \qquad \text{for } n > 2 \qquad (2)$$

The number of generated alternatives for quadrilateral patterns obtained from equations 1 and 2 are shown in Table 2.

Number of Facilities	Generated Alternative Layouts
2	32
3	1,792
4	143,360
5	14,909,440
6	1,908,408,320

Table 2. The number of generated alternatives for quadrilateral patterns.

Given the large number of alternatives, searching for the best layout by a complete analysis of all generated alternatives would be exhaustive. Therefore, a heuristic search is designed for solving this problem.

3.2 Heuristic Search

Heuristic search techniques may play a key role in supporting the development of heuristic methods for layout planning. These techniques define search strategies that may help diminish the effort wasted in the search of redundant paths, consequently facilitating the development of good solutions. The performance of these search strategies is largely dependent on the characteristics of the problems; hence it is very important to select an adequate search technique for each problem. The generation of such solutions normally depends not only on the search strategy, but also on the use of several efficient and effective rules or criteria to evaluate and direct the search at a more profitable path. The set of rules and criteria is generally called objective function, and for each problem there are potentially an infinite number of alternative ways of defining it.

The search techniques that we are most concerned with in this study belong to the family of beam search. Beam search is a well-known heuristic search technique developed in the mid 1970s for solving large-scale combination problems. This technique has been applied to some practical problems with relative success and is considered a very aggressive search technique. Beam search applies an objective function to appraise all the nodes in the same level of the decision tree, and only the best n nodes in this level are selected as beams, where n is called the beamwidth, usually user-defined (Shih *et al.* 1992). Beam search only moves downward in the decision tree to the next levels from the selected beam nodes, and all other nodes of the same level are ignored forever. The branches linking the beam nodes of the various levels of the decision tree may be interpreted as alternative potentially optimal decision paths. This search process is repeated level by level until the last is reached, and at this time, the best among the n alternative solutions is selected as the final solution to the problem.

The search structure of the proposed system is summarized in Figure 26. This figure presents a tree graph of heuristic search. The beam width n is set at 2. Each one of these n nodes is expanded to all possible alternatives.

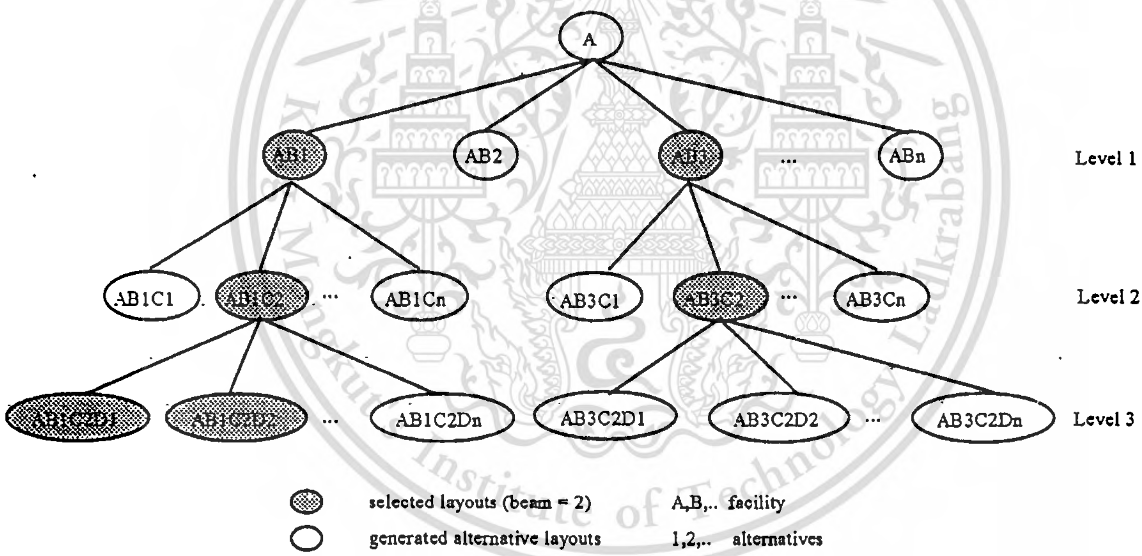


Figure 26 The search path of the improved heuristic search

Figure 26 shows search path of the heuristic search. Level 1 shows the generated alternatives of patterns A & B. Level 2 shows the generated candidates of patterns A, B & C which are generated from patterns AB1 and AB3. In the same way, level 3 shows the layout candidates generated from AB1C2 and AB3C2.

The reasons for applying beam search to the proposed system are considered under the following conditions.

First, beam search provides the simulated result flexibility. User can simulate the result of the layout by varying the number of beam width. The bigger number of beam width is chosen, the better the final result is obtained. On the other hand, the bigger number of beam width is chosen, the longer processing time will be taken.

Second, beam search gives a relatively good result when comparing to other heuristic search such as best first search, branch and bound and so on (Shih, L.C., Enkawa, T. and Itoh, K. 1992) while the implementation of the system (program coding) is easier.

Lastly, beam search is considered to be a less time consuming technique when comparing to best first search or branch and bound search. The reason is that beam search does not need to back track to the previous searched steps.

3.2.1 Objective Function

In searching for the best layout, the heuristic function calculates the costs in consideration of all practical aspects by acquiring knowledge from the knowledge base system. The system uses the potential energy model as a heuristic function.

Hsu and Kubitz(1987) defined the potential energy between two patterns as: when the two patterns overlap, an energy producing a force tends to separate them. The more they overlap, the larger the force is. On the other hand, when the two patterns are separated, an energy producing a force tends to pull the two patterns closer. Without overlap or separation, the patterns are said to be in equilibrium condition.

To formulate the potential energy model, the proposed formula below is adapted from the attractive force model proposed by Tam & Li(1991). This model ignores the geometric characteristics by if each block is a circle. Since the layout is the non-overlapping constraint, therefore, the formulation is defined as:

$$E_{ij} = {}^{1}/_{2} * (W_{ij} * (d_{ij})^2) \quad (3)$$

$$\sum_i \sum_j E_{ij} = E = {}^{1}/_{2} \sum_{i=1}^{n} \sum_{j=i+1}^{n} W_{ij} * (d_{ij})^2 \quad (4)$$

where

W_{ij} is the closeness weight between facilities i and j

E_{ij} is the energy exerted by an external force in moving the facility from equilibrium position to d_{ij} while obeying Hooke's law.

d_{ij} is the length from the center of facility i to the center of facility j which is equal to $d_{ij} = [(x_i - x_j)^2 + (y_i - y_j)^2]^{1/2}$, where (x_i, y_i) is the coordinate of the center point of facility i.

If f is the traveling frequency between facilities i and j, then equations 3 and 4 are changed to:

$$E_{ij} = {}^{1}/_{2} * (W_{ij} * (f * d_{ij})^2) \quad (5)$$

$$E = {}^{1}/_{2} \sum_{i=1}^{n} \sum_{j=i+1}^{n} W_{ij} * (f * d_{ij})^2 \quad (6)$$

For each E of any pattern i or j, there are many possible locations for the pattern. If a and b (a=1, 2, 3,..., p and b=1, 2, 3,..., q) are the side numbers of the activity pairs to be located, as mentioned in the pattern generator, then the distance between facilities i and j can be defined according to the rotation of facilities as:

$$d_{ij} = (d_{ij})_{ab} \tag{7}$$

Where $(d_{ij})_{ab}$ is the distance between patterns i and j whose side numbers a and b are adjoined.

By substituting equation 7 into equation 6, we obtain

$$E_{ab} = 1/2 \sum_{i=1}^{n} \sum_{j=i+1}^{n} W_{ij} * (f * (d_{ij})_{ab})^2 \tag{8}$$

From equation 8, the minimum value of E can be selected to evaluate the most cost effective layout. Equation 8 is used as a heuristic function in calculating the cost of layout. This value will be used as a criterion in selection of the most appropriate search path.

An alternative formulation is also presented by Ying and Wong (1989) as follows:

(a) if blocks i and j are connected,

$$E_{ij} = W_{ij} * \frac{r_i + r_j}{d_{ij}} p_{ij} + \frac{d_{ij}}{r_i + r_j} - 1 \tag{9}$$

(b) if blocks i and j are disconnected,

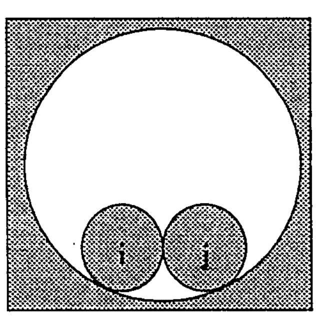
$$E_{ij} = W_{ij} * \frac{r_i + r_j}{d_{ij}} p_{ij} \tag{10}$$

where r_i and r_j are radius of blocks i and j respectively

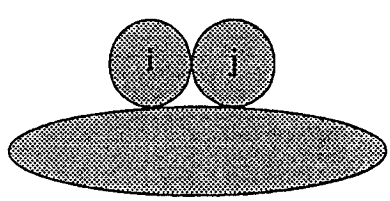
$$p_{ij} = \max \{ 0, (r_i + r_j) - d_{ij} \} \tag{11}$$

3.2.2 Closeness Weight

The Potential Energy as described in Dynamics of Oscillating Systems (Fowles 1967) is the energy of a system at an equilibrium configuration (see figure 27).



(a) Patterns i and j tend to move closer



(b) Patterns i and j tend to move apart

Figure 27 The stability configuration of patterns i and j.

This equilibrium is defined as a configuration for which all the generalized forces vanish. If the system is given a small displacement, however, it may or may not return to equilibrium. If a system tends to return to equilibrium, given a sufficiently small displacement, this equilibrium is *stable*; otherwise, the equilibrium is *unstable*.

The stability of a system depends directly on the sign of ***stiffness coefficient***. If the equilibrium is *stable*, the coefficient sign is positive, but if the equilibrium is *unstable,* the coefficient sign is negative.

The closeness weight, W_{ij}, in equation 8 is also defined the same way as the stiffness coefficient of the potential energy. If the W_{ij} is positive, then pattern i and pattern j tend to move closer together, but if the W_{ij} is negative, then pattern i and pattern j tend to move apart.

W Values	Definitions
-10	Definitely Apart
-8	Certainly Apart
-6	Probably Apart
0	Ignored
6	Probably Close
8	Certainly Close
10	Definitely Close

Table 3 The level of closeness weight.

Since the closeness weight represents relative measures of a system, it can be any number. The values -10 to 10 are simply convenient. Closeness weights are not probabilities. They are informal measures of closeness level for a pair of patterns. They represent the degree to which we believe that a pair of pattern is closer. A negative value represents a W_{ij} in which pattern i and pattern j tend to separate. A 0 represents a W_{ij} in which pattern i and pattern j have no connection and a positive value represents a W_{ij} in which pattern i and pattern j tend to move closer. Level of closeness represented by closeness weight used in the system is shown in table 3.

3.2.3 Improvement of Heuristic Search

Any heuristic search, by its nature, can lead to errors. They do not guarantee the best solution; they only increase the likelihood of finding a usable solution. To reduce errors that may occur in the above situation, selection of the most suitable pattern before generating the alternatives has to be undertaken. The strategies suggested by Wimer and Koren (1988) are used to improve the efficiency of the heuristic search. Three steps have been added to the algorithm of the selection of the next pattern to be inserted.

First, among all unallocated patterns, the system selects the one for which the sum of its W value between this pattern and each of the located patterns is maximum.

Second, if the W values of the first step are all equal then the system selects the one that has the largest area. The algorithm of the modified heuristic is shown below:

1. Let OPEN be a list of unallocated patterns and CLOSE be a list of allocated patterns.
2. Select a pair of the start patterns Pi and Pj from OPEN for which Wij is maximum.
3. If OPEN is empty, exit with failure.
4. Remove Pi and Pj from OPEN and place on CLOSE.
5. Allocation(Pi,Pj) {see Appendix I}.
6. Calculate costs(Eij) for every generated layout.
7. Select the n candidate layouts for which costs(Eij) of the layouts are lowest.
8. Name the layouts in 6 as Pi.
{There are n layouts of Pi and each Pi is an accumulation of adjoined patterns, Pi and Pj}.
9. If OPEN is empty, Pi is the solution.
10. Otherwise, select a next pattern, Pj, from OPEN for which Wij is maximum.
11. Remove Pj from OPEN and place on CLOSE.
12. Go to step 4.

3.2.4 Generated Alternative for the improved heuristic

From the above algorithm, Let s be the number of candidates in a set and n be the number of layout to be located. Therefore, the number of generated layouts is defined as:

$$2 * s * a_n * \left(\sum_{i=1}^{n-1} a_{i-1}\right) \qquad (12)$$

where

$a_1, a_2, a_3, \ldots, a_n$ are the number of sides of patterns.

Number of Patterns	Number of Candidates	Problem Space	Improved Problem Space
5	5	14,909,440	520
5	10		1,040
10	5	2.287 +E18	1,120
10	10		2,240
30	5	3.031 +E62	3,520
30	10		7,040

Table 4 The comparison of problem space.

Table 4 shows that the search space of the problem size is significantly reduce. This improved heuristic makes the system possible to help solve the problem with a bigger number of patterns.

3.3 Expert System

The designed expert system composed of 4 main modules as shown in figure 28. The knowledge system is the production system and uses Modus Ponens as inference strategy. The Inference Engine of the system employs the Forward Chaining to control the direction of inference and supports certainty reasoning.

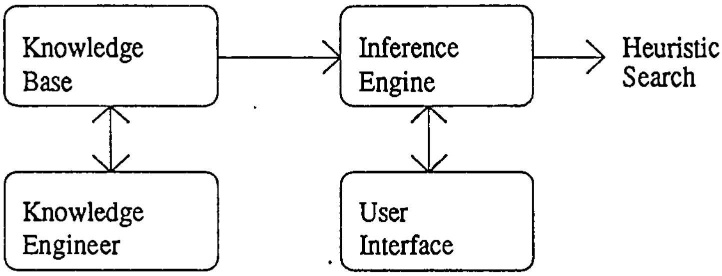


Figure 28 Block diagram of the Expert System

The main function of the expert system is to assign the closeness weight(W). The rule syntax is:

LABEL: if CONDITION then weight = VALUE.

From the rule syntax, LABEL is the rule label. In the rule, "if", "then", "weight", ":", "=" and "." are the reserved words but LABEL, CONDITION and VALUE are not. LABEL and CONDITION can be any string while VALUE can be any number from -10 to 10.

3.3.1 Inference Engine

The rule interpretation follows the application of a logical rule called Modus Ponens, That is *"if the condition is satisfied, the two patterns have to move closer with the given weight"*. According to MYCIN certainty function (Rich and Knight 1991, Neapolitan 1990), if "*the two patterns have to move closer*" is the hypothesis(h) and "*the condition*" is the evidence(e), a certainty factor of hypothesis(h) given the evidence(e), CF[h,e], is equal to VALUE (between -10 and 10). Since the VALUEs of the rules are provided by the expert who writes the rules, they reflect the experts' assessments of the strength of the evidence in support of the hypothesis.

3.3.1.1 Total weight calculation

MYCIN's knowledge base is composed of if-then rules which are used to assess various forms of patient evidence with the ultimate goal begin the formulation of a correct diagnosis and recommendation for a suitable therapy. A typical rule has the form

IF: the stain of the organism is gram positive, and
the morphology of the organism is coccus, and
the growth conformation of the organism is chains
THEN: there is suggestive evidence(0.7) that
the identity of the organism is streptococcus.

This is a rule that would be used by the inference mechanism to help identify the offending organism. The three conditions given in the IF part of the rule refer to attributes that help to characterize and identify organisms. When such an identification is relatively certain, an appropriate therapy may then be recommended.

The numeric value (0.7) given in the THEN part of the above rule corresponds to an expert's estimate of degree of belief one can place in the rule conclusion when the three conditions in the IF part have been satisfied. Thus, the belief associated with the rule may be thought of as a conditional probability, $P(h|e_1,e_2,e_3) = 0.7$, where h is the hypothesis that the organism is streptococcus, and e_1,e_2,and e_3 correspond to the three pieces of joint evidence given in the IF part, respectively.

MYCIN uses measures of both belief and disbelief to represent degrees of confirmation and disconfirmation respectively in a given hypotesis. The basic measure of belief, denoted by $MB(h,e)$, is actually a measure of the increased belief in hypothesis h due to the evidence e. This is roughly equivalent to the estimated increase in probability of $P(h|e)$ over $P(h)$ given by an expert as a result of the knowledge gained by e. A value of 0 corresponds to no increase in belief and 1 corresponds to maximum increase or absolute belief. Likewise, $MD(h,e)$ is a measure of the increased disbelief in hypothesis h due to evidence e. MD ranges from 0 to + 1 also, with + 1 representing maximum increase in disbelief and 0 representing no increase. In both measures, the evidence e may be absent or may be replaced with another hypothesis, $MB(h_1,h_2)$. This represents the increase belief in h_1 given h_2 is true.

In an attempt to formalize the uncertainty measure in MYCIN, definitions of MB and MD have been given in terms of prior and conditional probabilities. It should be remembered, however, the actual values are often subjective probability estimates provided by an Expert. We have for the definitions

$$MB(h,e) = \begin{cases} 1 & \text{if } P(h) = 1 \\ \dfrac{\max[P(h/e),P(h)] - P(h)}{\max[1,0] - P(h)} & \text{otherwise} \end{cases} \tag{13}$$

$$MD(h,e) = \begin{cases} 1 & \text{if } P(h) = 1 \\ \dfrac{\min[P(h/e),P(h)] - P(h)}{\min[1,0] - P(h)} & \text{otherwise} \end{cases} \tag{14}$$

The two measures MB and MD are combined into a single measure called the certainty factor (CF), defined by

$$CF(h,e) = MB(h,e) - MD(h,e) \tag{15}$$

From the above equations, the value of CF ranges from -1 to +1. Furthermore, a value of $CF = 0$ will result if e neither confirms nor unconfirms h (e and h are independent).

As MYCIN reasons, the CF's needs to be combined to reflect the operation of multiple pieces of evidence and multiple rules applied to a problem. There are 3 ways of combination which are:

- several pieces of evidence are combined to determine the CF of hypothesis,
- belief in a collection of several propositions are taken together and

- belief in one evident reflects the belief of another.

Likewise, the rules of weight assignment in this sytem are also designed as:

IF Density = "Heavy and dense"
THEN weight = "5".

The if part of above rule refers to attribute the help to characterized and identified closeness weight when weight is the recommended value attribute. The numeric value given in the THEN part is corresponds to expert's estimate of degree of closeness level.

In many applications, the closeness weight of a pair of facilities may be influenced by more than one condition. The VALUE needs to be combined to reflect the operation of multiple evidences (or conditions).

Therefore, the certainty factor of a hypothesis(h) given two evidences(e_1&e_2), CF (h,e_1&e_2), is computed by:

$$W_{total} = W1+W2-\frac{(W1*W2)}{10} \quad \text{if W1 and W2} \geq 0 \quad (16)$$

$$W_{total} = W1+W2+\frac{(W1*W2)}{10} \quad \text{if W1 and W2} \leq 0 \quad (17)$$

$$W_{total} = \frac{(W1+W2)}{(10-\min(|W1|,|W2|))} \quad \text{if } W1<0<W2 \quad (18)$$

$$Wtotal = 10 \quad \text{if } W1*W2 = -100 \quad (19)$$

where W is the VALUE.

For example:

1: if the density of material is very high
then weight = 5.

2: if the size of material is very long
then weight = 8.

Using above rules, the two factors are considered. Therefore, only two rules are put into the knowledge base instead of three rules. For the rule of combined conditions (the density of material is very heavy and the size of material is very long), Mycin's Belief function will take this into account. In certain cases of the above rules, the weight is 9 (by using equation 9). This is reasonable since the weight does not exceed 10.

Considering the number of rules, if the rules have to handle all the combinations of the conditions then the knowledge base would be very massive. For example, if four conditions are considered, then fifteen possible combinations of conditions occur. This means that fifteen rules have to be put into the knowledge base to cover only four factors. The number of rules which occurs according to the number of factors (n) is:

$$\sum_{r=1}^{n} {}^{n}C_{r} \qquad (20)$$

The number of rules, in this manner, exponentially increases while the number of factors linearly increases. Therefore, the use of the MYCIN certainty factor function has the added advantage of reducing the number of rules.

The other alternative method of combining conditions is "Mag Count" function proposed by Muther (1973). The Mag Count establishes a base value for the size of an item and then reduces or increases this base value by means of modifying values for the other influencing factors.

3.3.1.2 Chaining Direction

The inference engine of the system is forward chaining. The engine starts by going to the topmost rule and checking its condition. If the condition is satisfied with the existing fact then the W value is calculated and kept in the working memory, otherwise the inference engine goes on to the next rule. The step is repeated until all rules have been determined. After the rule inference process stops, the weight is calculated. There are two strategies whereby the system manages the closeness weights:

1. The W is concluded by only one rule. The concluded value is used as the closeness weight of the system.

2. The W may be concluded by more than one rule. Mycin's Belief Functions, equations 9 to 12, are used for calculating the W value under combination of conditions.

In short, The steps of the rule inference can be concluded as:

1. *Go to the topmost rule.*
2. *Check a condition of rule.*
3. *If the value of the condition is concluded then go to step 5 else go to next step.*
4. *Display question text.*
5. *If the condition is satisfied with the existing fact then go to step 8 else go to next step.*
6. *Put the concluded W value into the working memory.*
7. *If the rule still exists then go to the next rule and go to step 2 else go to next step.*
8. *Calculate the total value of W by using equations 9 to 12.*

The following pseudo code shows the procedure inference.

```
Procedure Inference:
Begin
Read GOAL;
Go to top most rule;
(For all rules;
 Go to topmost condition;
```

```
(For all conditions;
 (IF the condition is not concluded before;
  THEN Check the condition by asking question;
  ELSE Check the condition with the concluded value;)
 (IF the condition is true;
  THEN
     (IF there is no more condition;
      THEN rule := TRUE;
      ELSE go to next condition;)
  ELSE rule := FAIL;) )
 (IF rule := TRUE;
  THEN      (IF there is no rule and GOAL is concluded;
            THEN CALCULATE weight; {see also equations 5.1-5.4}
            ELSE go to next rule;)
  ELSE      (IF there is no rule;
      THEN use DEFAULT value;
      ELSE go to next rule;) ) )
END.
```

3.3.2 Knowledge Base

The knowledge in the knowledge base forms the rules for assigning the closeness weight by considering the interrelationship condition between facility areas. In considering the value of the closeness weight, the condition can be classified as:

- The condition causes the facility areas to be located apart. In this case, the W value is assigned as a negative value.
- The condition causes the facility areas to be located close together. In this case, the W value is assigned as a positive value.

In some special cases, the positive and negative values may be differently defined. For instance, the welding department must theoretically be put close to the chemical cleaning department to clean out all fluxes and dirt after the welding process. Unfortunately, this is not possible because a spark from the arc welding may cause a fire with the chemical cleaning solution. In such a case involving practical limitations, a negative value is assigned.

In the knowledge base, there are four main functions used in the system. First, the metafact "Question" is used for acquiring the information from the user. The syntax of the Question metafact is:

```
Question (ATTRIBUTE):
" TEXT1 ",
" TEXT2 ",
  ..........
" TEXAn ".
```

In the above syntax, "Question" is a reserved word. It has to be written every time when the knowledge engineers want to express the metafact. "ATTRIBUTE" that we want to retrieve the information from the user has to be written in the blanket sign. "TEXT" has to be written in the double quotation sign and end with comma if the text is not the end of the statement else end with period.

Second, the metafact Goal is used to express the attribute of the goal. The inference engine must search for the value of this attribute. The syntax of Goal is:

```
GOAL: ATTRIBUTE.
```

The syntax starts by a reserved word "GOAL:" and follows with ATTRIBUTE. GOAL structure is end with period. In this structure, A knowledge base can have only one goal.

Third, the fact DEFAULT is used to assign the value of W in case of no rule in the knowledge base can be applied to the situation. The syntax of DEFAULT is shown below:

```
DEFAULT: " VALUE ".
```

DEFAULT is a reserved word. The VALUE must be string and put in to a double quotation sign.

Fourth, The RULE is used for describing the way of assigning the W value. Its syntax and syntax definition are IF-THEN format.

In the knowledge base, there are three kinds of variables, TEXT, VALUE and ATTRIBUTE. All the values of these variables must be string. Only TEXT and VALUE must be put in to the double quotation sign. For VALUE, the surface format is represented as string but the inference engine will convert the VALUE string to be numeric for uncertainty reasoning. The example of knowledge base is shown in appendix II.

3.4 User interface and steps of running the process

Operating the system is very straightforward. Since the operating command is designed as the pop-down menu, the user just selects the menu and inputs the information to the system. Showing in figure 29 is the screen display of the system. The command button shown on the left hand side is the operating command. The details for each command are as follows.

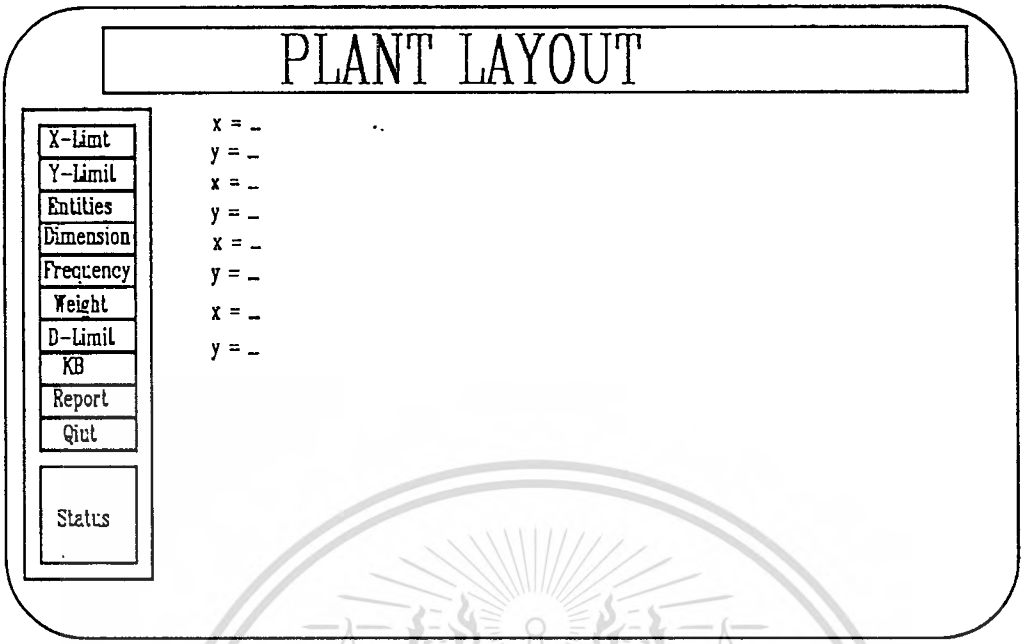


Figure 29 The screen display of the system.

- The X-Limit and Y-Limit will prompt the user about the total area of plant being considered.
- The Entities is command to ask the user about the number of patterns to be allocated.
- The Dimension is the dimension of every pattern.
- Frequency is the frequency of traveling for every pair of patterns.
- Weight is the command for starting the consultation. Before operating this command, the user has to operate the KB command.
- D-Limit is the number of alternatives to be considered during the search process.
- KB is the command for selecting and loading the knowledge base.
- Report is the command for assigning the name of the output file.
- Quit is used to terminate the system.

Figure 30 is a consultation screen from the system. The system queries the user for the plant information by displaying the question represented in the knowledge base. The user must answer questions posed by the system. After the consultation is over, the W value will be automatically assign to the heuristic search. The system displays the output as shown in figure 31.

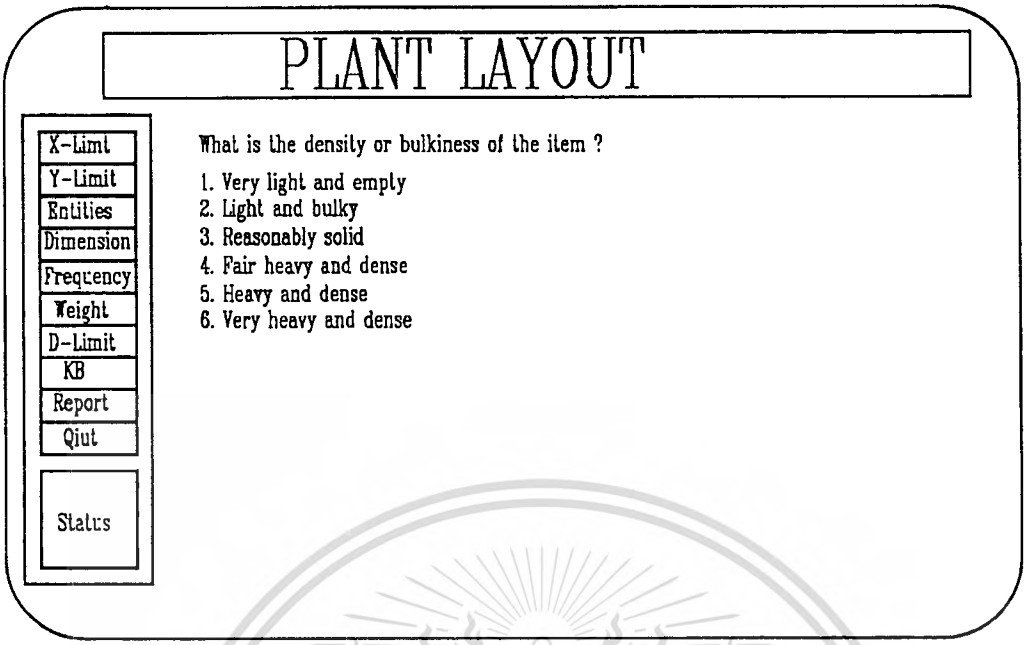


Figure 30 Consultation with the system.

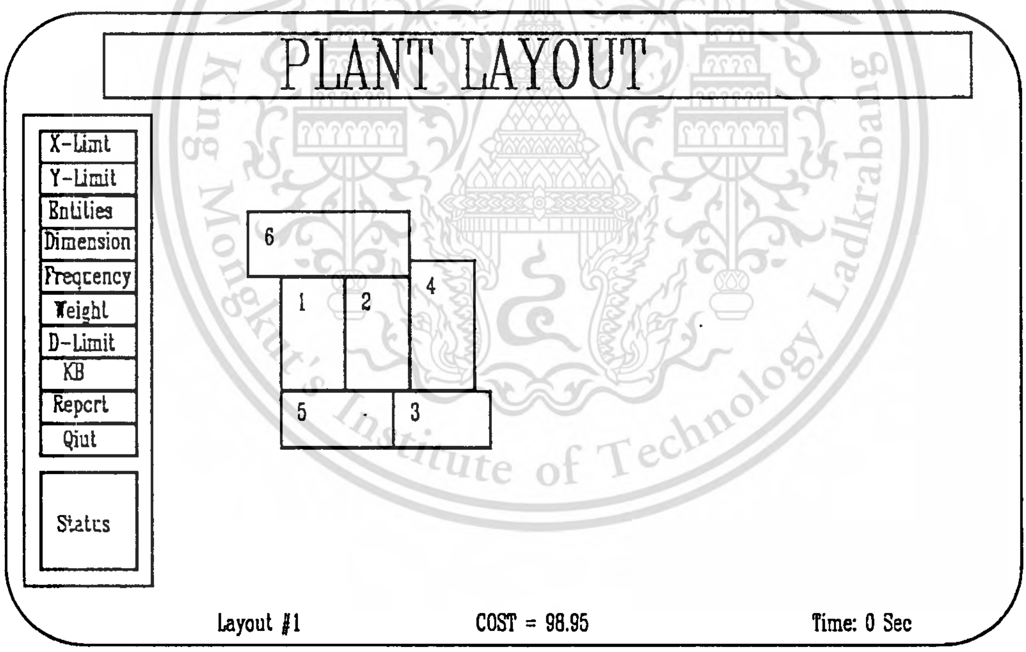


Figure 31 Output display of the system

Chapter 4:
PROGRAM DESIGN AND DATA STRUCTURE

In this chapter, the program design and data structure of the program will be presented. There are three main parts in this program, namely, knowledge compiler, inference engine and layout program. Figure 32 shows the block diagram of the program design. The input of the system is the knowledge base file which is a text file. The compiler compiles this knowledge base into an inference file which is designed to facilitate the inference process. The output of the inference engine is the closeness weight of all pair of facilities. Then, the facility layout process allocates the facilities and search for the best layout. In each process of the program, its data structure is designed and discussed in details in this chapter. The next section which is the knowledge compiler will cover language structure definition, data structure, parsing table, right-hand-side (RHS) table and compiling process. In the inference engine, the design of inference file data structure is discussed in section 4.2. The steps of the inference engine processes will not be discussed in this section since the details has been already discussed in chapter 3. Lastly, the layout program which is about the data structure used for facility layout and the heuristic search process will be discussed in section 4.3.

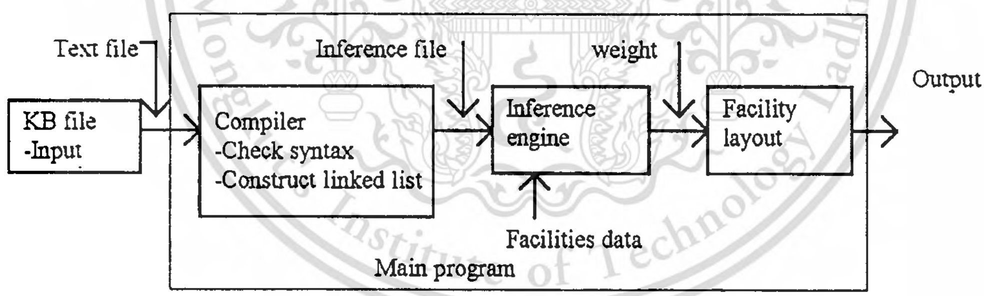


Figure 32 The block diagram of program design.

4.1. Knowledge compiler program

The knowledge compiler is used for compiling the knowledge base which is written in the if-then structure. Before inferring the closeness weight value, facts and assertions must be extracted from the knowledge base file. To extract facts and assertions, the knowledge compiler must be used. In this section, the design of language structure definition, data structure, parsing table, RHS table and compiling process are explained.

4.1.1 Language structure definition

The knowledge represented in the knowledge base has the language structure definition as follows:

```
1: <knowledge> -> <Quest><Goal><Def><Rule>
2: <Quest> -> QUEST LP VAR RP COLON STRING <Questlist> + STOP<Quest'>
3: <Quest'> -> <Quest> | λ
4: <Questlist> -> COMMA STRING <Questlist> |λ
5: <Goal> -> GOAL COLON STRING STOP
6: <Def> -> DEFAULT COLON STRING STOP |λ
7: <Rule> -> NUM COLON <IF> <Then> STOP <Rule'>
8: <Rule'> -> <Rule> | λ
9: <If> -> IF(Cond)
10: <Then> -> THEN <Cond)
11: <Cond> -> VAR EQU STRING <Cond'>
12: <Cond'> -> AND <Cond> | λ
```

From the above structure, the capital letter strings and λ are the terminal nodes. The strings in the bracket (< >) are non terminal nodes. The representation of terminal nodes is shown in table 2. The language structure definition is composed of four primitives: namely, Question, Goal, Default and Rule. The details of each primitive are as follows:

Question is used as a metafact of the system. It prompts the user for new fact to the attribute. The syntax of the "Question" is:

```
Question(attribute): "message",
                     "Choice 1",
                     "Choice 2",
                        :
                     "Choice n".
```

The 'Question', '(', ')', ':', '"', ',', and '.' are the reserved words. The "attribute", " message", "Choice 1", .. "Choice n" can be any string.

Goal is the target of the inference. In this system, Goal is assigned for finding the value of closeness weight (w). The syntax of "Goal" is *Goal: attribute.*

The "Goal:" and "." are the reserved word and "attribute" can be any string. The value of attribute for goal can be any integer ranged from -10 to 10 or string.

Default is a fact. This fact is assigned to the attribute of goal when no rules are concluded about goal. The syntax is *Default: "value."*

The "Default:" and "." are the reserved word. The value of default must be integer ranged from -10 to 10 or string of message. The primitive "Default" is not compulsory. If there is no "Default" in the knowledge base and there is no rule concluded about the attribute of "Goal", then, the "No Answer" message is shown on screen.

Rule is a conditional structure of if-then. It is used for drawing new fact from existing facts. The rule syntax is:

```
<Rule number>: IF <attribute 1> = "Choice"
               AND <attribute 2> = "Choice"
                 :                  :
               THEN <attribute 1> = "Choice"
               AND <attribute 3> = "Choice"
                 :                  :
```

The "IF", ":", "=", """, "AND", "THEN" and "." are reserved word. The "attribute" can be any string and choice is the "Choice" from the "Question" metafact. The following is the example in the knowledge base.

```
Question(Size):"What is the size of box ?",
                    "Small",
                    "Medium",
                    "Large".
Question(Imp): "Is it important ?"
                    "Important",
                    "Not important".
Goal: Weight.
Default: "No value can be concluded."
1: IF Size = "Small" and Imp = "Importance"
  Then Weight = "100 Kg".
2: IF Size = "Large" and Imp = "Importance"
  Then Weight = "200 Kg".
```

4.1.2 Data structure

There are three types of data in the system, variable data, rules, and a parsing table. The data structure of variable data and rule is organized by using linked list. The parsing table is done by using array.

4.1.2.1 Variable data

The variable data type is designed for storing 'attribute' 'message' and 'choice' data of the metafact 'question'. The structure of the data is designed by using double linked list. Figure 33 is the linked list of variable data written in C and figure 34 is the data structure written in graphical representation.

```
struct stlist{char *msg;
              struct stlist *next;};
typedef struct stlist Stlist;
struct varData { char name[80];
                 Stlist *quest;
                 struct varData *next;};
typedef struct varData VarData;
```

Figure 33 Variable data structure written in C.

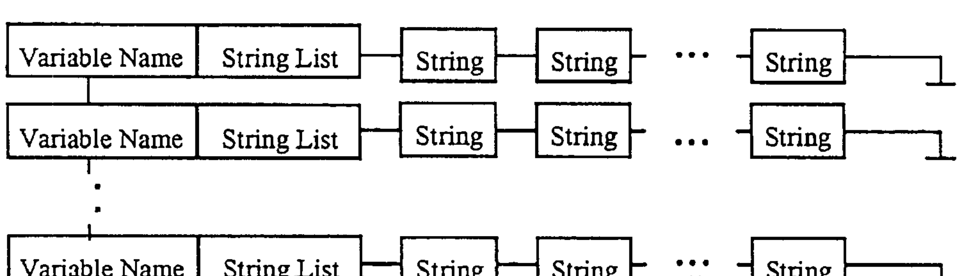


Figure 34 Data structure of list

From figure 33, the stlist (or string list in figure 34) is designed under the structure of VarData (or variable name in figure 34). The VarData is used for storing 'attribute' and stlist is used for storing 'message' and 'choice' of the question. Figure 35 shows the example of data structure of the 'question' of example in section 4.1.1.

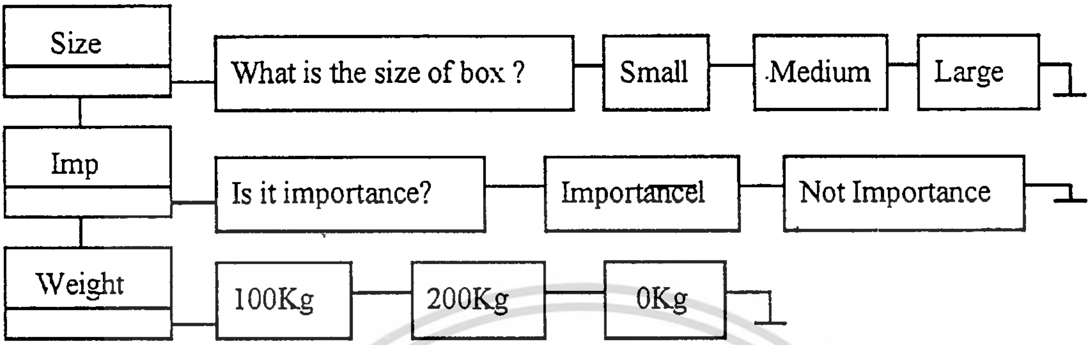


Figure 35 The example of 'question' data structure.

4.1.2.2 Rule

The rule structure is a three-way linked list. Each rule composes of three pointers: namely, next, cond and act. Figures 36 and 37 are the data structure of the rule.

```
Struct fact{ unsigned char Var;
             unsigned char Choice;
             struct fact *next; };
typedef struct fact Fact;
struct rule{ Fact*Cond;
             Fact *Act;
             struct rule *next; };
typedef struct rule Rule;
```

Figure 36 Rule data structure written in C.

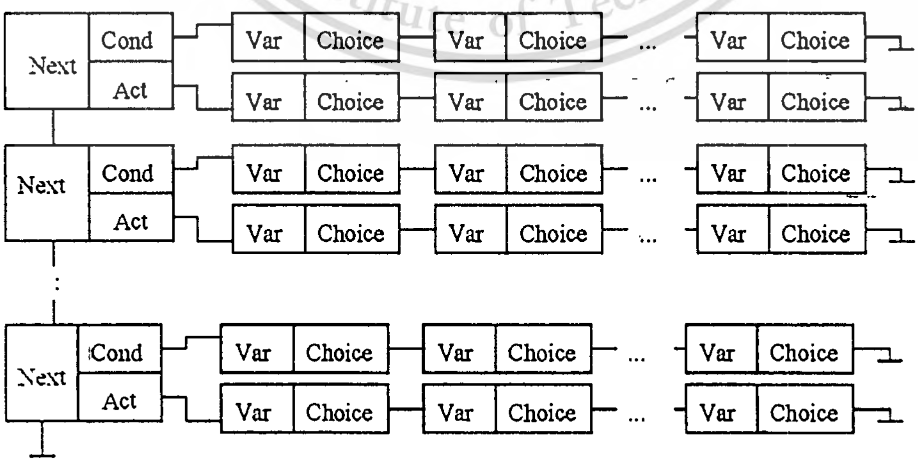
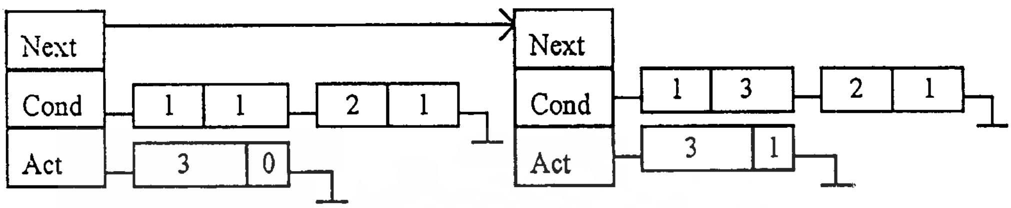


Figure 37 Rule data structure in graphical representation.

'Next' pointer is used for pointing the next rule. 'Cond' and 'Act' are pointers pointed to the sets of 'Fact' structures used for storing condition part and action part of the rule respectively. 'Fact' structure composes of 'var' and 'choice' fields for storing string as shown in figure 43. The value in the 'Var' and 'Choice' of rule data structure are the attribute and the value of rule represented in numbers. These numbers are codes of the production compiled from RHS table. The RHS table will be discussed in details in section 4.1.4. Figure 38 shows the example of rule in linked list structure.



rule1: if size = small and imp = yes then weight = 0.

rule2: if size = large and imp = yes then weight = 1.

Figure 38 An example of rule.

4.1.3 Parsing Table

Parsing table is an array storing the sequence of production to be compiled. The parsing table is a two-dimensional table. To optimizing the memory usage, the compress row is used instead of two dimensional arrays. The structure in figure 39 is a compress row designed from a two-dimensional array in figure 40. From the parsing table, the row labels are non-terminal tokens and the column labels are terminal tokens. To find the production in an array, the left-hand-side of production must follow the column label and the first token of the right-hand-side must follow the row label. From figure 40 at array(1,1), the left-hand-side of the production, '<S>', follows the column label ('1:<S>') while the first token of the right hand side, 'a', follows the row label ('1:a'). To search for the production to be processed, the compression row structure in figure 39 is used.

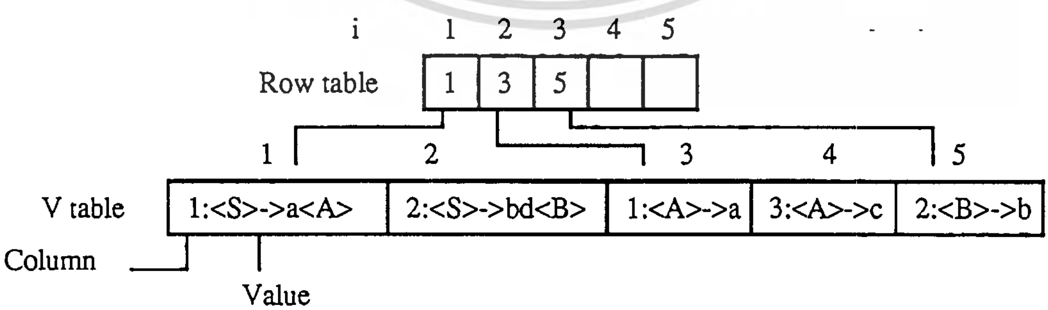


Figure 39 Parsing table in compression row structure.

	1:a	2:b	3:c	4:d	5:$
1:<S>	<S>->a<A>	<S>->bd<B>			
2:<A>	<A>->a		<A>->c		
3:<B>		<B>->b			

Figure 40 Parsing table in two dimensional array.

4.1.4 RHS Table

The Right Hand Side or RHS table is a one dimensional array used for storing the token used in the knowledge base. The table is used for assigning the token code for the terminal and non-terminal tokens. If the token is in the RHS table then the system returns the token code; else the system returns error. Table 5 and table 6 show the token codes of the terminal and non-terminal nodes.

Non-terminal symbol	Token codes
<knowledge>	0
<quest>	1
<quest'>	2
<questlist>	3
<goal>	4
<def>	5
<rule>	6
<rule'>	7
<if>	8
<then>	9
<cond>	10
<cond'>	11

Table 5 Non-terminal symbol codes

Terminal symbols	Symbols	Token codes
NUM	1 to 9	12
STRING	a to z and A to Z and 1 to 9	13
VAR	Combination of STRING	14
IF	IF	15
THEN	THEN	16
GOAL	GOAL	17
DEFAULT	DEFAULT	18
STOP	.	19
QUEST	QUEST	20
LP	(	21
RP	)	22
COLON	:	23
AND	AND	24
COMMA	,	25
EQU	=	26
EOL	/0	27

Table 6 Terminal symbol codes

4.1.5 Compiling process

There are four steps for compiling the knowledge base. They are:

- get token process,
- create parsing table,
- assign action symbol, and
- create inference file.

4.1.5.1 Get token process

To compile the knowledge base, the process searches for the terminal node and non terminal node in the file. This process is called 'get token.' To facilitate the checking process, the transition graph is used. Figure 41 is a transition graph of the system.

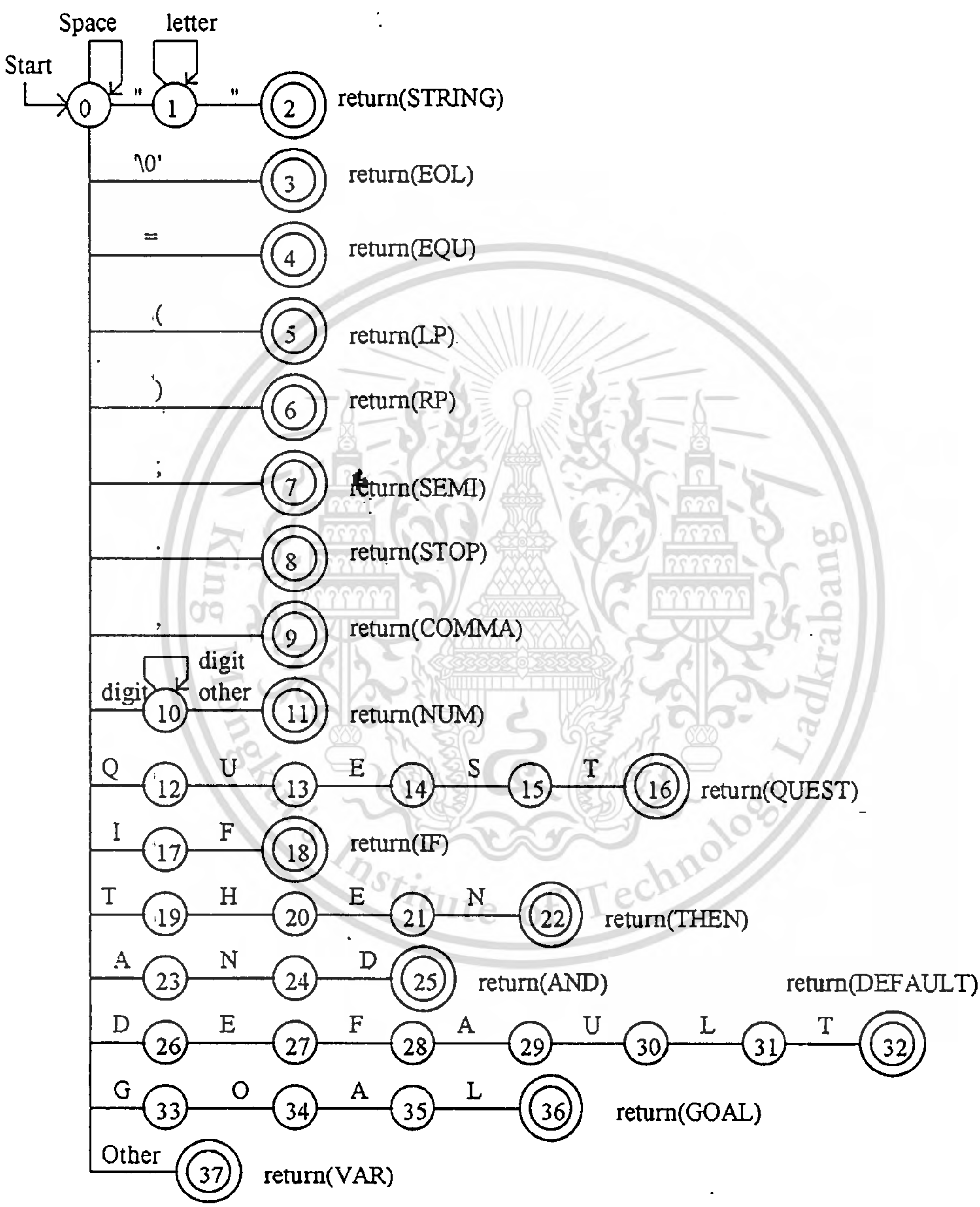


Figure 41 Transition graph for token compiling.

During the 'get-token' process, the syntax of the knowledge base is checked. The language structure definition is used for verifying the knowledge base. If there is no syntax error occurred, the tokens are put into the variable linked list and rule data linked list. In putting the token into the linked list, the tokens are encoded by using parsing and RHS table. The compiling process is written in pseudo code as follow:

```
Procedure Get-token(a);
repeat
Top(x);
if Non_terminal(x) then
  ( if Production(x,a,i) then
            (Pop();
            Push-RHS(i);)
   else Error();)
(else (if Terminal(x) then
            ( if x = a then
                    (Pop();
                    Get_token(a);)
             else Error();)
            else       (ActionRoutine(x);
                    Pop();))
            until x = '$';
            if x = 'a' then accept() else Error();
```

NB. ActionRoutine(x) is the process of putting the token into the linked list.

The system creates parsing table after the get-token process is finished. The parsing table sets the sequence of produotion rule to be compiled. At the same time, the system assigns the token codes by using RHS table. These token codes are used for creating the inference file.

4.2 Inference file

The input of the inference engine is the inference file which is the output of the compiler process. It is designed to use in the inference engine process. Figure 42 shows the structure of inference file. There are three major structures in this file: namely, string, rule and question structure.

Header
No. of rules
No. of variables
Default value
Rule no. 1
Rule no. 2
Rule no. 3
:
Rule no. n
Question of variable no. 1
Question of variable no. 2
Question of variable no. 3
:
Question of variable no. n

Figure 42 The inference file.

The string structure is used for recording header, the number of rules, the number of variables and default value. The structure of string is shown in figure 43. The structure is composed of string length and string message. Both of them are declared as characters.

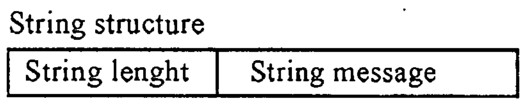


Figure 43 Structure of string

Rule structure is composed of 'No.of Cond,' 'No.of Act' and 'Fact' as shown in figure 50(a). The 'No.of Cond' and 'No.of Act' have the string structure. The 'Fact' structure is the string structure of 'Var' and 'Choice' as shown in figure 44(b).

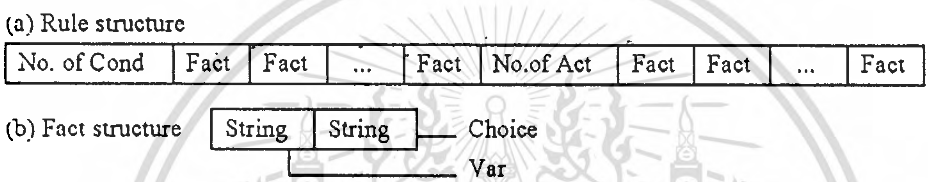


Figure 44 Structure of rule.

In the question structure, the structure is composed of 'No. of string sets' and 'string' as shown in figure 45. The first set of string is reserved for question message. Others are used for storing the options of the attribute or variable of rule.

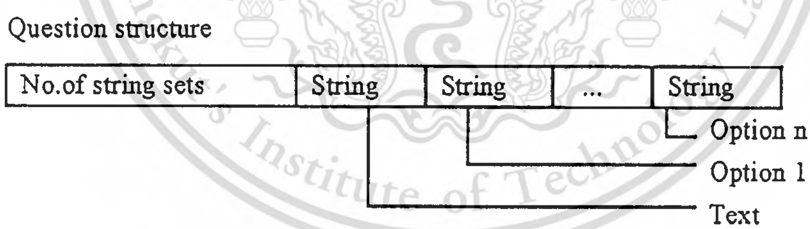


Figure 45 Structure of question.

4.3 Facility layout program

The plant layout program is dealing with the alternative layout generation and best layout selection. In the layout generation, a facility is allocated to all possible locations. In each location, a new layout alternative is generated. In the best layout selection, the generated alternative layout cost is calculated and compared with others. A set of lowest cost layouts is selected. To design the plant layout program, the data structure must be designed to satisfy the above processes.

4.3.1 Data structure

The data structure of the program has three parts: namely, the facility dimension structure, the facility factors structure and the layout structure.

The facility dimension structure is designed for storing the dimension of facility. This structure is used in the data retrieval process. The structure is shown in figures 46 and 47.

```
struct DIMENSION { int NO;
                   int sizeX;
                   int sizeY;
                   char use;
struct DIMENSION *right;
struct DIMENSION *left;}
struct DIMENSION *Dimension;
```

Figure 46 The dimension data structure written in C.

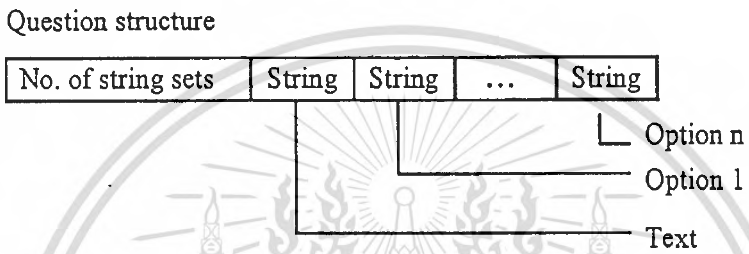


Figure 47 The facility dimension data structure.

From the above data structure, 'NO' is the sequence of facility. 'SizeX' and 'SizeY' are X-Y dimension of a facility and 'use' is a flag showing the status of a facility. If 'use' is 'Y' then the facility is in used; else the facility is not in used.

The facility factor structure is designed for storing the closeness weight (w) and traveling frequency (f) of a pair of facilities. This structure is used in the data retrieval process. The structure of data is shown in figures 48 and 49.

```
struct FACTOR { int BlockNo1;
                int BlockNo2;
                float weight;
                float frequency;
struct FACTOR *right;
struct FACTOR *left;}
struct FACTOR *Factor;
```

Figure 48 The data structure of factor written in C.

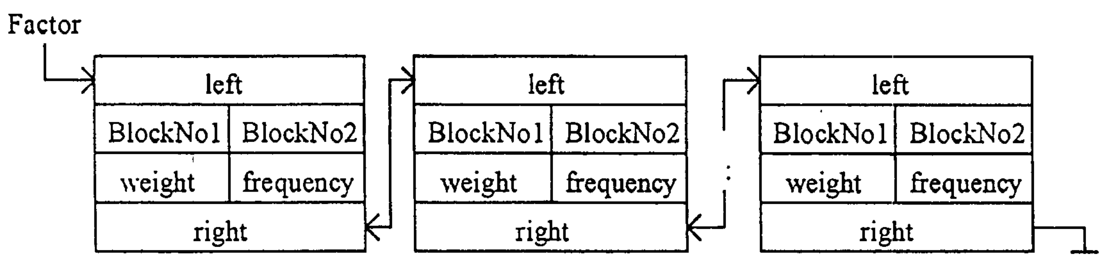


Figure 49 The data structure of factor.

From figure 48 and 49, the 'BlockNo1' and 'BlockNo2' are the number of two adjacency facilities. The 'frequency' and the 'weight' are the traveling frequency and the closeness weight between 'BlockNo1' and 'BlockNo2' respectively.

```
struct SPACE { int BlockNo;
               int x1, y1, x2, y2;
               float cost;
struct SPACE *parent;
struct SPACE *right;
struct SPACE *left;};
struct SPACE *space;
```

Figure 50 Data structure for the facility layout program.

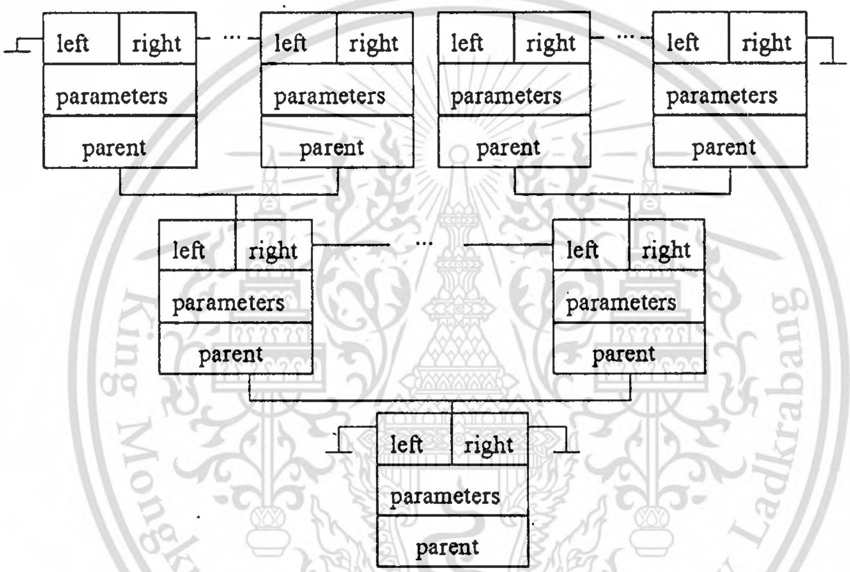


Figure 51 Data structure for the facility layout program.

The last part of the data structure is the data structure for facility layout program. The data structure is used when the facility allocation and heuristic search are used. Figures 50 and 51 are the data structure represented in C language and in graphical structure. There are four major fields for this linked list: namely, facility number, facility dimension, cost and pointer. The facility number (BlockNo) is used for indicating the facility considered. The facility dimension (x1, x2, y1 and y2) is used for recording the dimension of facility. The cost records the cost of layout between the facility and its adjacency facility. Lastly, the pointers (parent, left and right) are used for linking the facility to its adjacency facility.

4.3.2 Layout process

The layout process starts when the values of closeness weights (w) are assigned by the expert system. There are two procedures in the process. They are data input procedure and layout procedure.

The data input procedure prompts the user to input the data to the system. The dimension data will be put into the dimension data linked list of figures 4.15 and 4.16. The traveling frequency and weight data are put into factor linked list of figures 4.17 and 4.18. The traveling frequency data are retrieved directly from the user while the weight values are assigned by the expert system.

The layout procedure will process the following steps:

1) Select the next pattern to be inserted. The detail of the selection strategy is in section 3.2.3 of chapter 3.

2) Calculate the position for allocating the facility.

3) Check the overlap of facilities.

4) Calculate the total cost of layout.

5) Select a set of best layouts.

6) Repeat steps 1-5 until all facilities are located.

After the layout process finishes, the selected layouts in step 5 are the output of the system. The output of the system is presented in two forms, screen display and text file. For the screen display, the graphical representations of output layouts are shown. The text file of the output shows the list of the coordinates and other data of the selected layouts.

Chapter 5
CONCLUDING REMARKS

This chapter presents the conclusion of the thesis, the advantages of the proposed technique and also the further research.

5.1 Conclusion of the research

The presentation of this thesis is the proposed of new computerized technique for solving the facility layout problem. The designed system can handle the problems of general facility layout with the activity interrelationships and practical limitations of facility; problems in two-dimension; problems involving all kinds of patterns having linear sides and problems with no pre-locations and no orientation restrictions. The system is built to test the performance. The time complexity of the system is $O(n^3)$ when n is the number of operations (for the details of calculation, see appendix I).

The system integrates a heuristic approach to layout with a heuristic search using AI technique to solve the problem. For the beam search, the potential energy model is used as a heuristic function. The expert system and certainty factor function (or Mycin's belief function) are also used for supporting the heuristic function in providing the numerical evaluation of facility layout characteristics.

The major advantage of this method is that the system can take care of the practical limitations of facility relationship in both positive and negative manners. The positive relationship tends to move the facilities closer while the negative relationship tends to move the facilities apart. The value assigned for this relationship is called closeness weight. This closeness weight is defined by using the functional characteristics of facility. In defining the closeness weight, the expert system is used as a decision support system.

Using the beam search, not only the closeness weight has been flexibly considered but also the large problem space has been considered. The system constructs almost all possible layout alternatives. In selecting the best layout, the designed system uses the advantage of the objective function (in the heuristic search) to reduce the size of problem space. This makes it possible to search for the best layout from a large problem space at a reasonable speed. Table 7 shows the CPU speed of the program tested on 120 MHz personal computer (in the last column). The third column of table 7 shows the number of the improved problem size and the fourth column shows the problem space. It is obvious that the number of alternatives is significantly reduced.

Number of Patterns	Beam Width	Problem Size (Candidates)	Problem Space (Alternatives)	Processing Time(Minutes)
5	5	520	14,909,440	00:00.20
	10	1,040		00:00.33
10	5	1,120	2.287 +E18	00:01.60
	10	2,240		00:02.70
30	5	3,520	3.031 +E62	01:10.64
	10	7,040		02:22.48

Table 7. The processing time and the problem size.

The other advantage of the presented methods is that the system employs the Mycin Belief function to reduce the size of the knowledge base. Instead of constructing all rules for combinations of conditions, the system uses the Mycin Belief function to calculate the W value for those rules having the combination conditions.

5.2 Comparison study of the research

Table 8 is the analysis of facility layout techniques. For the layout process, the techniques are classified as mathematical approach, matrix approach, graph theory approach and graphic approach. For the data analysis, the methods are single criteria analysis, multiple criteria analysis, and positive-negative value (PNV) analysis. The search processes are classified as depth-first-search (DFS), branch and bound (BAB), beam search (beam), and simulated annealing (SA). The analyzed techniques are systematic layout planning (SLP), process chart (PorChart), improvement technique (Improv), construction technique (Constru), multiple criteria (MultiCri), Tam & li approach, planar graph, optimal aspect ratio, cutting point interchange (Cut), expert system (ES), Malakooti et al. approach and CLASS.

Analysis of Facility Layout Techniques													
		Layout Process				Data Analysis			Search Process				
		Math	Matrix	Graph	Graphic	Single	Multi	PNV	DFS	BAB	Beam	SA	Note
1	SLP				*			*					Not many alternatives
2	ProChart				*			*					Not many alternatives
3	Improve		*			*				*			
4	Constru		*			*				*			
5	MultiCri		*				*			*			
6	Tam&Li	*					*			*			
7	Planar			*		*			*				
8	Optimal			*		*			*				
9	Cut			*		*						*	
10	ES		*				*						Search by rule
11	Malakooti		*				*		*				
12	CLASS		*			*						*	
13	Boon				*			*			*		

Table 8 The analysis of facility layout techniques

To compare the proposed technique with others, the facility layout process is analyzed as layout process, data analysis and search process. For the layout process, the techniques such as mathematical approach, matrix approach or graph theory approach are very restricted with the rectangular pattern. The graphical approach is considered as more flexible for the layout process and the pattern is not limited to the rectangular. The techniques that used the graphical approach for the layout process are SLP, ProChart and the proposed method. However, the methods presented by SLP and ProChart are done manually. Therefore, the proposed layout process gives the most advantages when comparing with other methods. For the data analysis, only the proposed method can deal with *the positive and negative value* (PNV) of facilities relationship. The beam search of the proposed method is considered to be a very efficient heuristic search method.

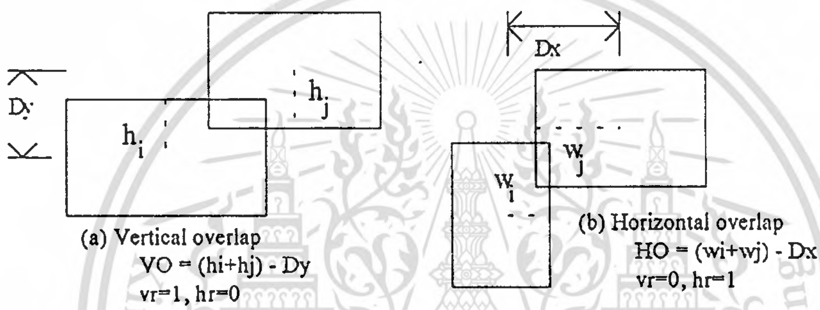


Figure 52 the overlapping conditions.

The pattern allocation can be implemented by using mathematics. The linear programming is the method for the solution. The constraint equations are defined by using the overlapping conditions of a pair of patterns. The objective function is to minimize the overall overlapping areas among patterns. Figure 52 shows the layout of patterns for defining the constraint equations.

The constraint equations are defined by using the overlap freeing condition as follows:

$$HO_{ij} = hr*\max\{0,(w_i+w_j)-Dx\}$$
$$VO_{ij} = vr*\max\{0,(h_i+h_j)-Dy\}$$

where hr is the horizontal overlap. This horizontal overlap is in x-direction more than y-direction and it is equal to 1 if the patterns are horizontally overlapped else it is equal to 0. On the other hand, vr is defined the same way in y-direction and it is equal to 1 if the patterns are vertically overlapped else it is equal to 0.

The objective function of this model is:

$$\text{MIN } L = \sum_{i,j=1}^{m} (HO_{ij} + VO_{ij})$$

The advantage of using mathematical model is the speed of computation time. On the other hand, the disadvantages are that the layout pattern is limited to rectangular pattern and the model works only by using the existing layout. The rearrangement of patterns is not considered in this model.

In allocating the pattern by using matrix technique, the total area is divided into several unit cells. To locate a pattern in to this area, the unit cells which are occupied by a pattern will be marked. Therefore, next pattern cannot be located at the marked unit cells. Figure 53 shows the facility allocation by using matrix. Every unit cell is labeled with the letters. The unit cells that are labeled with letter 'A' are the area of pattern 'A'. The unit cells that are labeled with letter 'B' are the area of pattern 'B' and so on. To improve the efficiency of layout, the exchange of locations between a pair of patterns is considered. In figure 53, there are two layouts, initial and final layout. The final layout is an improvement of initial layout and the shape of patterns in the final layout are different from their shape in the initial layout. The advantage of this technique is that it can be used with any shape of pattern and the shape of pattern can be rearranged.

A	A	A	A	A	A	A	B	B	B	B	B
A	A	A	A	A	A	A	B	B	B	B	B
A	A	A	A	A	A	A	B	B	B	B	B
A	A	A	A	A	A	A	B	B	B	B	B
C	C	C	C	C	C	C	D	D	D	D	D
C	C	C	C	C	C	C	D	D	D	D	D
C	C	C	C	C	C	C	D	D	D	D	D

Initial Layout

B	B	B	B	B	B	B	B	B	B	B	B
B	B	B	B	C	C	C	C	B	B	B	B
C	C	C	C	C	C	C	C	C	C	C	C
C	C	D	D	D	D	D	D	D	C	C	C
A	A	D	D	D	D	D	D	D	D	A	A
A	A	A	A	A	A	A	A	A	A	A	A
A	A	A	A	A	A	A	A	A	A	A	A

Final Layout

Figure 53 layout process using matrix.

The disadvantage of this technique is the time consuming since the rearrangement of layout process have to move every unit cell of the pattern and the overlap checking process has to check every unit cells whether it is occupied or not.

Graph theory technique represents the layout of patterns in a tree structure. The rearrangement of patterns in the layout can be done by changing the structure of a tree. This technique combines the advantage of mathematical model technique and matrix layout technique. It allocates the patterns in the faster speed and the patterns can be rearranged. However, the technique also has the disadvantage because the layout of this technique is limited to the rectangular pattern.

The graphic technique makes the pattern layout in the same manner as the human do the layout. The overlapping of patterns can be checked by using mathematics. Therefore, this technique can makes the pattern layout in a faster speed and there is no limitation for the shape of layout pattern. Therefore, the graphic technique is considered to be the most advanced and the most beneficial technique.

In term of data analysis, the single criteria considers only the material handling cost. The multiple criteria considers the material handling cost and the relationship cost. For the positive and negative value (PNV), not only the material handling cost and the relationship cost are considered but also the negative relationship cost is considered. The PNV is the innovation of this thesis.

For the search process, the beam search considers less alternatives than the depth-first search and branch-and-bound but it provides more promising results. This means that beam search takes less time than depth-first search and branch-and-bound. When comparing the beam search with simulated annealing, the techniques are considered to have the compatible performance.

5.3 Innovative contribution of the research

In conclusion, this thesis has exploited all the advantages of the above techniques as described in the comparison study, section 5.2. The techniques employed here and considered to be the major innovative contributions of this research are the PNV technique, the Mycin's Model application, and the combination of the graphical technique and the heuristic search for solving the layout problems. This makes it possible to solve more flexible and complicated problems in a more practical manner; thus giving more practical solutions for industrial applications.

5.4 Further study

Future research could concentrate on the further development of knowledge to improve the layout solution. In any practical layout, many factors can have an impact on the W value. Therefore, providing more details concerning the justification of the ω value assigned to a pair of facilities will create the most useful tool for solving the practical facility layout problems in both manufacturing and service industries.

The improvement of the model efficiency could emphasized on the improvement of heuristic search technique. The algorithms such as genetic, simulated annealing and neural network, should be studied to imprement and test for the results comparison.

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APPENDIX I
ANALYSIS OF ALGORITHM.

Time complexity of algorithm is calculated as follows:

1. Closeness weight assignment (w_{ij}).

The closeness weight of facilities is considered from the facilities interrelationship which is done by expert system. In this case, the assignment of a pair of facilities is counted as 1 operation. If n is the number of facilities to be located, the number of operations for assigning the closeness weight of the system is ${}^nC_2$ operations.

2. Next facility to be inserted selection.

The next facility to be inserted is considered from maximum closeness weight (max w_{ij}) of facilities. If the number of facilities which has the maximum closeness weight is more than one, then the areas of these facilities are compared. The one that has the largest area is selected.

Let m be the number of w_{ij} and $m = {}^nC_2$ (same as step 1),
w(i) is the i^{th} member of w_{ij} and $1 < i < m$ and
max is the variable.

```
Procedure NextFacility;
step 1: let i=1, max := w(i);
step 2: if i > m-1 then stop;
step 3: if w(i+1)>max then max := w(i+1) else
            if (w(i+1)=max) and (area(w(i+1))>max)
            then max := w(i+1);
```

The "next facility to be inserted" composed of two comparisons for each facility of the list -one to determine that the end of the list has not been reach and another to determine whether to updáte the temporary maximum. In the worst case one more step is added to the determining whether to update the temporary maximum step. Three comparisons (in the worst case) are used for each of the second through the m^{th} elements and one more comparison is used to exist the loop when $i = n+1$, exactly $3(m-1)+1 = 3m-2$ comparisons or $3{}^nC_2-2$ operations.

3. Layout alternatives generation.

The layout alternatives generation composes of two processes, cost calculation and alternatives selection.

3.1 Cost calculation.

From equation $E = ½\, w(fd_{ij})^2$

The operations for cost calculation are 4 operations.

3.2 Alternative selection.

A set of best alternatives is selected in this process. Let s be the number of best alternatives to be selected. EM(i) is the lowest cost of best alternative. E(i) is the cost of i^{th} alternative and $a_1, a_2, a_3, \dots a_n$ are the number of sides for facility 1,2,3,... n.

step 1: if i £ s then EM(i) := E(i);

step 2: find maxEM(i); {2s-1 operations}

step 3: if E(i) < maxEM(i) then EM(i) := E(i);

The operations from step 1 to 3, which equal to 2s+1, are repeated $2a_1a_2$ times. Therefore, the total numbers of operations are $2a_1a_2(4+(2s+1)+1)+1$.

4. This process consists of two procedures, the next facility to be inserted selection and the facility allocation and facility selection.

4.1 The next facility to be inserted of this step is a bit difference from the next facility to be inserted of step 3. In this process, the total value of w between a facility to be inserted and facilities already inserted is considered. For example, if facilities 1 and 3 are already inserted and facility 2 and 4 are the facility to be inserted. To consider the next facility to be inserted (2 or 4), the total cost of $w_{12}+w_{32}$ is compared with $w_{14}+w_{34}$. If $w_{12}+w_{32}$ is more than $w_{14}+w_{34}$ then facility 2 is selected and vice versus the facility 4 is selected. If k is the number of facilities already allocated ($k \geq 2$) and n is the number of facility to be layout: Therefore,

1) Compute w value for k-1 operations,

2) Find max(w) 1 operation and

3) Test to exit.

The operations of step 1-3 are k+1 and the numbers of repeating loops are n-k times. Therefore, the total numbers of operations, including starting step, are (n-k)(k+1)+1.

4.2 The facility allocation and facility selection.

The steps of the facility allocation and facility selection are as follows:

1) Adjoin the unadjioned side

2) If the adjoined facilities are not overlapped, then compute E(i).

3) Calculate the E_{total} which is equal to 5k operations.
   (from equation 8 of chapter 3)

4) Find the s lowest cost of alternatives which is equal to 2s+1 operations.

5) Check for exit.

From the above steps, the number of operations is 1+1+5k+2s+1+1 or 5k+2s+4 operations. The above steps are repeated for

$$2sa_n \left(\sum_{i=1}^{n-1} a_i - (n-2) \right) \text{ operations.}$$

For testing the system, let n=k+1, s=5 and k³2. Therefore, the above equation is changed to be:

$$10a_{k+1}\left(\sum_{i=1}^{k} a_i - (k-1)\right)$$

- For rectangular pattern facilities, therefore

$k=2 \quad 10a_3(a_1+a_2-1) \quad = 40(2*4-1)$
$k=3 \quad 10a_4(a_1+a_2+a_3-2) \quad = 40(3*4-2)$
$k=4 \quad 10a_5(a_1+a_2+a_3+a_1-3) \quad = 40(4*4-3)$
$\vdots$
$k=n-1,\ 10a_{n-1}(a_1+a_2+\ldots a_{n-1}-(n-2)) \quad = 40((n-1)4-(n-2)) \quad = 40(3k+1)$

The total number of facility allocation and facility selection operations are 40(3k+1)(5k+2s+4)+1 operations.

5. The operation of the system starts from step 1 to 3 if there are only two facilities to be considered. For more than two facilities, step 4 of the algorithm is activated and repeated until all facilities are located. If k is a number of already located facilities and n is the number of facilities to be located, then the number of operations for s=5, a_1=4 and a_2=4 are;

$k=2,\ {}^nC_2+2\,{}^nC_2-1+2a_1a_2+2(2a_1a_2-s)s+1+1 = 3\,{}^nC_2+303$
$k=3,\ 40(3*2+1)(23)+1+(n-2)(3)+1$
$k=4,\ 40(3*3+1)(28)+1+(n-3)(4)+1$
$k=5,\ 40(3*4+1)(33)+1+(n-4)(5)+1$
$\vdots$
$k=n-2,\ 40(3n-5)(5n+3)+1+2(n-1)+1$
$k=n-1,\ 40(3n-2)(5n+8)$
(NB.the calculation of w value for k=n-1 is not needed.)

(3*2+1)(22)+(3*3+1)(27)+(3*4+1)(32)+...(3n-2)(5n+8)
by using Newton first forward difference

i	x	y(sum)	Δy	$\Delta^2 y$	$\Delta^3 y$
0	1	161	280	149	30
1	2	441	429	179	30
2	3	870	608	209	
3	4	1478	817		
4	5	2295			
:	:	:	:	:	

$$y_p = y_0 + p\Delta y_0 + \frac{p(p-1)}{2!}\Delta^2 y_0 + \frac{p(p-1)(p-2)}{3!}\Delta^3 y_0$$

$$= 161 + p280 + \frac{p(p-1)}{2!}149 + \frac{p(p-1)(p-2)}{3!}30$$

$2y_p = 322 + 560p + 149p^2 - 149p + 10p^3 - 30p^2 + 20p$

from $p = (x_p - x_0)/h$

and $h = \Delta x = 1\text{-}2 = 2\text{-}3 = \ldots = 1,\ x_0 = 1$

we get $p = x_p - 1$

$2y_p = 322+560(x_p-1)+149(x_p-1)^2-149(x_p-1)+10(x_p-1)^3-30(x_p-1)^2+20(x_p-1)$

substitute $x = x_p$, $y = y_p$

$2y = 322+560(x-1)+149(x-1)^2-149(x-1)+10(x-1)^3-30(x-1)^2+20(x-1)$

$2y = 10x^3+89x^2+223x$

substitute $x = n$ we get

$y = 5n^3+44.5n^2+111.5n$

6. Time complexity of algorithm for all operations when k=1 to n are equal to the number of operation from steps 1 to 4. Therefore,

$f(n)=3\,{}^{n}C_2+512+40(5n^3+44.5n^2+111.5n)+3(n-2)+4(n-3)+5(n-4)+\ldots+(n-1)2+2(n-2)$

and $g(n) > f(n)$ is $O(n^3)$

Time complexity of algorithm is $O(n^3)$

APPENDIX II
TEST OF THE ALGORITHM

The system has been developed to be a computer package. It is implemented in Turbo Pascal and operates on IBM-AT or compatible computer with 640 K memory on board under DOS. A graphics card and VGA color monitor are required. The output of the system is displayed on screen and the coordinates of the layout are kept in ASCII text file. The program has approximately 5208 lines and its executable file is about 124 K bytes. In order to interface with the ASCII knowledge base file, the rule compiler is also developed. By using this compiler, the rule syntax is checked before the program is executed. The knowledge base, or rules, can be written by any kind of word processor providing ASCII text file. The system can handle up to 1,000 rules.

Prior to running the system, a design expert or a knowledge programmer has to include his knowledge into the Knowledge Base. When running the program, Rules Inference Unit infers the knowledge by using the information acquired from the users. The value of W will be concluded and the E value is calculated. With this E value, the Problem Solving Unit searches for the solution in problem space.

1: INPUT:
- *Number of facilities*
- *Dimension of all facilities*
- *Boundary of the area being located*

2: CONSULTATION:
- *System asks questions*
- *User input the facility properties information*
- *System assigns the w-value*

3: PROCESSING:
- *System generates alternative layout*
- *Heuristic search searches for the best layout*

4: OUTPUT:
- *Screen display*
- *Report file*

Figure 54 Steps of the system operation

The steps of the system operation are shown in figure 54. The system starts by acquiring the information of facility areas dimensions, total area, unit file name and number of daughter nodes(n). The expert system then questions the user about the facility areas' properties. By using the facility areas dimensions and properties, the system calculates the E value and searches for the best layout.

For knowledge development, the facility layout expert can create his own knowledge by using a word processor. The system will automatically load this knowledge file into the

Heuristic Rules module and use it as domain knowledge.

System performance has been evaluated and tested many times. The given recommended layouts are as expected. The results also show the potential applications to solve the complex facility layout problems. In the example, a test run was made using the following data..

PROBLEM

A small industrial plant has four facility areas. The details of the facilities are:

1) metal forming area
2) welding area
3) chemical cleaning area and
4) storage area

From the historical data, the traveling frequencies among the four facility areas are shown in table 9.

The functional characteristics of the welding and chemical cleaning area are hazardous. The materials flowing among metal forming, welding, storage and chemical cleaning area are heavy and not susceptible to any damage. The materials flowing between welding and chemicals cleaning area are very susceptible to damage. The number of alternatives to be selected at each level is 5.

	Travelling frequency relationships				Area
	Forming	Welding	Cleaning	Storage	dimensions
(1)Forming	-	20	10	20	2 x 1
(2)Welding	-	-	20	18	2 x 1
(3)Cleaning	-	-	-	15	1 x 1
(4)Storage	-	-	-	-	2 x 2

Table 9 Travelling frequency relationships and area dimensions.

Closeness weight between forming and welding (w_{12}).

The material flowing between these rooms is not hazardous. The density of the flowing material is fairly heavy and dense. The shape of the flowing material is long and irregular. The risk of material handling is susceptible to damage by crushing. The condition of handling is clear, firm and stable. The system operates by consulting the expert system for the value of closeness weights (see also appendix II). The questions and answers for the metal forming area and metal welding area are:

What is the condition apparent between this pair of departments?
1.Hazard such as fire hazard or vibration.
2.None of the above conditions.
>2
What is the density or bulkiness of the item ?
1.Very light and empty.
2.Light and bulky.

3.Reasonably solid.
4.Fair heavy and dense.
5.Heavy and dense.
6.Very heavy and dense.
>4
How can you define the shape of material flowing between departments ?
1.Very flat and stackable.
2.Readily stackable or nestable.
3.Fairly stackable or slightly nestable.
4.Basically square with some stacking quality.
5.Long, rounded, or somewhat irregular.
6.Very long, spherical or irregular.
7.Extra long, curved, or especially irregular.
>5
How do you define the risk of damage to material?
1.Not susceptible to damage at all.
2.Susceptible to negligible or practically no damage.
3.Slightly susceptible to some damage.
4.Susceptible to damage by crushing, breaking, scratching.
5.Very susceptible to some damage.
6.Highly susceptible to some damage.
7.Highly fragile.
>4
What is the condition of the item?
1.Clear, firm and stable.
2.Oily, flimsy and unstable or awkward to handle.
3.Covered with grease, hot and very flimsy or slippery.
>1

From the above conditions, the rule that applies to density condition is rule 5. The rule that applies to shape is rule 12. The rule that applies to damage is rule 18 and the rule that applies to condition is rule 23. The closeness weight assigned from rules 5, 12, 18 and 23 are 3, 3, 0 and 0. Therefore, the total value of closeness weight can be obtained as follow:

Let Wa = weight assigned by rule 5 = 3,
Wb = weight assigned by rule 12 = 3,
Wc = weight assigned by rule 18 = 0 and
Wd = weight assigned by rule 23 = 0.
Therefore, w_{12} = sum of Wa, Wb, Wc and Wd.
Wab = (3 + 3) - (3*3)/10 = 6 - 0.9 = 5.1
Wabc = (Wab + Wc) - (Wab*Wc)/10
= (5.1 + 0) - (5.1*0)/10 = 5.1
Wabcd = (Wabc + Wd) - (Wabc*Wd)/10
= (5.1 + 0) - (5.1*0)/10 = 5.1

Closeness weight between forming and cleaning (w_{13}).

The material flowing between these rooms is not hazardous. The density of the flowing material is fairly heavy and dense. The shape of the flowing material is irregular. The risk of material handling is highly susceptible to some damage. The condition of handling is awkward to handle.

From the above conditions, the rule that applies to density condition is rule 5. The rule that applies to shape is rule 12. The rule that applies to damage is rule 21 and the rule that applies to condition is rule 25. The closeness weight assigned from rules 5, 12, 21 and 25 are 3, 3, 7 and 3. By using the same processes as for finding w_{12}. Therefore, the total value of closeness weight(w_{13}) is 8.97.

Closeness weight between forming and storage (w_{14}).

The material flowing between these rooms is not hazardous. The density of the flowing material is fairly heavy and dense. The shape of the flowing material is long, round and irregular. The risk of material handling is highly susceptible to some damage. The condition of handling is hot.

From the above conditions, the rule that applies to density condition is rule 5. The rule that applies to shape is rule 12. The rule that applies to damage is rule 21 and the rule that applies to condition is rule 26. The closeness weight assigned from rules 5, 12, 21 and 26 are 3, 3, 7 and 5. By using the same processes as for finding w_{12}. Therefore, the total value of closeness weight(w_{14}) is 9.26.

Closeness weight between welding and cleaning (w_{23}).

The material flowing between these rooms is not hazardous. The density of the flowing material is very light. The shape of the flowing material is long, round and irregular. The risk of material handling is susceptible to damage by crushing. The condition of handling is firm and stable.

From the above conditions, the rule that applies to density condition is rule 2. The rule that applies to shape is rule 12. The rule that applies to damage is rule 18 and the rule that applies to condition is rule 23. The closeness weight assigned from rules 2, 12, 18 and 23 are -5, 3, 0 and 0. By using the same processes as for finding w_{12}. Therefore, the total value of closeness weight(w_{23}) is -2.86.

Closeness weight between welding and storage (w_{24}).

The material flowing between these rooms is not hazardous. The density of the flowing material is fairly heavy and dense. The shape of the flowing material is basically square. The risk of material handling is slightly susceptible to some damage. The condition of handling is firm and stable.

From the above conditions, the rule that applies to density condition is rule 5. The rule that applies to shape is rule 11. The rule that applies to damage is rule 18 and the rule that applies to condition is rule 23. The closeness weight assigned from rules 5, 11, 18 and 23 are 3, 0, 0 and 0. By using the same processes as for finding w_{12}. Therefore, the total value of closeness weight(w_{24}) is 3.

Closeness weight between cleaning and storage (w_{34}).

The material flowing between these rooms is not hazardous. The density of the flowing material is fairly heavy. The shape of the flowing material is somewhat irregular. The risk of material handling is highly susceptible to some damage. The condition of handling is clear.

From the above conditions, the rule that applies to density condition is rule 5. The rule that applies to shape is rule 12. The rule that applies to damage is rule 21 and the rule that applies to condition is rule 23. The closeness weight assigned from rules 5, 12, 21 and 23 are 3, 3, 7 and 0. By using the same processes as for finding w_{12}. Therefore, the total value of closeness weight(w_{34}) is 8.53.

First pair of facilities to be inserted.

In short, the values of closeness weight are given as follows; W_{12} = 5.1, W_{13} = 8.97, W_{14} = 9.26, W_{23} = -2.86, W_{24} = 3 and W_{34} = 8.53. Since the maximum value of W is W_{14}, facilities 1 and 4 are the first pair of facilities to be allocated.

Allocation of facilities 1 and 4 and selected set of candidates.

After facilities 1 and 4 are selected, the pattern allocation subsystem generates alternative layouts. The selected layouts generated from patterns 1 and 4 are shown in figure 55. The layout alternatives generated in this level have many alternatives but only two different patterns of layout are selected. In selecting the layout alternatives, the layout with the same pattern is not selected.

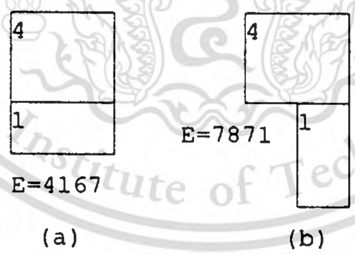

Figure 55 Selected alternatives for the first level.

Cost calculations (E_{14})

In figure 34(a), the distance between departments 1 and 4 (d_{14}) is 1.5. Therefore,

$$\begin{aligned} E_{14} &= 1/2\,(W_{14})*(f_{14}*d_{14})^2 \\ &= 1/2\,(9.26)*(20*1.5)^2 \\ &= 4167 \end{aligned}$$

In figure 34(b), the distance between departments 1 and 4 (d_{14}) is calculated as follow:

$$\begin{aligned} d_{14} &= [(0.5)^2+(2)^2]^{1/2} \\ &= [4.25]^{1/2} \\ &= 2.061 \end{aligned}$$

Therefore,

$$E_{14} = 1/2\ (W_{14})*(f_{14}*d_{14})^2$$
$$= 1/2\ (9.26)*(20*2.061)^2$$
$$= 7871$$

Next facility to be inserted.

From the generated alternatives, patterns (a) and (b) shown in figure 34 are selected as a set of candidates. The system then selects the next pattern to be inserted by considering W values as follows:

The total W of pattern 2 is: $W_{21}+W_{24}=5.1+3=8.1$.

The total W of pattern 3 is: $W_{31}+W_{34}=8.97+8.53=17.5$.

The total W of pattern 3 is greater than the total W of pattern 2. Therefore, pattern 3 is selected to be the next pattern to be inserted.

Allocation of facility 3 and candidates selection.

Pattern 3 is located around patterns 1 and 4 and the non-overlap layouts are selected as the alternatives. By using the heuristic function, a set of candidates is selected. Figure 35 shows five selected candidates and their E values.

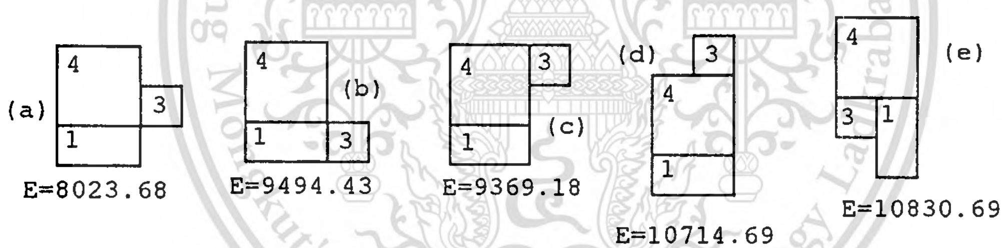

Figure 56 The selected alternatives for the second level.

Cost calculations (E_{143})

The total cost of the allocated patterns is

$$E_{143} = E_{total} = E_{14} + E_{13} + E_{34}$$

From figure 35 (a),

$$E_{14} = 4167$$
$$E_{13} = 1/2\ (W_{13})*(f_{13}*d_{13})^2$$
$$= 1/2\ (8.97)*(10*d_{13})^2$$
$$d_{13} = [(1.5)^2+(1)^2]^{1/2}$$
$$= 1.8028$$
$$E_{13} = 1/2\ (8.97)*(10*1.8028)^2$$
$$= 1457.625$$
$$E_{34} = 1/2\ (W_{34})*(f_{34}*d_{34})^2$$
$$= 1/2\ (8.53)*(15*d_{34})^2$$
$$d_{34} = [(1.5)^2+(.5)^2]^{1/2}$$
$$= 1.5811$$

E_{34} $= 1/2\ (8.53)*(15*1.5811)^2$
$= 2399.0625$
E_{total} $= 4167 + 1457.625 + 2399.0625$
$= 8023.68$

With the calculation of the same fashion, the values of E_{total} for figure 35(b), (c), (d) and (e) are 9494.43, 9369.18, 10714.69 and 10830.69.

Using the selected alternatives from the previous step, figure 35, the last pattern, pattern 2, is inserted and rotated around these candidates. The system, then, generates a new set of layout alternatives and calculates the values of E_{total} for all alternatives. Based on these E_{total} values, a set of candidates is selected as shown in figure 36.

Because there is no further facility to be inserted, the selected candidates in figure 36 are the proposed solutions.

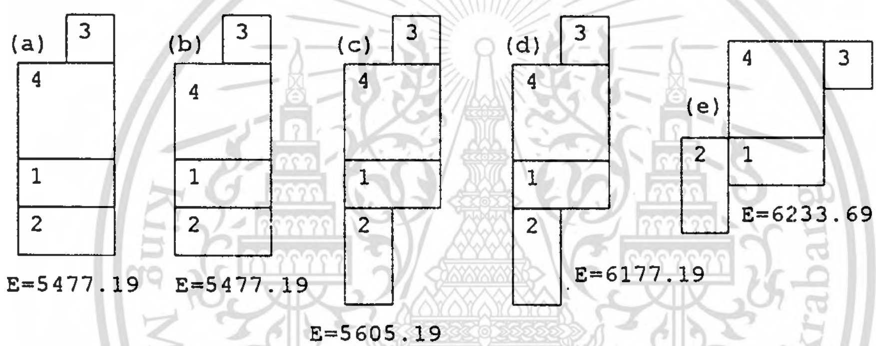

Figure 57 The layout generated by the heuristic.

To conclude the steps of facility allocation and candidate selection processes, figure 37 is presented. The system, first, selects and allocates facilities 1 and 4. The generated alternatives of facilities 1 and 4 are in level 1 and layouts (a) and (b) are selected. In the second level, facility 3 is selected as the next pattern to be inserted and allocated. The selected candidates of this level are (a), (b), (c), (d) and (e). The proposed layouts and their associated costs of this problem are presented in level 3 of the following graph.

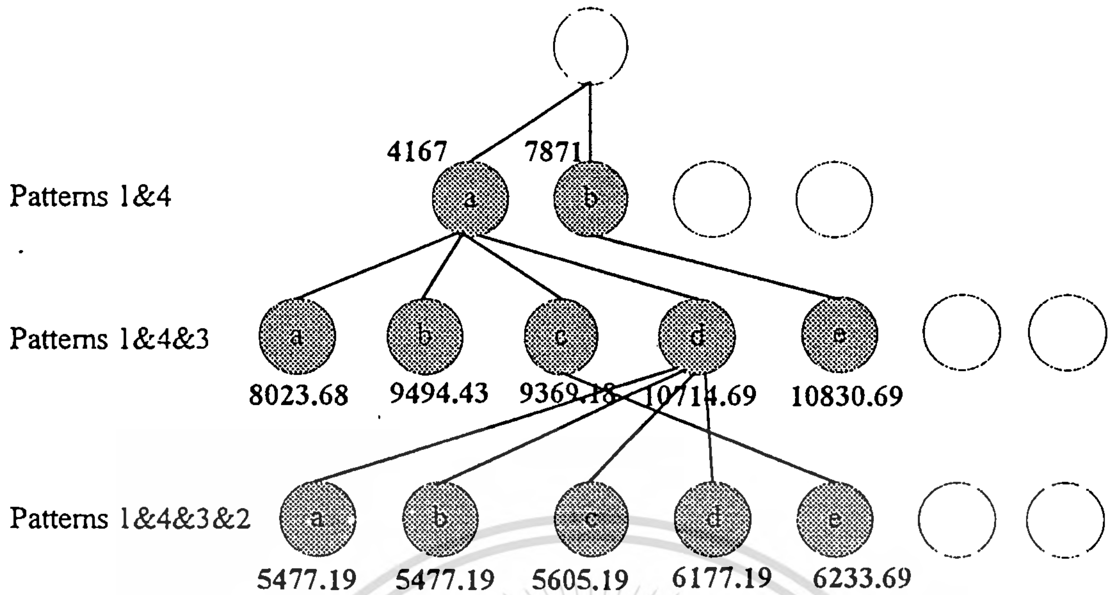

Figure 58 the structure of beam search.

The system generates many alternative layouts instead of only one. The user is requested to input the number of alternatives by including the n value. From figure 4, the five alternative layouts are given as the output of the system. These layouts are shown on the monitor in graphical representation. On the monitor screen, only one layout is shown at a time and the user presses the space bar on the keyboard the next layout will appear. The user can also save all the layout coordinates into the report file.

The screen print out of the running process including the programming steps for the above example are as follows:

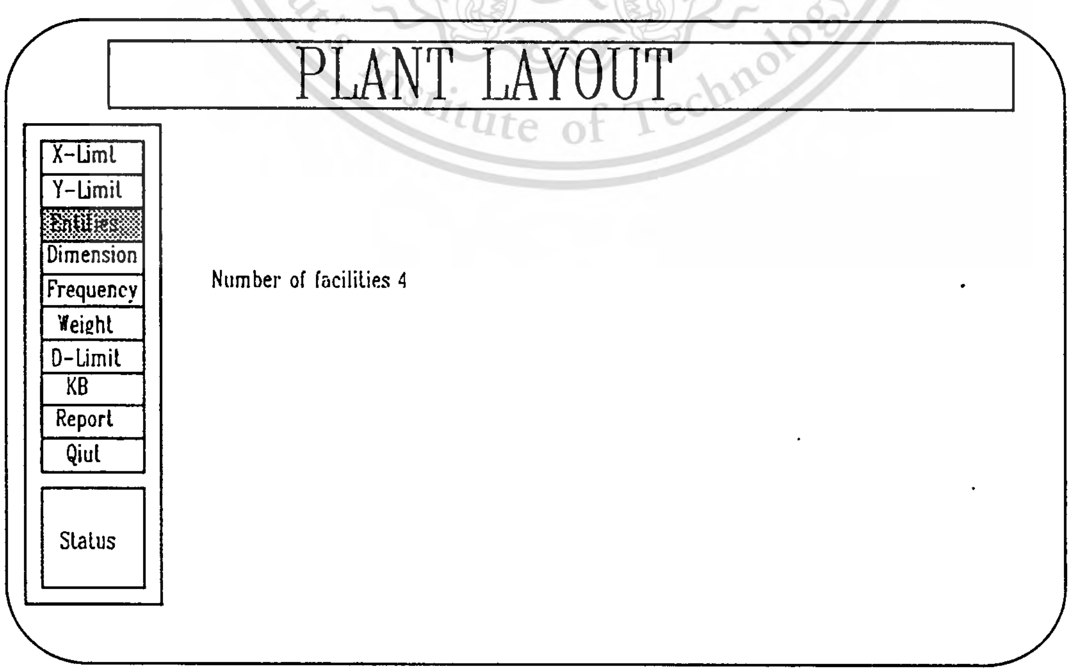

Figure 59 inputting the number of facilities to layout.

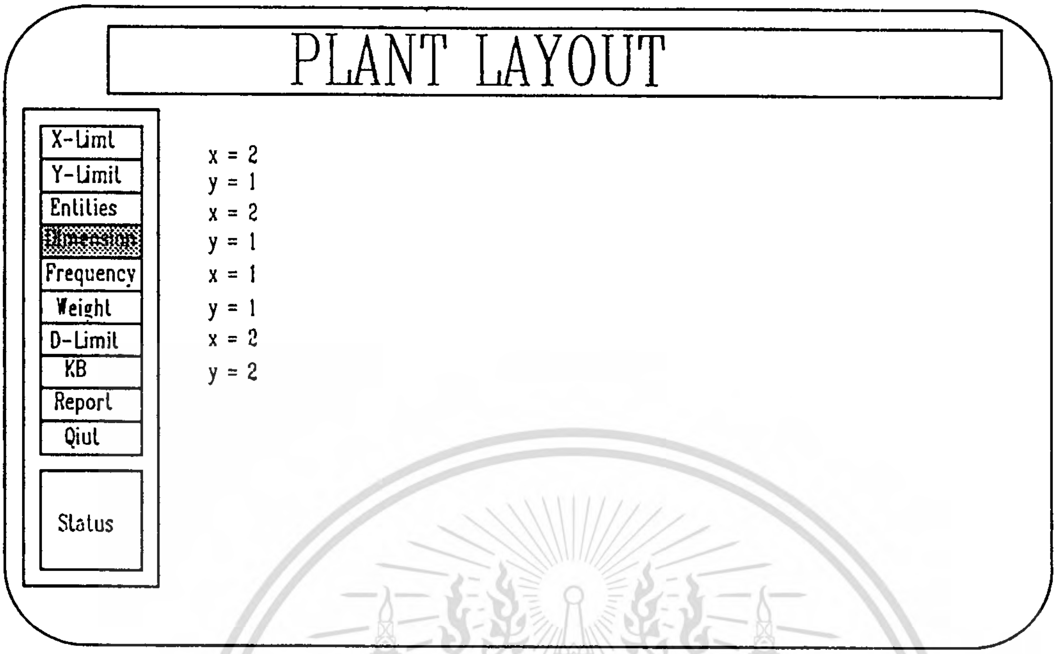

Figure 60 inputting the dimensions of facilities.

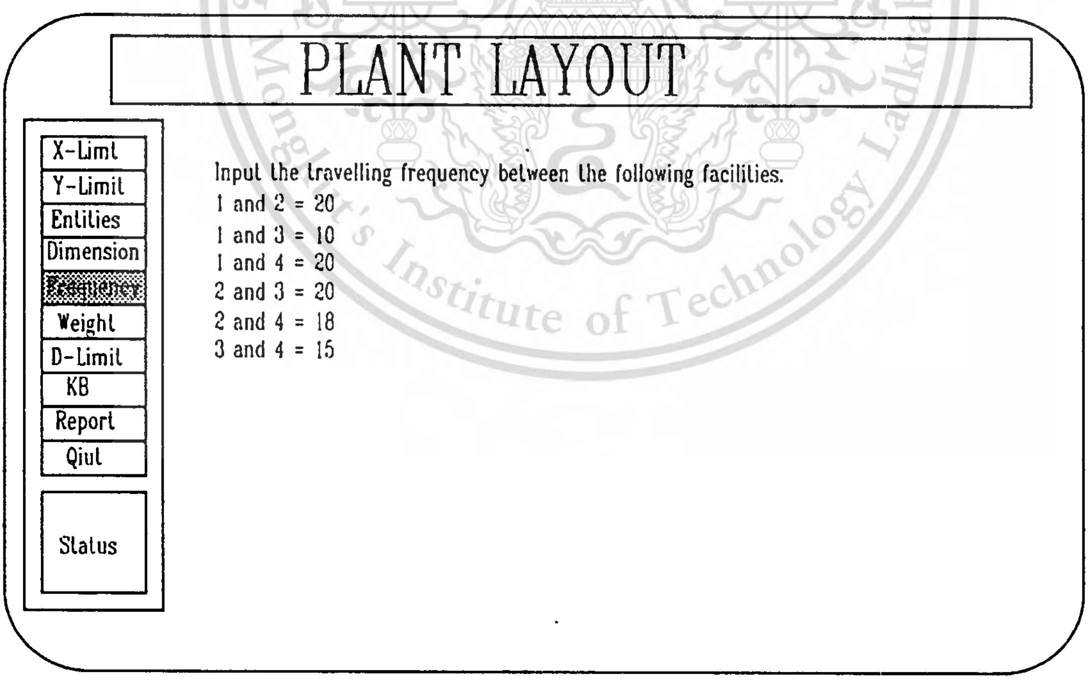

Figure 61 inputting the facility traveling frequences.

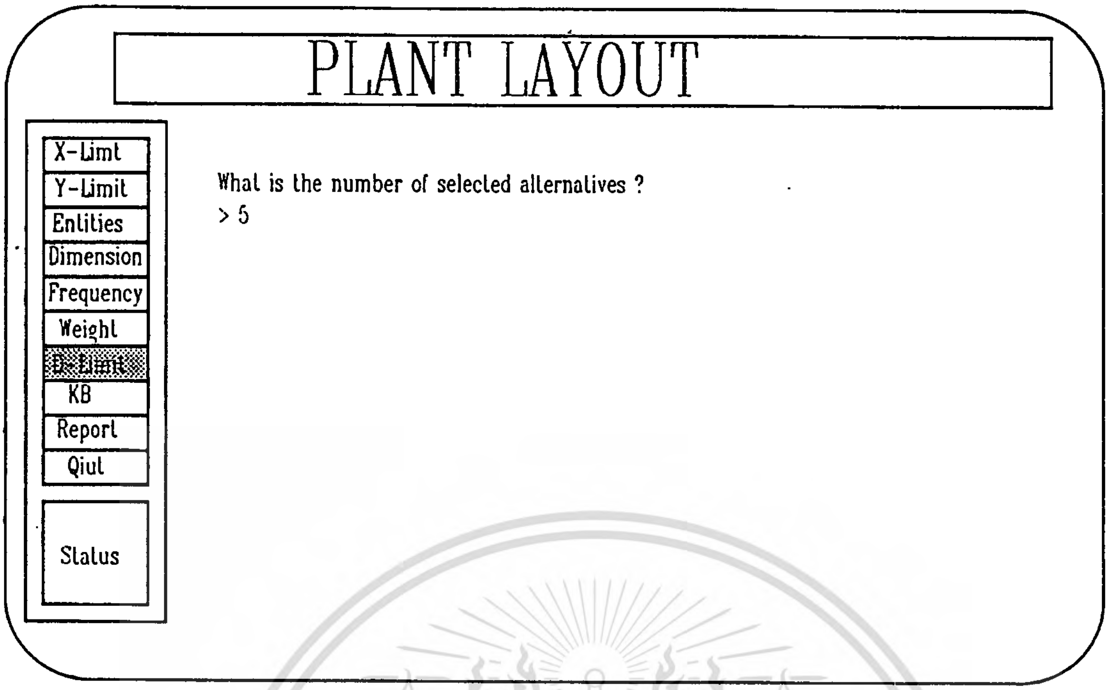

Figure 62 inputting the number of selected alternatives.

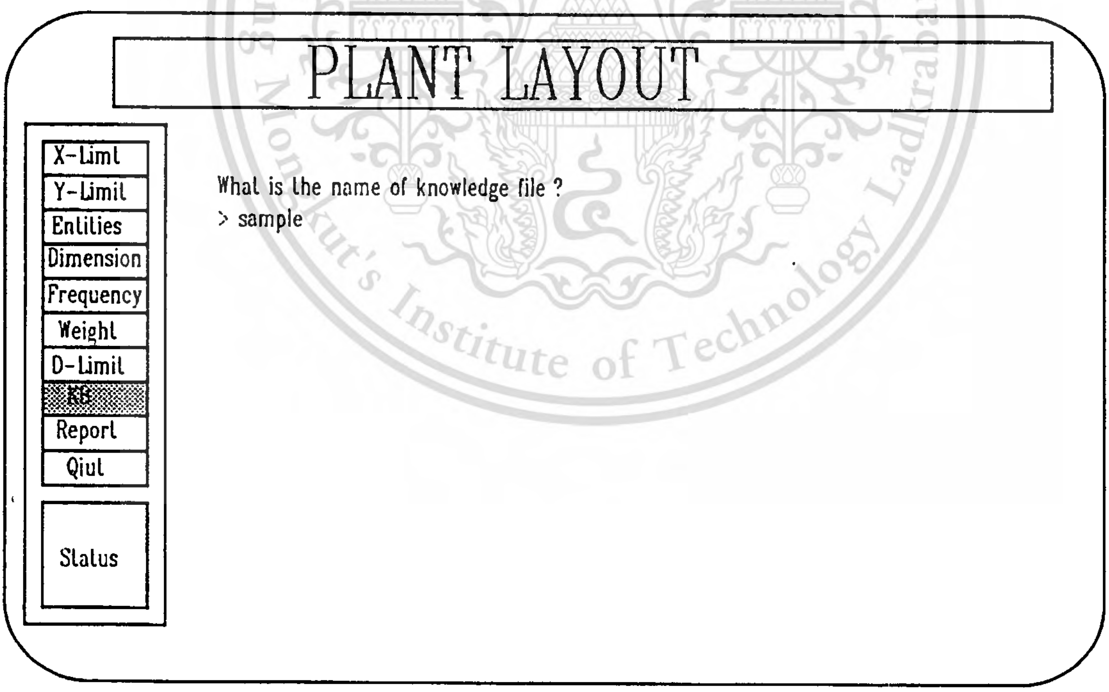

Figure 63 selecting the knowledge base file.

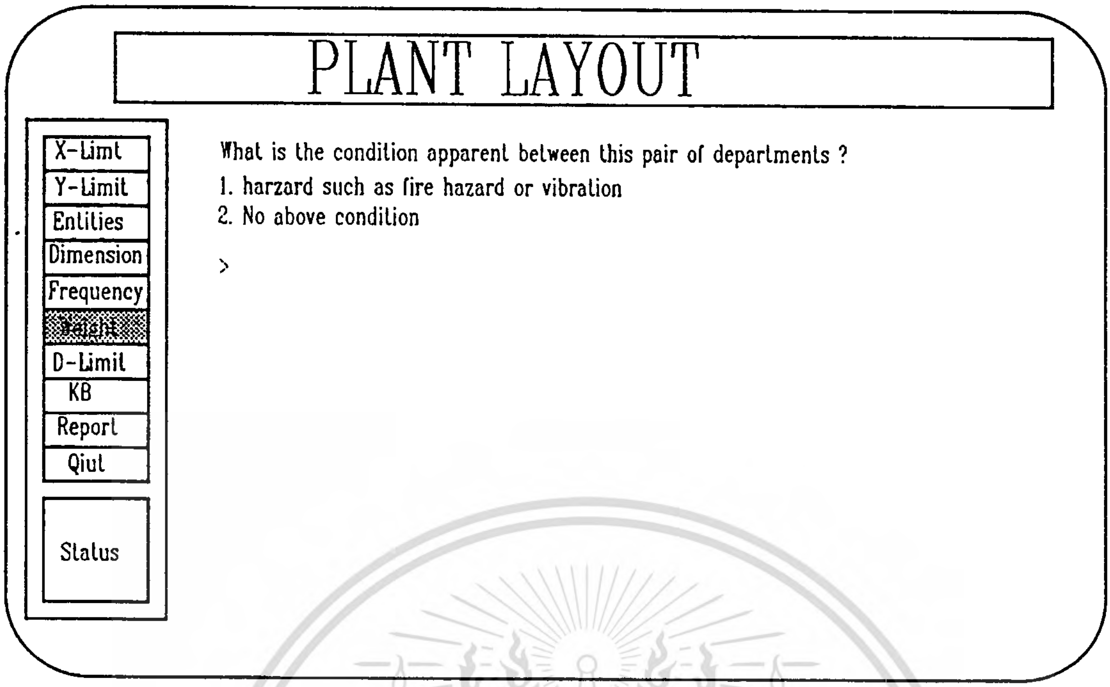

Figure 64 the question for attribute hazard.

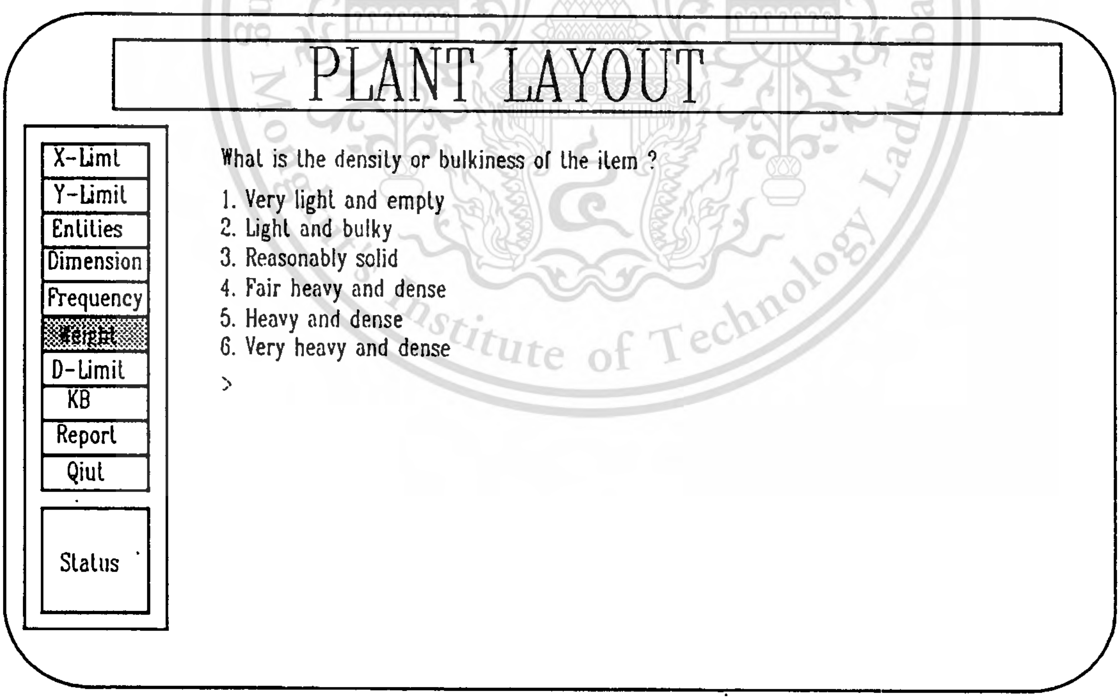

Figure 65 the question for attribute density.

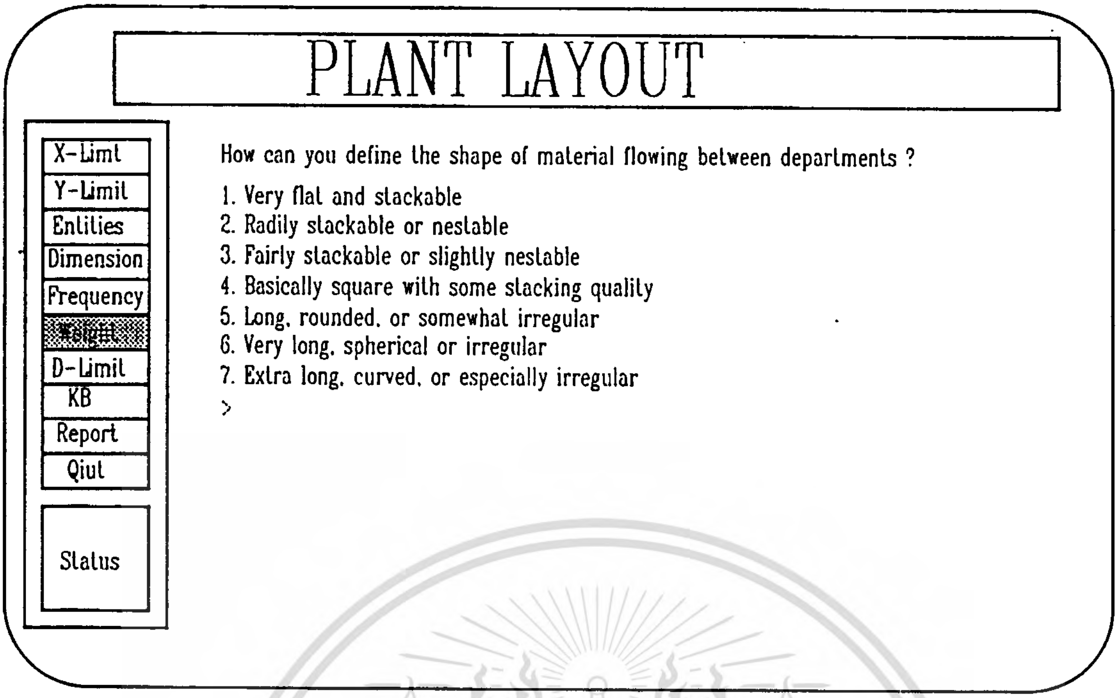

Figure 66 the question for attribute shape

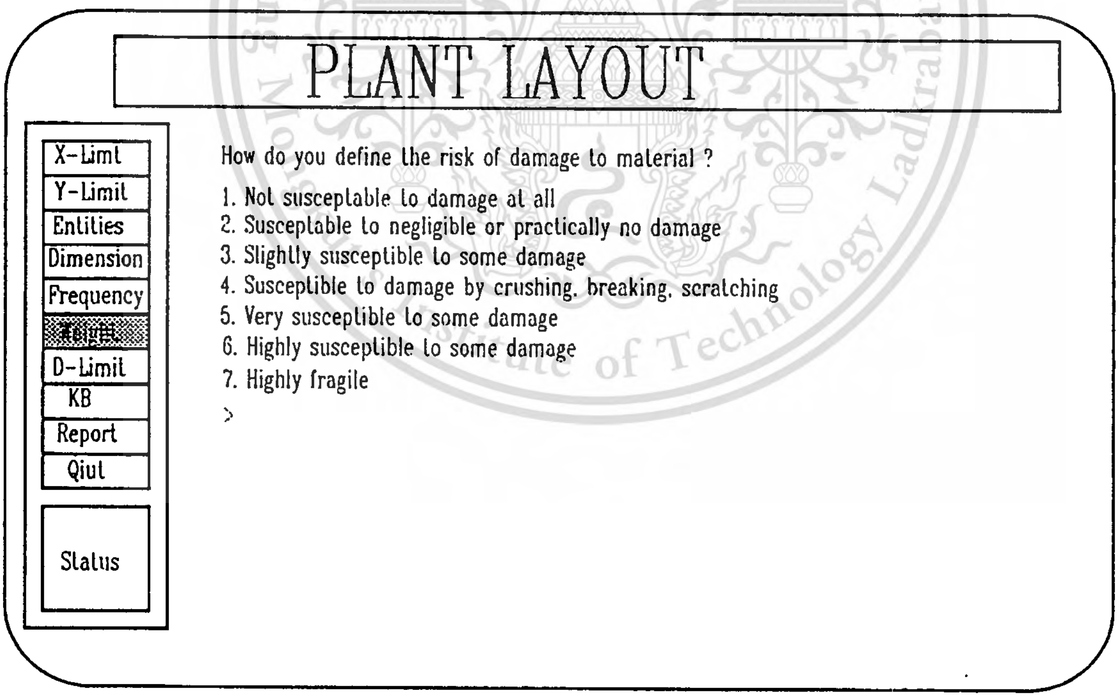

Figure 67 the question for attribute damage.

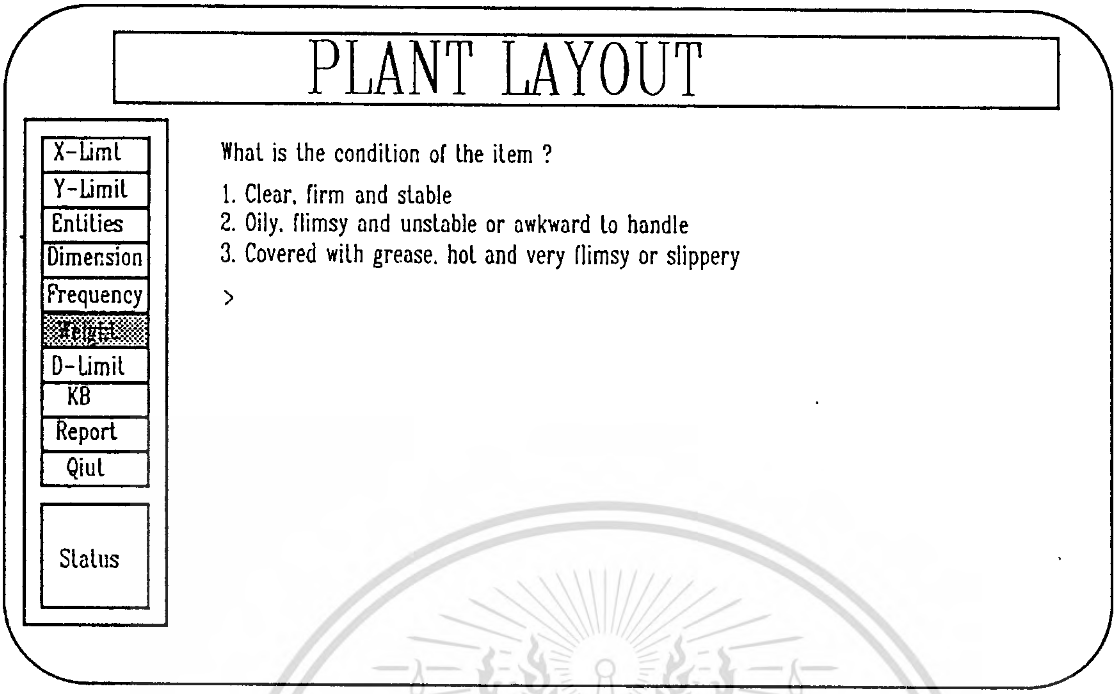

Figure 68 the question for attribute condition.

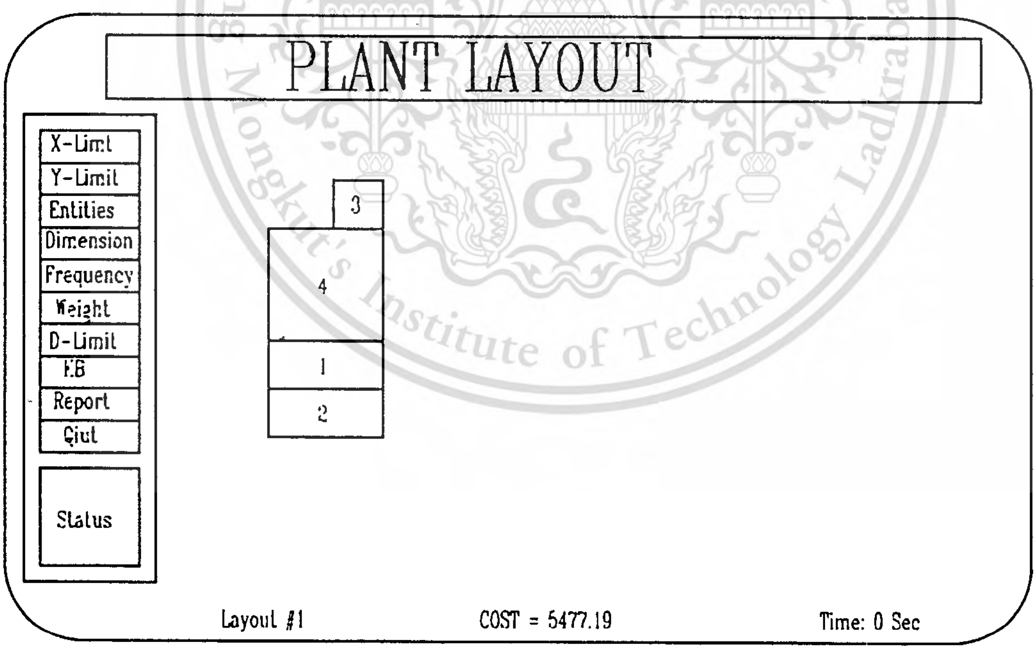

Figure 69 output display of the system

APPENDIX III
ILLUSTRATIVE CASE OF KNOWLEDGE

The prototype knowledge is adapted from the "Modifying Factors and Add-On Values" table developed by Muther(1973). Five factors of material conditions have been considered for the weight assignment.

1. Risk of hazard to facilities, and employees.
2. Density or bulkiness of the item.
3. Shape of the item.
4. Risk of damage to material.
5. Condition of item.

Except for the risk of hazard factor, the rest of the factors have many degrees of closeness weight. Details of each factor are:

- The risk of hazard
  - The weight value is assigned to be zero value.
- Density or bulkiness
  - Very light and empty.
  - Light and bulky.
  - Reasonably solid.
  - Fairly heavy and dense.
  - Heavy and dense.
  - Very heavy and dense.
- Shape
  - Very flat and stackable.
  - Readily stackable or nestable.
  - Fairly stackable or slightly nestable.
  - Basically square with some stacking quality.
  - Long, round, or somewhat irregular.
  - Very long, spherical or irregular.
  - Extra long curved, or especially irregular.
- Risk of damage
  - Not susceptible to damage at all.
  - Susceptible to negligible or practically no damage.
  - Slightly susceptible to some damage.
  - Susceptible to damage by crushing,breaking, scratching
  - Very susceptible to some damage.
  - Highly susceptible to some damage.
  - Highly fragile.

- Condition
  - – Clear, firm and stable.
  - – Oily, flimsy and unstable or awkward to handle.
  - – Covered with grease, hot and very flimsy or slippery.

Following is the knowledge base used in the system. It is composed of 5 questions and 26 rules. The default of the knowledge is 0 and the goal is weight.

Question(Hazard): "What is the condition apparent between this pair of departments?",
"Hazard such as fire hazard or vibration",
"None of the above conditions.".
Question(Density): "What is the density or bulkiness of the item ",
"Very light and empty.",
"Light and bulky.",
"Reasonably solid.",
"Fair heavy and dense.",
"Heavy and dense.",
"Very heavy and dense.".
Question(Shape):"How can you define the shape of material flowing between departments",
"Very flat and stackable.",
"Readily stackable or nestable.",
"Fairly stackable or slightly nestable.",
"Basically square with some stacking quality.",
"Long, rounded, or somewhat irregular.",
"Very long, spherical or irregular.",
"Extra long, curved, or especially irregular.",
Question(Damage): "How do you define the risk of damage to material",
"Not susceptible to damage at all.",
"Susceptible to negligible or practically no damage.",
"Slightly susceptible to some damage.",
"Susceptible to damage by crushing, breaking, scratching.",
"Very susceptible to some damage.",
"Highly susceptible to some damage.",
"Highly fragile.".
Question(Condition): "What is the condition of the item",
"Clear, firm and stable.",
"Oily, flimsy and unstable or awkward to handle.",
"Covered with grease, hot and very flimsy or slippery.".

GOAL:weight.

DEFAULT:"0".

1:IF Hazard = "Hazard such as fire hazard or vibration"
THEN weight = "-10".

2:IF Density = "Very light and empty."
THEN weight = "-5".

3:IF Density = "Light and bulky."
THEN weight = "-3".

4:IF Density = "Reasonably solid."
THEN weight = "0".

5:IF Density = "Fair heavy and dense."
THEN weight = "3".

6:IF Density = "Heavy and dense."
THEN weight = "5".

7:IF Density = "Very heavy and dense."
THEN weight = "7".

8:IF Shape = "Very flat and stackable."
THEN weight = "-7".

9:IF Shape = "Readily stackable or nestable."
THEN weight = "-5".

10:IF Shape = "Fairly stackable or slightly nestable."
THEN weight = "-3".

11:IF Shape = "Basically square with some stacking quality."
THEN weight = "0".

12:IF Shape = "Long, rounded, or somewhat irregular."
THEN weight = "3".

13:IF Shape = "Very long, spherical or irregular."
THEN weight = "5".

14:IF Shape = "Extra long, curved, or especially irregular."
THEN weight = "7".

16:IF Damage = "Not susceptible to damage at all."
THEN weight = "-5".

17:IF Damage = "Susceptible to negligible or practically no damage."
THEN weight = "-3".

18:IF Damage = "Slightly susceptible to some damage."
THEN weight = "0".

19:IF Damage = "Susceptible to damage by crushing, breaking, scratching."
THEN weight = "3".

20:IF Damage = "Very susceptible to some damage."
THEN weight = "5".
21:IF Damage = "Highly susceptible to some damage."
THEN weight = "7".
22:IF Damage = "Highly fragile."
THEN weight = "9".
23:IF Condition = "Clear, firm and stable."
THEN weight = "0".
25:IF Condition = "Oily, flimsy and unstable or awkward to handle."
THEN weight = "3".
26:IF Condition = "Cover with grease, hot and very flimsy or slippery."
THEN weight = "5".

APPENDIX IV

PUBLICATIONS LIST

1. Sirinaovakul, B. and Tajchayapong, P., "An intelligent approach to computer aided facility layout," Proceedings of 1991 International Conference on Industrial Electronics, Control and Instrumentation, Kobe, Japan, 1, 1991, 87-90.

2. Sirinaovakul, B. and Tajchayapong, P., "Approach to plant layout design using Expert Systems," Proceedings of the International Conference on Computer Integrated Manufacturing, Singapore, 1991, 499-502.

3. Sirinaovakul, B., and Thajchayapong, P., "A knowledge base to assist a heuristic search approach to facility layout," International Journal of Production Research, 32, 1994, 141-160.

4. Sirinaovakul, B. and Tajchayapong, P., "An Analysis of Computer Aided Facility Layout Techniques," Proceedings of the International Conference on Computer Integrated Manufacturing, Singapore, 1995, 513-520.

5. Sirinaovakul, B. and Tajchayapong, P., "A Beam Search Technique for VLSI Layout," FSTW Microelectronics and Information Technilogy Conference, Bangkok, 1995, 21-25.

An Intelligence Approach to Computer Aided Facility Layout

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ABSTRACT: The paper contributes to the development and construction of artificial intelligence to solve a plant layout design problem. The heuristic for patterns allocation, the heuristic search and heuristic function for problem solving, and the plant design knowledge base are used to construct the intelligent system. The patterns allocation procedure is the heuristic for generating the alternative layouts. In the problem solving procedure, the search heuristic searches for the best layout from the candidate layouts and the heuristic function directs the search process in the most profitable direction.

INTRODUCTION

The problem of facility layout is to determine an optimal layout of activity areas so that given specifications are satisfied. The problem belongs to class of spatial allocation problems that have been studied in various contexts including stock cutting, manufacturing cell layout and VLSI design. Although the type of facilities to be laid out may vary in each context, the problem formulation remains largely the same. In general, the dimensions and properties of facility are given for determining the interconnection cost between every facility pairs. Then, the expected layout is selected under the minimizing interconnection cost constraint. In the facility layout problem, the objectives is to arrange the facility areas to optimize the interrelationship among operating personal, material flow, information flow, and the methods required in achieving enterprise objectives efficiently, economically, and safely[1]. Therefore, the interconnection cost is considered to be the enterprise objectives and it is varied directly to the facility areas location.

The study of computerized plant layout techniques has been done for many years. Most of the efforts are spent on the quantitative techniques. These rely on mathematical, statistical and modeling approaches to the problem solving[1]. In the conventional computerized methods, the weight of closeness relationship is calculated by the product of distance, frequency of traveling and material handling. Then, the exchanges between locations of the activities are considered. The best location of activities are selected based on the closeness relationship value. CRAFT[2] algorithm is the first successful program presented. It interchanges activity locations in the initial layout to find improved solutions based on material flow data. PLANET[1] uses interdepartment flow data and adds the "penalty" cost associated with separating departments. In DISCON[3] aspect, the system is formulated and solved as a nonconvex mathematical programming using a procedure termed DISPersion CONcentration. By using the conventional computerized techniques, there are two major disadvantages. First, it does not consider enough possible outcomes in the computer program to arrive at the best optimal solution. Second, it can not consider the practical limitation[4] of the plant design problems, such as, the intangibleness of factors, the human aspects of the layout problems and so on.

To cope with the above problems, the artificial intelligence (AI) technique for facility layout design is presented. Kumara et al.[5] used the augmented transition network of natural language processing as the heuristic of expert system to determine the practical limitation of the alternate layout and WEB grammar to present the patterns allocation knowledge captured from expert. Abdou et al.[6] develops an expert system approach to define appropriate layouts of machining facilities under specific combinations of manufacturing and material handling system. The EXSYS system and the relationship chart have been used to construct the knowledge base. Malakooti et al.[7] develop an expert system for multiple-criteria facility layout.

This paper discusses the approach of artificial intelligence for facility layout. The topics are about problem description, problem solving, system design, knowledge structure and system operation. The paper also presents the example of operation and knowledge and the system evaluation.

PROBLEM DESCRIPTION

The number, dimensions and properties of the activity areas are given at the initial state of the system. The goal is to arrange the given activity areas to optimize the interconnection cost. The system, therefore, has to decide where each activity area should be located next to which in order to minimize the overall cost.

PROBLEM SOLVING

In order to solve the problem, the system must proposes the layout alternatives and, then, selects the best layout from the layout alternatives. In the problem-solving process, there are two concerns. First, how to develop the layout alternatives for the exiting problem. Second, if too many layout alternatives have been developed, how can we select the best alternative among them. The follows are discussed these concerns.

The problem-solving system composes of two major processes; the patterns allocation heuristic and the best alternatives selection heuristic. The patterns allocation heuristic generates the layout alternatives and the best alternatives selection heuristic search for the best layout from the generated alternatives.

The patterns allocation heuristic starts with a pair of facility areas, namely; major and minor. The process, then, puts the minor onto a side of the major and proposes this combination as a first alternative. Next, the minor rotates around itself and places its next side onto the same side of major. This combined area is the next alternative. After all sides of minor are placed onto the side of major, the minor is moved to next side of major. The method repeats until all sides of major are placed and all facility areas are located. All of these alternatives are the set of proposed alternatives to be selected for the best candidate. Fig 1 shows a pattern being located along the side of major. The sixteen alternatives layouts are shown in fig 1(c) to fig 1(r) and the steps of the heuristic are given below:

Step 1. Randomly select a facility area and call it major.
Step 2. Select the next facility area and call it minor.
Step 3. Match the examining sides of major and minor by adjoining their sides together and call this adjoined patterns as major.
Step 4. Move the minor toward major, rotate minor around a reference point whenever necessary.
Step 5. Assign all the created patterns in step 3 and 4 as layout alternatives.
Step 6. If there is another facility area, then go to step 2; otherwise, terminate the process.

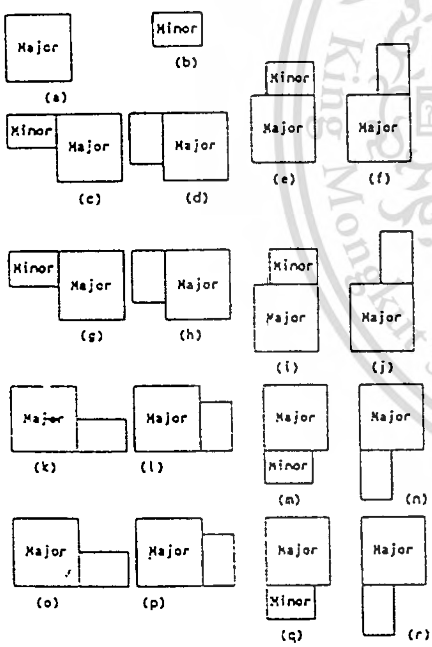

Fig 1. shows how a pattern locates its side onto the side of "Major".
(a) Major. (b) Minor. (c) places minor onto a side of major.
(c), (d), (g) and (h) rotates minor around the reference point.
(c), (e), (k) and (m) moves minor to other sides of major.

By using the described patterns allocation heuristic, the number of generated alternatives is exponentially increased when the number of activity areas is increased. For example, two rectangular areas can generate 16 alternatives while three rectangular areas generated maximum 256 alternatives. Table 1 shows the number of generated alternatives. (1) and (2) are the formulas for calculating the number of generated alternatives.

$$\text{Minimum Generated Alternatives} = 16^{(n-1)} \quad (1)$$

$$\text{Maximum Generated Alternatives} = 8^{(n-1)} * n! \quad (2)$$

when
$n = 2,3,4, \ldots n$ *and*
n = *the number of activity areas.*

No. of areas	Min. Layouts	Max. Layouts
2	16	16
3	256	384
4	4,096	12,288
5	65,536	491,520
6	1,048,576	23,592,960

Table 1. the numbers of generated alternatives for the quadrilateral areas.

According to a large number of alternatives, the searching for the best layout by a complete analysis of all generated alternatives can be exhaustively analyzed. The best alternative selection heuristic is designed for solving this problem. It reduces a large problem to a reasonable size and guides the search process in the most profitable direction.

In order to start the best alternative selection heuristic, the first activity area is randomly selected as a root node. Then, next activity area is inserted to match with the root node and the pattern allocation heuristic is applied. The process repeats until all activity areas are inserted. The layouts generated at this level are the layout alternatives. From these alternatives, the best alternative of the above activity pair will be selected by the best alternative selection heuristic. The selected activities pair is the best allocation of activity areas and it is assigned to be the next parent node. The system selects next unlocated activity area to match with the located areas and applies the allocation heuristic again. The system repeats the process above until all activity areas are applied. The details of heuristic are explained as follows.

Step 1. Select the first activity area.
Step 2. Select the second activity area.
Step 3. Apply the pattern allocation heuristic.
Step 4. Select the best alternative.
Step 5. If there are some activity areas not located, then select the unlocated area and return to step 3; otherwise, terminate.

On searching for the best candidate procedure, along the way the heuristic function calculates the costs in consideration of all practical limitations by acquiring the knowledge from the knowledge base system. The heuristic function used in the process is determined by the product of traveling frequency, distance and significant relationship value (practical limitation value) of activity pairs. The product is called "level of closeness(LC)" and it is the guideline for the search direction in the problem space.

$$LC = d * f * w$$

where
d = *distance*
f = *frequency*
w = *weight*

Distance is the length of the center of one activity area to the center of the other.
Frequency is the forecasting data of the frequency of traveling

between two departments.
Weight, in this sense, means the value assigned for the significance of relationship between activity pairs.

The high value of weight means the two activity areas have to be located together. On the other hand, the low value of weight means the two activity areas have to be separated. The example of high value of weight is the storage and production area and low value is the storage for the flammable material and the arc welding areas.

Heuristics, by their nature, can lead to errors. They do not guarantee the correct solution; they only increase the likelihood of finding a usable solution. In the searching process of the problem space, it is possible to select the wrong path, since this path may show the better LC value in the early state but it may have the worse LC value in the later state. If the wrong path has been selected, the optimal solution will not be met. In order to reduce the errors occurred in the above situation, the set of best candidates at each level must be selected instead of only one candidate. Therefore, at each level, all the proposed candidates of all sets are sorted by the LC value. The set of best candidates is selected as the next proposed candidates. The number of the selected best candidates for each set at each level is an adjustable number. It is shown that if the bigger number of candidates is selected, the better solution is produced. On the other hand, if the bigger number of candidates is selected, the longer processing time is taken.

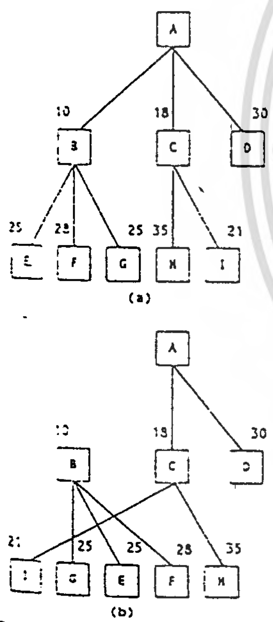

Fig 2. The graphical representation of problem-solving.

Fig 2. illustrates the graphical representation of the described problem-solving. Initially, there is only one node, A. The system then applied the patterns allocation heuristic to node A. The 3 new nodes, B, C and D, are generated. The heuristic function, which is an estimation of the LC value, is applied to each of these new nodes. The new generated nodes are assigned the LC values and sorted by the LC value. Since B and C are selected to be the set of most promising node, they are expanded next. They generate E, F, G, H and I as a set of new generated daughters. The heuristic function, then, is applied to them and the new generated nodes are sorted by the LC value again as shown in fig 2b. The first two of these new generated nodes, I and G, are selected as the new promising nodes. The process is repeated until a solution is found.

In designing the plant layout, practical limitation value, or weight, is the most important factor because of its flexibility. The proposed method takes the advantage of expert system to assign this value. The forward-chaining rule-based system is designed to be an expert system tool for plant layout design. As a result, the knowledge engineers or plant layout expert must implement the knowledge of the weight value assignment into the knowledge base.

How to design weight value depends on the art of plant designer. There are many factors that have the influence on the value such as type of material flow, type of material handlers and so on. The designer has to design their own value since these values are varied according to the functional characteristics of a plant. The knowledge of the weight, significant of relationship, value assignment is obtained from the skill and experience of the plant design expert.

SYSTEM DESIGN

The structure of the designed system is shown in fig 3. The main components are as follows.

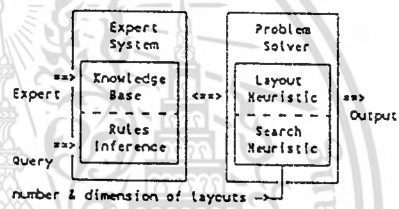

Fig 3. Blocks Diagram of Designed System

The expert system consists of 2 subsystems, namely; the heuristic rules subsystem and the rules inference subsystem. The heuristic rules are rules that explain how to assign the value of w and the rules inference is the inference engine that is used for selecting the appropriate rule at the certain situation. The search direction of the inference engine is a forward chaining method.

Problem Solver composed of the layout and search heuristic. The layout heuristic generates the layout alternative and search heuristic search for the best layout. The solution of problem solver is graphically shown on screen.

Before running the system, expert or a knowledge programmer has to represent his knowledge into the Knowledge Base. When running the program, the system will prompt the user of the number of activity areas, dimensions and frequency of traveling. Then, Rules Inference Unit infers the knowledge by using the information acquired from the user. The value of w will be concluded and the LC value is calculated. By using the LC value, the Problem Solver Unit searches for the solution in problem space.

The represented knowledge in the knowledge base is the rules for assigning the practical limitations values. They assign weight of practical limitations so that the activity areas which have a low value have to be put close together. On the other hand, the areas that are distantly separated will have a high value. However, in some special cases, the low and high value may be differently defined. For instance, the welding department must theoretically be put close to the chemical cleaning department to clean out all fluxes and dirts after the welding process. Unfortunately, this is not possible because the spark fire from the arc welding may cause fire from the cleaning chemical solution. This case is defined as an practical limitation of factors. Therefore, a high value is assigned.

KNOWLEDGE STRUCTURE

The knowledge in the knowledge base has to represent in the following structure:

<Header>
Question for 1st condition
Question for 2nd condition
Question for 3rd condition
:
:
DEFAULT <value>
Rule 1
Rule 2
Rule 3
:
:

The HEADER is used for identifying the name of the knowledge. It can be any characters and must be placed at the top of the knowledge. The set of QUESTIONs is followed the HEADER. Third part of knowledge is DEFAULT and the last is a set of rules.

The details of knowledge base components are explained as follows:

Question is a meta-fact for prompting the answer from the user. The structure of Question Unit is shown in fig 4.

Question ATTRIBUTE
TEXT?
VALUE 1
VALUE 2
VALUE ..

Fig 4. the structure of Question.

The system asks the user for the value of ATTRIBUTE by displaying TEXT and VALUE1, 2, ... TEXT is the leading question for the value for ATTRIBUTE. The VALUE1, 2, .. are the proposed values for ATTRIBUTE of the Question.

$$\# \langle value \rangle : \langle Answer_{Quest1} \rangle , \langle Answer_{Quest2} \rangle , ..$$

Fig 5a the structure of rule.

Conclusion	Condition
#4 :	1, 1,
#6 :	2, 1,

Fig 5b. the example of rules.

Rules are represented in the table-look-up format as shown in fig 5. They consists of two parts. The first column of the rule represents the conclusion part and the rest of the columns represent the series of conditions part. The two parts are separated by colon.

The sequence of columns in condition part is in the same as that of ATTRIBUTE in Question. Example 1 shows the example of Questions and Rules.

Example 1 The example of Questions and Rules
Question Attribute 1
What is the value of Attribute 1 ?
-1) 1
-2) 2.
Question Attribute 2
What is the value of Attribute 2 ?
-1) 1
-2) 2.

#4 : 1, 1,
#6 : 2, 1,

From the rules of example 1, they can be rewritten in the IF-THEN format as follow:

IF Attribute 1 = 1 and
Attribute 2 = 1
THEN weight = 4.
IF Attribute 1 = 2 and
Attribute 2 = 1
THEN weight = 6.

Default is the fact of the knowledge base. It automatically assigns the value of weight(w) to the system in the case that no rules cover the conditions. The structure of Default is:

Default WEIGHT.

Example 2 The example of default.

Default 1.

The example means that all the unassigned conditions will have the w-value equal to 1.

Example 3 shows the part of represented knowledge in a knowledge base. The knowledge used in this system is adapted from Muther's "modifying factors and add-on values" table[4]. This knowledge is an maintainable knowledge. The plant layout expert can represent and adjust their own idea of w-value of the plant layout design into this knowledge base.

Example 3 Knowledge represents in a knowledge base.

Question Condition
What is the condition apparent between this pair of departments ?
-1) Undesirable conditions such as fire hazard or vibration
-2) Not conditions above.
Question Activity
What is the activity happened between this pair of departments ?
-1) Materials
-2) Services
-3) Both materials and services.
Question Material

Please tell me about the bulkiness or density of material
-1) Light such as knocked-down corrugated carton
-2) Heavy and dense such as solid casting
-3) Very heavy and dense such as die block.
Question Risk
Please specify the risk of damage
-1) Not susceptible to any damage at all such as scrap iron
-2) Susceptible to damage by crushing or breaking
-3) Highly susceptible to very damage such as explosives.
Default 1
• con. Act. Mat. Risk
#0 : 1, Null,Null,Null
#2 : 2, 1, 1, 1,
#3 : 2, 1, 2, 3,
#6 : 2, 1, 3, 1,
#8 : 2, 1, 3, 2,
#10: 2, 1, 3, 3,

SYSTEM OPERATION

The flow diagram of the system operation is shown in fig 6. The system starts by acquiring the information of facility areas dimensions, total area, unit file name and number of daughter nodes. The expert system, then, questions the user about the facility areas properties. By using the facility areas dimensions and properties, The system calculates the LC value and search for the best layout.

For the knowledge development, the plant layout expert can create his own knowledge by using word processor. The system will automatically load this knowledge file into the Heuristic Rules module and use it as a consultation knowledge.

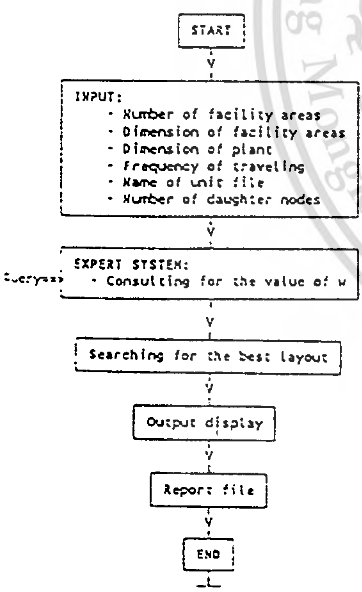

Fig 6 the flow diagram of the system operation

RESULTS AND CONCLUSIONS

The system performance has been evaluated and tested many times. The given recommended layouts are as expected. The results also show the potential applications to solve the complex plant layout problems. In example 4, the tested run was made upon the following data.

Example 4 The plant has four activity areas. The details of the activity areas are:

1) metal forming area
2) welding area
3) chemical cleaning area and
4) storage area

From the forecasting data, the traveling frequency among the activity areas are as follows.

	forming	welding	cleaning	storage
forming	-	20	2	20
welding	-	-	20	18
cleaning	-	-	-	1
storage	-	-	-	-

Activity areas dimensions

forming	2 x 1
welding	2 x 1
cleaning	1 x 1
storage	2 x 2

For the functional characteristics of activity area, welding and chemical cleaning area are hazard. The flowed materials among metal forming, welding, storage and chemical cleaning area are heavy and not susceptible to any damage . The flowed materials between storage and chemical cleaning area are susceptible to vary damage.

Recommended layout

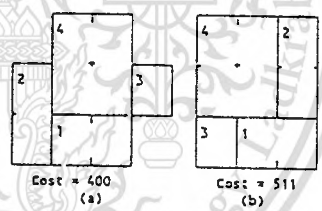

Fig 7(a) shows the result layout for unlimited boundary.
(b) shows the result of 3x3 total area.

By using the expert system, many efforts that used to be put on the design of plant layout has been reduced. When comparing to the manual design, the expert system can give the result much more faster than the human expert. Table 2 shows the approximate processing time of the system which tests on 10 MHz personal computer.

No. of patterns	No. of daughters	Processing time
5	5	9 seconds
	10	15 seconds
10	5	1:42 minutes
	10	3:17 minutes
20	5	19:8 minutes
	10	37:51 minutes

Table 2. The approximate processing time of the system.

When comparing to the conventional computer programs, the expert system approach can give the designer more flexibilities since the knowledge in the knowledge base is the storage of skill and experience. The designed system also has the advantage of reducing the problem space by using the heuristic search in the problem solver unit.

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APPENDIX

The ASCII file of the first recommended layout
Entities : 4
X Lim. : 100
Y Lim. : 100
Lim. : 110
Cost : 400.19999C4100
KB. unit file : SAMPLE.PLU

Pair of entities		Weight	Frequency
1	2	4	20
1	3	4	2
1	4	4	20
2	3	0	20
2	4	4	18
3	4	6	1

no.	Size	Address	Degree
1	2*1	-1,0	0
2	2*1	-2,-1	90
3	1*1	1,-1	0
4	2*2	-1,-2	0

The ASCII file of the second recommended layout
Entities : 4
X Lim. : 3
Y Lim. : 3
D Lim, : 100
Cost : 511.3622680700
KB. unit file : SAMPLE.PLU

Pair of entities		Weight	Frequency
1	2	4	20
1	3	4	2
1	4	4	20
2	3	0	20
2	4	8	18
3	4	8	1

no.	Size	Address	Degree
1	2*1	-1,0	0
2	2*1	0,-2	90
3	1*1	-2,0	0
4	2*2	-2,-2	0

APPROACH TO PLANT LAYOUT DESIGN USING EXPERT SYSTEMS

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ABSTRACT

This paper presents the use of artificial intelligence technique for plant layout. It contributes to the development and construction of artificial intelligence to solve a more flexible solution for plant layout design. The heuristic procedure for pattern allocation, the heuristic search for problem solving and the plant design knowledge base are used to construct the intelligent system. The practical software program for this study has been successfully developed and tested on a microcomputer-80386. It yields the major advantages to the traditional computerized plant layout technique in both the ability to handle of practical limitations and the better processing time in computation.

INTRODUCTION

Approaches for plant layout design are manual and computerized techniques. For the manual technique, Muther[1] developed a method called systematic plant layout. He presented a material handling cost calculation and the relationship chart in his method. The relationship chart determines the arrangement in layout by considering the interrelationship among the activity areas which is given by the weight of closeness. The departments which have the highest weight will be put close together and the departments which have lower weight will be put farther respectively. The practical limitation factors are also included in his method.

The computerized plant layout techniques, such as CRAFT[2], PLANET[3], DISCON[4] and so on, has been done for many years. Most of the efforts are spent on the quantitative techniques. These rely on mathematical, statistical and modeling approaches to the problem solving[3]. In the conventional computerized methods, the weight of closeness relationship is calculated by the product of distance, frequency of traveling and material handling. Then, the exchanges between locations of the activities are considered. The best location of activities are selected based on the closeness relationship value.

CRAFT algorithm is the first successful program presented. It interchanges activity locations in the initial layout to find improved solutions based on material flow data. PLANET uses interdepartment flow data and adds the "penalty" cost associated with separating departments. In DISCON aspect, the system is formulated and solved as a nonconvex mathematical programming using a procedure termed DISpersion CONcentration.

By using the conventional computerized techniques, there are two major disadvantages. First, it does not consider enough possible outcomes in the computer program to arrive at the best optimal solution. Second, it can not consider the practical limitation[1] of the plant design problems, such as, the intangibleness of factors, the human aspects of the layout problems and so on[3]. To cope with the above problems, the artificial intelligence (AI) technique for the plant layout design is presented. Kumara et al.[5] used the augmented transition network of natural language processing as the heuristic procedure of expert system to determine the practical limitation of the alternate layout and WEB grammar to present the patterns allocation knowledge captured from expert.

In this paper, the expert system approach will be discussed. The topics are about problem description and problem solving for plant design. The paper also covers the topics about the design of expert system for plant design and its knowledge representation.

PROBLEM DESCRIPTION

In plant layout, the system is to determine an optimal layout of activity areas so that a given specification of the system is satisfied. The dimensions and properties of the activity areas are given, the system, therefore, decides where each activity area should be located.

The design of the problem solving system is based on the assumption that the activity areas have rectangular shape and the number of activity areas is finite.

The goal of problem solving is to indicate which department should be located next to which and where it should be located in order to minimize the overall cost.

PROBLEM SOLVING

The problem solving strategy of the system composes of two major processes: the best candidate selection process and pattern allocation heuristic algorithm. The system starts with the candidate selection process. It randomly selects the first pattern as a root node. From this node, the system applies the pattern allocation heuristic algorithm to generate a new set of patterns as the proposed candidates. Next, the system uses the best candidate selection process to check for the best candidate of the proposed patterns. Then, it checks to see if all the patterns are allocated. If so, the system selects the best candidate to be the solution and then quits. If not, the system uses the best candidate to be the next parent node and repeats the process.

On searching for the best candidate procedure, along the way the heuristic function calculates the costs in consideration of all practical limitations by acquiring the knowledge from the knowledge base system. The heuristic function used in the process is determined by the product of traveling frequency, distance and significant relationship value (practical limitation value) of activity pairs. The product is called "level of closeness(LC)" and it is the guideline for the search direction in the problem space.

$$LC = d*f*w$$

where

d = distance

f = frequency

w = weight

Distance is the length of the center of one activity area to the center of the other.

Frequency is the forecasting data of the frequency of traveling between two departments.

Weight, in this sense, means the value assigned for the significance of relationship between activity pairs.

The high value of weight means the two activity areas have to be located together. On the other hand, the low value of weight means the two activity areas have to be separated. The example of high value of weight is the storage and production area and low value is the storage for the flammable material and the arc welding areas.

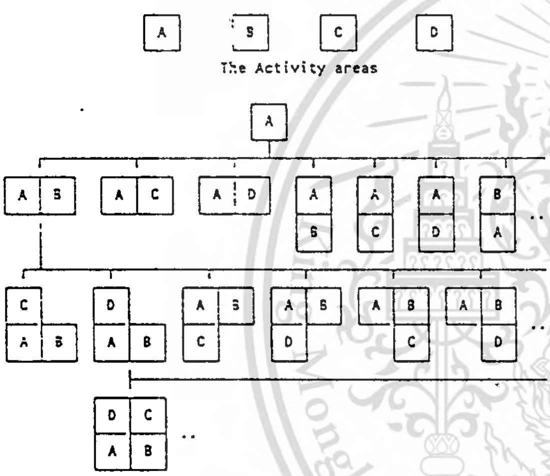

Fig 1. The problem solving process

Fig 1 shows an example of algorithm described above. Let A, B, C, and D are the four activity areas, being located. A is an arbitrary area selected by pattern allocation heuristic algorithm. Level 2 shows the proposed candidates generated from A and the rests of the activity areas (B, C and D). From the candidates in level 2, the best candidate selection process calculates the level of closeness(LC) values. By considering the LC value, the process selects |A|B| combination as a best candidate. Then, the system checks and finds that pattern C and D are not allocated. From |A|B| combination, the pattern allocation heuristic algorithm generates a new set of proposed candidates at level 3. These candidates show the proposed allocation of the activity areas. The systems repeats the process until the solution is found.

In the searching process of the problem space, it is possible to select the wrong path, since this path may show the better LC value in the early state but it may have the worse LC value in the later state. If the wrong path has been selected, the optimal solution will not be met. In order to solve this problem, the set of best candidates at each level must be selected instead of only one candidate. Therefore, at each level, all the proposed candidates of all sets are sorted by the LC value. The set of best candidates is selected as the next proposed candidates. The number of the selected best candidates for each set at each level is an adjustable number. It is shown that if the bigger number of candidates is selected, the better solution is produced. On the other hand, if the bigger number of candidates is selected, the longer processing time is taken.

In designing the plant layout, practical limitation value, or weight, is the most important factor because of its flexibility. The proposed method takes the advantage of expert system to assign this value. The forward-chaining rule-based system is designed to be an expert system tool for plant layout design. As a result, the knowledge engineers or plant layout expert must implement the knowledge of the weight value assignment into the knowledge base.

How to design weight value depends on the art of plant designer. There are many factors that have the influence on the value such as type of material flow, type of material handlers and so on. The designer has to design their own value since these values are varied according to the functional characteristics of a plant. The knowledge of the weight, significant of relationship, value assignment is obtained from the skill and experience of the plant design expert.

In generating a new set of patterns, the algorithm of pattern allocation is used. The algorithm starts with a pair of activity areas, namely; major and minor. The system inserts the minor onto a side of the major and proposes this combination area as the first candidate. Next, the minor rotates around itself and replaces its next side onto the same side of major. This combined area is the next candidate. The process repeats until all sides of minor and major are replaced and all activity areas are located. All of these candidates are the set of proposed candidates to be selected for the best for one level. This process goes on under the direction of the heuristic search and the heuristic function of best candidate selection process. Fig 2 shows a pattern being located along side of major.

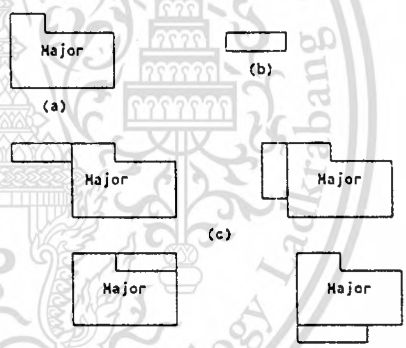

Fig 2. shows how a pattern locates onto the side of "Major".
(a) An arbitrary activity area (first "Major"). (b) Minor.
(c) Pairwise matching of the sides of the patterns.

KNOWLEDGE REPRESENTATION AND INFERENCE ENGINE

The knowledge represented in the knowledge base is the rules for explaining the practical limitations values. They assign weight of practical limitations so that the activity areas which have a low value have to be put close together. On the other hand, the areas that are distantly separated will have a high value. However, in some special cases, the low and high value may be differently defined. For instance, the welding department must theoretically be put close to the chemical cleaning department to clean out all fluxes and dirts after the welding process. Unfortunately, this is not possible because the spark fire from the arc welding may cause fire from the cleaning chemical solution. This case is defined as an practical limitation of factors. Therefore, a high value is assigned.

The designed knowledge base composes of three units; Question, Rule and Default. Question is a meta-fact for prompting the answer from the user. The structure of Question Unit is:

Question ATTRIBUTE
TEXT?
VALUE 1
VALUE 2
VALUE ..

The system asks the user for the value of ATTRIBUTE by displaying TEXT and VALUE1, 2, ... TEXT is the leading question for the value for ATTRIBUTE. The VALUE1, 2, .. are the proposed values for ATTRIBUTE of the Question.

Rule is the set of knowledge explaining the assignment of the practical limitation value or weight. Rule uses IF-THEN format as a structure. The first column of the rule represents the conclusion and the rest of the columns represent the series of conditions. The sequence of columns in condition is in the same as that of ATTRIBUTE in Question. Example 1 shows the example of Questions and Rules.

Example 1 The example of Questions and Rules
Question A
What is the value of A ?
-1) 1
-2) 2.
Question B
What is the value of B ?
-1) 1
-2) 2.
#4 : 1, 1,
#6 : 2, 1,

From the first rule of example 1, It can be rewritten in the IF-THEN format as follow:

IF A = 1 and
B = 1
THEN 4.

Default is the fact of the knowledge base. It automatically assigns the value of weight to the system in the case that no rules cover the condition. The structure of Default is:

Default WEIGHT

The knowledge used in this system is adapted from Muther's "modifying factors and add-on values" table[1]. This knowledge is an maintainable knowledge. The plant layout expert can represent and adjust their own idea of plant layout design into this knowledge base. Example 2 is a part of knowledge in a knowledge base.

Example 2 Knowledge represents in a knowledge base.
Question Condition
What is the condition apparent between
this pair of departments ?
-1) Undesirable conditions such as fire hazard or vibration
-2) Not conditions above.
Question Activity
What is the activity happened between
this pair of departments ?
-1) Materials
-2) Services
-3) Both materials and services.
Question Material
Please tell me about the bulkiness or density of material
-1) Light such as knocked-down corrugated carton
-2) Heavy and dense such as solid casting
-3) Very heavy and dense such as die block.
Question Risk
Please specify the risk of damage
-1) Not susceptible to any damage at all such as scrap iron
-2) Susceptible to damage by crushing or breaking
-3) Highly susceptible to very damage such as explosives.
Default 1
* con. Act. Mat. Risk
#0 : 1, Null,Null,Null
#2 : 2, 1, 1, 1,
#8 : 2, 1, 2, 3,
#6 : 2, 1, 3, 1,
#8 : 2, 1, 3, 2,
#10: 2, 1, 3, 3,

SYSTEM DESIGN

The designed system is an expert system tool. The knowledge has to be implemented by the plant layout expert. The expert (or knowledge engineer) has to build the knowledge of assigning the value of w. By using this knowledge, the tool will generate the questions for acquiring the information from the user. Fig 3 is the block diagram of expert system design.

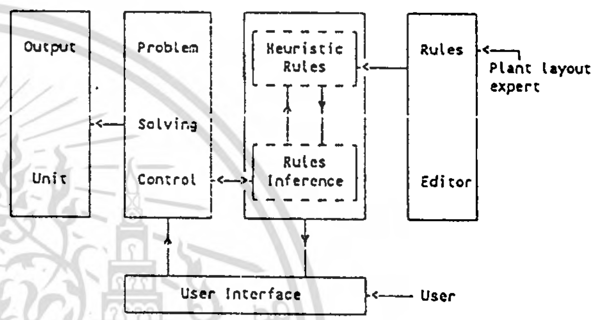

Fig 3. Blocks Diagram of Designed Expert System

The details of each block can be explained as follows.

The forward chaining expert system is designed for assigning the value of w. It consists of 2 subsystems. They are heuristic rules subsystem and rules inference subsystem. Heuristic rules are rules that explain how to solve the problem and rules inference is the inference engine that is used for selecting the appropriate rules at the certain situation. The search direction of the inference engine is a forward chaining method.

Problem Solving Control is the module of the heuristic search as described in problem solving strategy. User Interface is the module that the system will acquire the information from the user. The module is the interface between the user and the system. Output Unit is output of the solution. The solution of plant design is shown in graphic on screen. Rule Editor is the editor for the knowledge programmer to input or edit the knowledge. To edit the rules in the knowledge base, the knowledge programmer can use any kind of word processor that gives text output file.

The steps of operations are: an expert or a knowledge programmer implements the knowledge into the Knowledge Base by using Rule Editor. Inference Engine Unit infers the knowledge by gaining the information from the user through User Interface Unit. The value of w(= load) will be concluded by Inference Engine. Problem Solving Control Unit in the activity dimension from the user through User Interface Unit. The Problem Solving Control Unit can search for the solution in problem space by using the value of w, the frequency of traveling and the dimension of activity area. The solution will be shown on screen by the Output Unit.

USER INTERFACE

As described in problem solving section, the "level of closeness (LC)" value is calculated from

$$LC = f*d*w.$$

The values of f(traveling frequency) and d (distance) can be acquired directly from the user but the value of w is interpreted from the activity areas information. These information is relatively flexible and depends on the functional characteristics of plant.

In acquiring the value of w, the Heuristic Rules and Rules Inference module of the system are activated. The user has to select the knowledge before beginning the consultation. When the system starts consultation, It prompts the user for the information of the activity areas. The user must response the question by selecting the most appropriate answer from the given menu. After the consultation has finished, the system gives the recommended layout on screen in the graphic form. The dimensions and coordinates output of the recommended layout is also given in the ASCII file. Fig 4 is the example of the graphical display outputs.

For the knowledge development, the plant layout expert can create his own knowledge by using word processor. The system will automatically load this knowledge file into the Heuristic Rules module and use it as a consultation knowledge.

RESULT AND CONCLUSION

The system performance has been evaluated and tested many times. The given recommended layouts are as expected. The results also show the potential applications to solve the complex plant layout problems. In example 3, the tested run was made using the following data.

Example 3 There are four activity areas. The detail of each activity areas are:

1) metal forming area
2) welding area
3) chemical cleaning area and
4) storage area

From the forecasting data, the traveling frequency among the activity areas are as follows.

	forming	welding	cleaning	storage
forming	-	20	2	20
welding	-	-	20	18
cleaning	-	-	-	1
storage	-	-	-	-

Activity areas dimensions	
forming	2 x 1
welding	2 x 1
cleaning	1 x 1
storage	2 x 2

For the functional characteristics of activity area, welding and chemical cleaning area are hazard. The flowed materials among metal forming, welding, storage and chemical cleaning area are heavy and not susceptible to any damage . The flowed materials between storage and chemical cleaning area are susceptible to vary damage.

Recommended layout

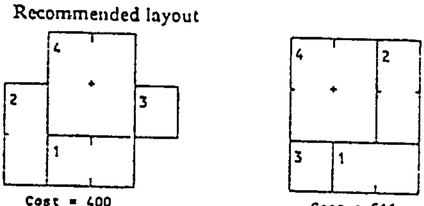

Fig 4 The recommended layouts of the system

By using the expert system, many efforts that used to be put on the design of plant layout has been reduced. When comparing to the manual design, the expert system can give the result much faster than the human expert. When comparing to the conventional computer programs, the expert system approach can give the designer more flexibilities since the knowledge in the knowledge base is the storage of skill and experience. The designed system also has the advantage of reducing the problem space since the heuristic search in the problem solving control unit reduces a great deal of solution searching.

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APPENDIX

The ASCII file of the first recommended layout
Entities : 4
X Lim. : 100
Y Lim. : 100
D Lim. : 110
Cost : 400.1999904100
KB. unit file : SAMPLE.PLU

Pair of entities		Weight	Frequency
1	2	4	20
1	3	4	2
1	4	4	20
2	3	0	20
2	4	4	18
3	4	6	1

no.	Size	Address	Degree
1	2*1	-1,0	0
2	2*1	-2,-1	90
3	1*1	1,-1	0
4	2*2	-1,-2	0

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A knowledge base to assist a heuristic search approach to facility layout

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This paper presents a construction model for facility layout. An artificial intelligence technique has been used to solve the problems of allocating patterns within a layout. The designed system consists of pattern allocation, a heuristic search and a knowledge base system. The system first generates alternative layouts by using a pattern allocation. The heuristic search searches for the best layout from these generated alternatives. The heuristic function, or closeness weight, is also used for directing the search process to the most profitable choice of layout by acquiring knowledge from the knowledge base. An experimental system is constructed for testing purposes only. The results from the system show potential for solving complex facility layout problems.

1. Introduction

The main functions of facility layout design are to allocate facilities under the activity interrelationship and to optimize their space requirements. The objective is to design an efficient arrangement of space required by a facility into an integrated whole, which is called area allocation. The area allocation technique has been studied in various contexts including stock cutting, very-large-scale integration (VLSI) design and facility layout. In each context, the problem formulation remains largely the same. Using an area allocation technique, the dimensions and properties of a facility are given to determine the interrelationship cost between all facility pairs. A satisfactory layout is then usually selected under the constraint of minimizing interrelationship costs. For a stock cutting problem, a set of patterns is fitted onto a plate to minimize scrap. For VLSI design, the problem is the location of electronic components onto a die to satisfy the component layout rules. In a facility layout problem, the objective is to arrange the facility areas to optimize the interrelationship between operating personnel, materials flow and information flow. This requires methods that meet the enterprise objectives efficiently, economically and safely.

Computerized facility layout techniques have been studied for many years. Most of the effort has been spent on quantitative techniques that rely on mathematical, statistical and modelling approaches to problem solving. In conventional computerized methods, the weight of the closeness relationship between activity locations in the facility layout is defined by the product of distance, frequency of travelling and material-handling cost. The exchanges of activities between locations is considered. The most cost-effective location for activities is selected on the basis of the closeness

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relationship value. Previous approaches to solving the problems include the CRAFT algorithm (Buffa *et al.* 1964) which was the first successful program. The algorithm uses a heuristic approach to interchange facility locations. The initial layout is required before an improved solution based on material flow data can be found. The limitations of this algorithm are that CRAFT does not work without the initial layout and does not take any rating of relationships among activities into account. Alternative approaches, such as CORELAP (Lee and Moore 1967) and ALDEP (Seehof and Evans 1967) which do not start from the initial layout and instead generate a layout from scratch. They locate the activities according to the rating of the highest relationship activity. However, these algorithms also have limitations. They do not consider the exception conditions when the two departments must be separated for some reason. PLANET (Apple and Deisenroth 1972) accounts for these limitations by using the interdepartment flow data and adding the 'penalty' cost associated with separating departments. A further system, DISCON (Drezner 1980) is formulated and solved by non-convex mathematical programming using a procedure termed dispersion concentration. This algorithm also takes the closeness weight into account. More recently, Tam and Li (1991) present the divide-and-conquer strategy for solving the problem. This strategy consists of three phases: cluster analysis, initial layout and layout refinement. This method produces the initial layout of each cluster which can then be refined by finding the positions of patterns to minimize the total force.

In using these conventional computerized techniques, there are two points to consider. First, conventional computerized techniques do not consider enough possible outcomes in the computer program to arrive at the optimal solution, especially for the construction methods such as CORELAP and ALDEP. Therefore the improved methods, such as COL (Vollmann *et al.* 1968) and COFAD (Tompkins and Reed 1976), are presented to obtain a better solution, but the methods are still very sensitive to the initial layout.

Second, it is difficult to take the practical limitations of facility design problems such as the intangible factors and the human aspects of the layout into account. This is because any facility layout problem has multiple criteria in selecting the best layout and it is very specific in domain and problem. Thus the flexibility of practical limitation considerations is very important.

Malakooti and Tsurushima (1989) commented that any facility layout is an ill-structured problem for three reasons. First, there are multiple criteria. Second, it is hard to determine a problem space and third there are many domain-specific and problem-specific constraints.

To cope with such ill-structured problems, artificial intellegence (AI) techniques for facility layout design have been formulated. Kumara *et al.* 1988) used an augmented transition network of natural language processing as the heuristic of an expert system to determine the practical limitations of the alternate layout, and WEB grammar to present the pattern allocation knowledge captured from the human expert. Malakooti and Tsurushima (1989) developed an expert system and multiple-criteria decision making. The expert system interacts with the decision maker (DM), and reflects the DM's preferences in the selection of rules and priorities. Abdou and Dutta (1990) developed an expert system approach to define appropriate layouts of machining facilities under specific combinations of manufacturing and material handling systems. The EXSYS expert system shell and the relationship chart have been used to construct a knowledge base. Raoot and Rakshit (1991) presented the fuzzy set theory to solve a facility layout problem. The procedures for aggregating the expert's opinion, location, selection and placement of the facility, and for evaluating layout were presented. The major disadvantage of these presented systems is that they cannot handle some of the practical layout limitations.

It should be evident that solving the practical limitations of facility layout by using a computerized technique is not as simple a matter as it may seem. Although there are many computerized techniques being proposed to solve the problem, they can still solve only one aspect of any problem. For instance, when the heavy load of flown material is considered, the hazard of facility is left unsolved. It is because of such relational characteristics that the layout facilities may be close together, a so-called 'positive relationship'. On the other hand, the layout facilities may be apart, a so-called 'negative relationship'. Most of the proposed methods solve the problem by assuming the relational characteristic of facilities have only a 'positive relationship'. This assumption makes the most of the algorithms unable to solve some of the practical limitations of layout. Sirinaovakul and Thajchayapong (1991) also proposed a system using heuristic layout and heuristic search to solve the practical layout limitations. An expert system is also presented to help the heuristic search in assigning a closeness weight for the activities relationship.

This paper then discusses the use of AI to solve a facility layout problem. Three designed systems, namely pattern generation algorithm, heuristic search and knowledge base, are presented. Topics covered include problem solving, pattern generator, heuristic search, expert system and implementation. The paper also presents operation examples and concluding remarks.

2. Problem solving

For solving the facility layout problem, the number, dimension and properties of the facility areas are given in the initial state. The goal is to decide where each facility area should be located to minimize the overall cost. Figure 1 is the proposed diagram of the problem-solving technique.

There are three major processes in the system: the pattern generator, the heuristic search and the expert system. The pattern generator constructs the alternative layouts. The heuristic search searches for a set of low-cost layouts among these constructed alternatives. This heuristic search had dual functions. First, the so-called heuristic function calculates the cost of the layout, which is used as a criterion of selection. Second, the system selects a set of low-cost layouts. The expert system is used in helping the system to calculate the layout cost. It works as a tool to increase the flow of information concerning facilities to the heuristic function.

To start the procedure (Fig. 2), the pattern generator selects a pair of activity areas or patterns having the highest W value and locates them. The output from the pattern generator is alternative layouts. To select the best layout of these alternatives, the system uses a heuristic search technique. The distances are calculated, the frequencies of travelling are put in by the user, and the closeness weights are assigned by the expert

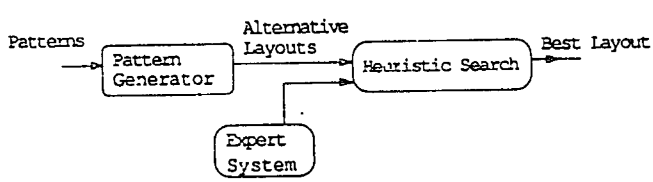


Figure 1. Structure of the problem-solving technique.

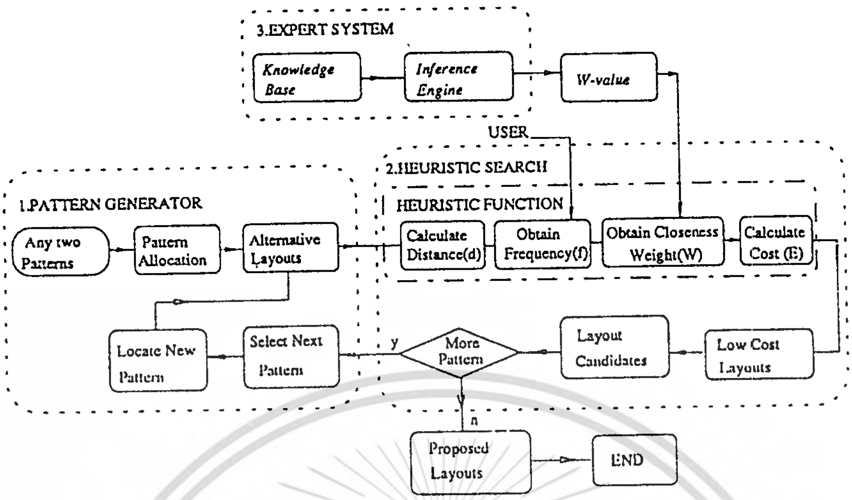


Figure 2. Flow diagram of the proposed process.

system. In assigning the closeness weight, the functional characteristic, the interrelationship between the facilities, the material flow condition and the practical limitations of the facility layout are taken into account by the knowledge base of the expert system. Using the distance, frequency of travelling and closeness weight, the costs of the layout are calculated. Using these layout costs, the heuristic search selects a set of low-cost layouts as layout candidates. The system then searches for the next pattern to be located. If there is no further patterns, then the system uses the layout candidates as the proposed layouts. If further patterns exist, the system selects the next pattern to be located on the basis of its *W* value and locates it around the selected layout. Alternative layouts are generated again and costed. The system repeats the above process until there are no further patterns to be located. The details of each process are discussed below.

3. Pattern generator

The proposed pattern generator is adapted from the heuristic approach to two-diensional stock cutting problems proposed by Dagli and Tatoglu (1987). The process starts with a pair of facility areas, namely A and B. Pattern B is put onto a side of patttern A so that the sides of A and B adjoin. This combined area, A and B, is proposed as a first alternative. Next, pattern B is rotated around itself and placed so that its perpendicular side adjoins the same side of A and this combined area is also proposed as an alternative. Pattern B is then moved to the next corner of A and rotated around itself. Pattern B is then moved to the perpendicular side of pattern A after all sides of B are adjoined onto all corners of a side of pattern A. In generating the alternatives, the overlapping of the combined area is checked. If the patterns overlap, the alternative is rejected. The method repeats the above procedures until all possible combinations of patterns A and B have been considered and all facility areas are located. Figure 3 shows the layout alternatives of two patterns generated from the pattern generator.

For the allocation of more than two facility areas, the process is similar but some additional steps are included. Assume that C is the next pattern to be inserted onto the generated alternatives, AB. With the same algorithm, the system locates C onto A and B respectively. All generated non-overlapped patterns are selected as the alternatives.

Given the large number of alternatives, searching for the best layout by a complete analysis of all generated alternatives would be exhaustive. Therefore a heuristic search is designed for solving this problem.

4. Heuristic search

By using a tree search technique, the heuristic search starts when the pattern generator selects a facility pair having the highest W value and and generates the layout alternatives. With the heuristic function, alternatives having the lowest costs are selected as candidate layouts. The next unallocated facility area is then inserted to match with this candidate by the pattern generator. The system repeats the above processes until all facility areas are located. The final layout is the layout with lowest cost selected by the heuristic function after all facility areas have been located.

4.1. *Heuristic function*

In searching for the best layout, the heuristic function calculates the costs in consideration of all practical aspects by acquiring knowledge from the knowledge base system. The system uses the potential energy model as a heuristic function.

Hsu and Kubitz (1989) defined the potential energy between two patterns as follows: when the two patterns overlap, an energy producing a force tends to separate them. The more they overlap, the larger the force is. On the other hand, when the two patterns are separated, an energy producing a force tends to pull the two patterns closer. Without overlap or separation, the patterns are said to be in equilibrium condition.

To formulate the potential energy model, the proposed formula below is adapted from the attractive force model proposed by Tam and Li (1991). This model ignores the geometric characteristics by assuming that each block is a circle. Since the layout is the non-overlapping constraint, therefore the formulation is defined as

$$E_{ij} = \tfrac{1}{2} W_{ij} d_{ij}^2 \tag{3}$$

and

$$\sum_i \sum_j E_{ij} = E = \tfrac{1}{2} \sum_{i=1}^{n} \sum_{j=i+1}^{n} W_{ij} d_{ij}^2, \tag{4}$$

where W_{ij} is the closeness weight between facilities i and j, E_{ij} is the energy exerted by an external force in moving the facility from equilibrium position to d_{ij} while obeying Hooke's law and d_{ij} is the length from the centre of facility i to the centre of facility j which is equal to $d_{ij} = [(x_i - x_j)^2 + (y_i - y_j)^2]^{1/2}$, where (x_i, y_j) is the coordinate of the centre point of facility i.

If f is the travelling frequency between facilities i and j, then equations (3) and (4) are changed to

$$E_{ij} = \tfrac{1}{2} W_{ij} (f d_{ij})^2 \tag{5}$$

and

$$E = \tfrac{1}{2} \sum_{i=1}^{n} \sum_{j=i+1}^{n} W_{ij} (f d_{ij})^2. \tag{6}$$

For each E of any pattern i or j, there are many possible locations for the pattern. If a and b ($a = 1, 2, 3, \ldots, p$ and $b = 1, 2, 3, \ldots, q$) are the side numbers of the activity pairs to

Observing the ordering of next pattern to be inserted, if $P_1, P_2, P_3, \ldots, P_n$ are the patterns being located, then the pairs of pattern generation are considered as follows:

$$(P_1P_2), ((P_1P_3)(P_2P_3)), \ldots ((P_1P_n)(P_2P_n) \ldots (P_{n-1}P_n))$$

The pseudo-code of the above procedure is provided in Appendix 1.

Obviously, the number of generated alternatives from the above algorithm is exponentially increased when the number of facility areas is increased. Let $a_1, a_2, a_3, \ldots a_n$ be the number of sides of pattern $A_1, A_2, A_3, \ldots, A_n$. The maximum number of generated alternatives of pattern A_1 and A_2 is $2a_1a_2$. If only one side of two patterns is reduced by the adjoined sides, then the alternatives for three patterns are $2^2a_1a_2a_3(a_1+a_2-1)$. With the same assumption, the maximum numbers of generated alternatives for n patterns is

$$2a_1a_2 \qquad \text{for } n=2 \qquad (1)$$

$$2^{n-1}a_1a_2a_3\ldots a_n(a_1+a_2-1)(a_1+a_2+a_3-2)\ldots(a_1+a_2+\ldots a_{n-1}-(n-2)) \qquad \text{for } n>2 \qquad (2)$$

The number of generated alternatives for quadrilateral patterns obtained from equations (1) and (2) is shown in Table 1.

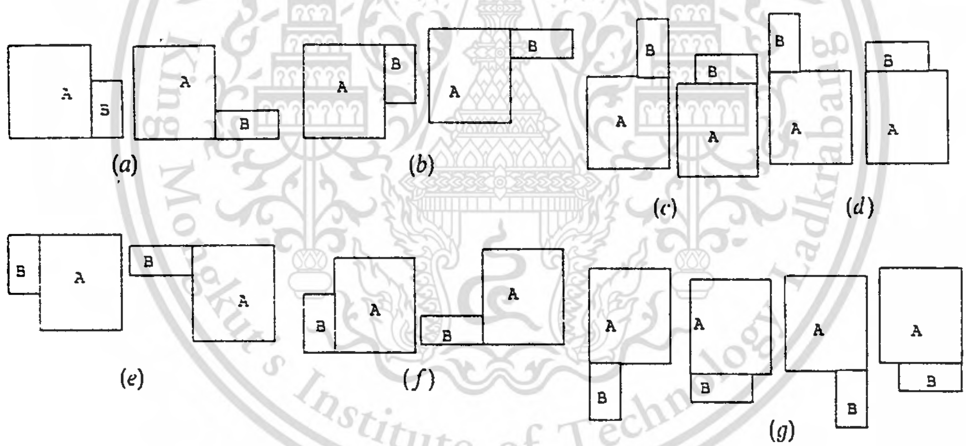


Figure 3. Some generated alternatives of two patterns: (*a*) place B on a corner of A and rotate around itself; (*b*) move B to the next corner of A and rotate around itself; (*c*) move B to the other side of A and rotate; (*d*) move B to the next corner of the same side; (*e*) move B to the next side of A; (*f*) move B to the next corner of the same side; (*g*) move B to the last side of A and rotate.

Number of facilities	Generated alternative layouts
2	32
3	1792
4	143 360
5	14 909 440
6	1 908 408 320

Table 1. Number of generated alternatives for quadrilateral patterns.

be located, as mentioned in the pattern generator, then the distance between facilities i and j can be defined according to the rotation of facilities as

$$d_{ij}=(d_{ij})_{ab}, \tag{7}$$

where $(d_{ij})_{ab}$ is the distance between patterns i and j whose side numbers a and b are adjoined.

By substituting equation (7) into equation (6), we obtain

$$E_{ab}=\tfrac{1}{2}\sum_{i=1}^{n}\sum_{j=i+1}^{n} W_{ij}(f(d_{ij})_{ab})^2.$$

Off all the values of E_{ab}, we need to select the minimum value:

$$\min E_{ab}=\tfrac{1}{2}\sum_{i=1}^{n}\sum_{j=i+1}^{n} W_{ij}(f(d_{ij})_{ab})^2. \tag{8}$$

From equation (8), the minimum value of E can be selected to evaluate the most cost-effective layout. Equation (8) is used as a heuristic function in calculating the cost of layout. This value will be used as a criterion in selection of the most appropriate search path.

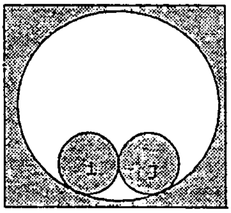
An alternative formulation is also presented by Ying and Wong (1989).

4.2. *Closeness weight*

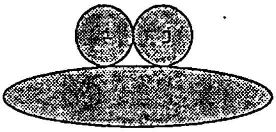
The potential energy as described in Analytical Mechanics (Fowles 1977) is the energy of a system at an equilibrium configuration (Fig. 4). It is defined as a configuration for which all the generalized forces vanish. If the system is given a small displacement, however, it may or may not return to equilibrium. If a system always tends to return to equilibrium, given a sufficiently small displacement, the equilibrium is *stable*; otherwise, the equilibrium is *unstable*. The stability of a system depends directly on the sign of *stiffness coefficient*. If the equilibrium is *stable*, the coefficient sign is positive but, if the equilibrium is *unstable*, the coefficient sign is negative.

The closeness weight W_{ij}, in equation (8) is also defined the same way as the stiffness coefficient of the potential energy. If W_{ij} is positive, then pattern i and pattern j tend to move closer together but, if W_{ij} is negative, then pattern i and pattern j tend to move apart.

Since the closeness weight represents relative measures of a system, it can be any number. The values from -10 to 10 are simply convenient. A negative value represents a W_{ij} in which pattern i and pattern j tend to separate. A 0 represents a W_{ij} in which pattern i and pattern j have no connection and a positive value represents a W_{ij} in which pattern i and pattern j tend to move closer.



(*a*)



(*b*)

Figure 4. The stability configuration of patterns i and j at an equilibrium position: (*a*) patterns i and j tend to move closer; (*b*) patterns i and j tend to move apart.

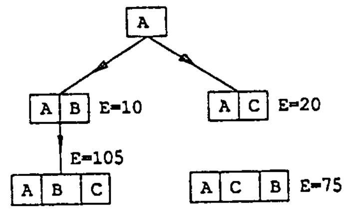


Figure 5. Selecting the wrong path.

4.3. *Improvement in heuristic search*

Any heuristic search, by its nature, can lead to errors. They do not guarantee the best solution; they only increase the likelihood of finding a usable solution. During a search, it is possible that the process selects the wrong path. In some cases, a path may show a better E value (low value) in the early stages but it may have a worse E value (high value) in the later stages. If the wrong path is selected at an early stage, the optimal solution would not be met. For example, let A, B and C be the quadrilateral patterns with all sides $=1$ and $W_{ab}=20$, $W_{ac}=40$, and $W_{bc}=30$. If we select A as an initial node then the generated alternatives are AB and AC. From equation (8), the value of E for AB is $10(1)^2$, and E for AC is $20(1)^2$. From the E value, we select AB as the next parent. We then generate ABC and calculate the E value. The E value for ABC is 105 or $10+20(2)^2+15$. However, if we consider ACB, the E value is 75 or $20+10(2)^2+15$. This means that the generated alternative, namely AB, selected in the upper level is wrong since the E value of ACB is better than that of ABC. Figure 5 illustrates this problem.

To reduce errors that may occur in the above situation, selection of the most suitable pattern before generating the alternatives has to be undertaken. The strategies suggested by Wimer and Koren (1988) are used to modify the heuristic search. Three steps have been added to the algorithm of the selection of the next pattern to be inserted.

First, of all the unallocated patterns, the system selects the one for which the sum of its W value between this pattern and each of the located patterns is maximum.

Second, if the W values of the first step are all equal, then the system selects the one that has the largest area.

Third, a set of candidate layouts at each level is selected instead of selecting the best layout. The number of candidates in the selected set at each level is an adjustable number. From the experiment, it is shown that, if a larger number of alternatives is selected, the better the final solution produced. On the other hand, a larger number of candidates takes a longer processing time. The number of generated layouts is defined as

$$2sa_n\left(\sum_{i=1}^{n-1} a_i-(n-2)\right) \qquad \text{for } n>2$$

where $s=$ the number of candidates in a set, $n=$ the number of layouts to be located and $a_1, a_2, a_3, \ldots, a_n=$ number of sides of the patterns.

The algorithm of the modified heuristic is shown in Appendix 2.

5. Expert system

The expert system is designed to assign the closeness weight W. The rule syntax is shown in Fig. 6.

From Fig. 6, LABEL is the rule label. In the rule, 'if', 'then', 'weight', ':', '=' and '.' are the reserved words but LABEL, CONDITION and VALUE are not. LABEL and

LABEL: if CONDITION then weight = VALUE

Figure 6. Rule syntax of the expert system.

CONDITION can be any string while VALUE can be any number from -10 to 10.

The rule interpretation is that 'if the condition is satisfied, the two patterns have to move closer with the given weight'. According to the MYCIN certainty function (Neopolitan 1990, Rich and Knight 1991), if 'the two patterns have to move closer' is the hypothesis h and 'the condition' is the evidence e, a certainty factor $CF[h,e]$ of hypothesis h given the evidence e is equal to VALUE (between -10 and 10). Since the VALUEs of the rules are provided by the expert who writes the rules, they reflect the experts' assessments of the strength of the evidence in support of the hypothesis.

In many applications, the closeness weight of a pair of facilities may be influenced by more than one condition. The VALUE needs to be combined to reflect the operation of multiple evidences (or conditions). Therefore the certainty factor $CF(h, e_1$ and $e_2)$ of a hypothesis given two pieces of evidence, can be computed from

$$W_{\text{total}} = W_1 + W_2 - \frac{W_1 W_2}{10} \quad \text{if } W_1 \text{ and } W_2 \geqslant 0 \tag{9}$$

$$W_{\text{total}} = W_1 + W_2 + \frac{W_1 W_2}{10} \quad \text{if } W_1 \text{ and } W_2 \leqslant 0 \tag{10}$$

$$W_{\text{total}} = \frac{10(W_1 + W_2)}{10 - \min(|W_1|, |W_2|)} \quad \text{if } W_1 < 0 < W_2 \tag{11}$$

$$W_{\text{total}} = 10 \quad \text{if } W_1 W_2 = -100 \tag{12}$$

where W is the VALUE. For example

(1) if the density of material is very high then weight $=5$ and
(2) if the size of material is very long then weight $=8$.

Using the above rules, the two factors are considered. Therefore only two rules are put into the knowledge base instead of three rules. For the rule of combined conditions (the density of material is very heavy and the size of material is very long), Mycin's belief function will take this into account. In certain cases of the above rules, the weight is 9 (using equation 9). This is reasonable since the weight does not exceed 10.

Considering the number of rules, if the rules have to handle all the combinations of the conditions, then the knowledge base would be very massive. For example, if four conditions are considered, then 15 possible combinations of conditions occur. This means that 15 rules have to be put into the knowledge base to cover only four factors. The number of rules which occurs according to the number n of factors is

$$\sum_{r=1}^{n} {}^{n}C_{r}$$

The number of rules, in this manner, exponentially increases while the number of factors linearly increases. Therefore the use of the MYCIN certainty factor function has the added advantage of reducing the number of rules.

The other alternative method of combining conditions is the 'Mag Count' function proposed by Muther (1973). The Mag Count establishes a base value for the size of an item and then reduces or increases this base value by means of modifying values for the other influencing factors.

5.1. *Inference engine*

The inference engine of the system is forward chaining. The engine starts by going to the topmost rule and checking its condition. If the condition is satisfied with the existing fact, then the *W* value is calculated and kept in the working memory; otherwise the inference engine goes on to the next rule. The step is repeated until all rules have been determined. After the rule inference process stops, the weight is calculated. There are two strategies whereby the system manages the closeness weights.

(1) *W* is concluded by only one rule. The concluded value is used as the closeness weight of the system.
(2) *W* may be concluded by more than one rule. Mycin's belief functions, equations (9)–(12), are used to calculate the *W* value under a combination of conditions.

In short, the steps of the rule inference can be concluded to be as follows.

Step 1. Go to the topmost rule.
Step 2. Check a condition of the rule.
Step 3. If the value of the condition is concluded, then go to step 5; else to the next step.
Step 4. Display question text.
Step 5. If the condition is satisfied with the existing fact, then go to step 8; else go to next step.
Step 6. Put the concluded *W* value into the working memory.
Step 7. If the rule still exists, then go to the next rule and go to step 2; else go to next step.
Step 8. Calculate the total value of *W* using equations (9)–(12).

See also Appendix 3 for procedure inference.

5.2. *Knowledge base*

The knowledge in the knowledge base forms the rules for assigning the closeness weight by considering the interrelationship condition between facility areas. In considering the value of the closeness weight, the condition can be classified as follows.

(1) The condition causes the facility areas to be located apart. In this case, the *W* value is assigned a negative value.
(2) The condition causes the facility areas to be located close together. In this case, the *W* value is assigned a positive value.

In some special cases, the positive and negative values may be differently defined. For instance, the welding department must theoretically be put close to the chemical cleaning department to clean out all fluxes and dirt after the welding process. Unfortunately, this is not possible because a spark from the arc welding may cause a fire with the chemical cleaning solution. In such a case involving practical limitations, a negative value is assigned.

The prototype knowledge is adapted from the 'modifying factors and add-on values' table developed by Muther (1973). Five factors of material conditions have been considered for the weight assignment:

(1) risk of hazard to facilities, and employees;
(2) density of bulkiness of the item;
(3) shape of the item;
(4) risk of damage to material;
(5) condition of the item.

Except for the risk of hazard factor, the rest of the factors have many degrees of closeness weight. Details of each factor are as follows:

(1) risk of hazard:
  (*a*) weight value is assigned to be negative;
(2) density of bulkiness:
  (*a*) very light and empty;
  (*b*) light and bulky;
  (*c*) reasonably solid;
  (*d*) fairly heavy and dense;
  (e) heavy and dense;
  (*f*) very heavy and dense;
(3) shape:
  (*a*) very flat and stackable;
  (*b*) readily stackable or nestable;
  (*c*) fairly stackable or slightly nestable;
  (*d*) basically square with some stacking quality;
  (*e*) long, rounded, or somewhat irregular;
  (*f*) very long, spherical or irregular;
  (*g*) extra long, curved or particularly irregular;
(4) risk of damage:
  (*a*) not susceptible to damage at all;
  (*b*) susceptible to negligible or almost no damage;
  (*c*) slightly susceptible to some damage;
  (*d*) susceptible to damage by crushing, breaking and scratching;
  (*e*) very susceptible to some damage;
  (*f*) highly susceptible to some damage;
  (*g*) highly fragile.
(5) condition:
  (*a*) clear, firm and stable;
  (*b*) oily, flimsy and unstable or awkward to handle;
  (*c*) covered with grease, not and very flimsy or slippery.

The details of the above knowledge base are shown in Appendix 4.

6. Implementation

The system has been developed into a computer package. It is implemented in TURBO PASCAL and operates on an IBM or compatible computer with 640 K byte memory on board under DOS. A graphics card and VGA colour monitor are required. The output of the system is displayed on screen and the coordinates of the layout are kept in ASCII text file. The program has approx. 5208 lines and its executable file is about 108 K byte. To interface with the ASCII knowledge base file, the rule compiler is also developed. By using this compiler, the rule syntax is checked before the program is executed. The rules in the knowledge base can be written on any kind of word processor providing ASCII file. The system can handle up to 1000 rules.

Prior to running the system, a design expert or a knowledge programmer has to include his or her knowledge into the knowledge base. When running the program, the rules inference unit infers the knowledge by using the information acquired from the users. The value of W will be concluded and the E value is calculated. With this E value, the heuristic search searches for the solution in problem space.

The steps of the system operation are as follows:

(1) Input:
  (*a*) number of facilities;
  (*b*) dimension of all facilities;
  (*c*) number of candidates;
  (*d*) boundary of the area being located;

(2) Consultation:
  (*a*) system asks questions;
  (*b*) user inputs information about the facility properties;
  (*c*) system assigns the W value;

(3) Processing:
  (*a*) system generates alternative layout;
  (*b*) heuristic search searches for the best layout;

(4) Output:
  (*a*) screen display;
  (*b*) report file.

The system starts by acquiring information concerning the facility areas' dimensions, total area and number n of daughter nodes. The expert system then questions the user about the facility areas' properties. By using the facility areas' dimensions and properties, the system calculates the E value and searches for the best layout.

For knowledge development, the facility layout expert can create his or her own knowledge by using a word processor. The system will automatically load this knowledge file and use it as domain knowledge.

System performance has been evaluated and tested many times. The given recommended layouts are as expected. The results also show potential applications to solve complex facility layout problems. As an example, a test run was made using the following data.

6.1. *Problem*

A small industrial plant has four facility areas. The details of the facilities are:

(1) metal-forming area,
(2) welding area,
(3) chemical cleaning area and
(4) storage area.

From the hypothetical data, the travelling frequency relationships and dimensions of the four facility areas are given in Table 2.

The functional characteristics of the welding and chemical cleaning areas are hazardous. The materials flowing between metal-forming, welding, storage and chemical cleaning areas are heavy and not susceptible to any damage. The materials flowing between welding and chemical cleaning areas are very susceptible to damage.

6.2. *Operation*

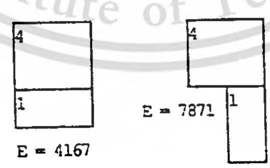
By consulting the expert system, the values of closeness weight are given as follows: $W_{12}=5{\cdot}1$, $W_{13}=8{\cdot}97$, $W_{14}=9{\cdot}26$, $W_{23}=-2{\cdot}86$, $W_{24}=3$ and $W_{34}=8{\cdot}53$. The maximum value of W is W_{14}. The selected layouts generated from patterns 1 and 4 are shown in Fig. 7.

From the generated alternatives, the patterns shown in Fig. 7 are selected as a set of candidates. The system then selects the next pattern to insert by considering W values as follows. The total W of pattern 2 is $W_{21}+W_{24}=5{\cdot}1+3=8{\cdot}1$. The total W of pattern 3 is $W_{31}+W_{34}=8{\cdot}97+8{\cdot}53=17{\cdot}5$. The total W of pattern 3 is greater than the total W of pattern 2. Therefore pattern 3 is selected to be the next pattern to insert. Pattern 3 is located around patterns 1 and 4 and the non-overlap layouts are selected as the alternatives. By using the heuristic function, a set of candidates is selected. Figure 8 shows five selected candidates and their E values.

Using the selected alternatives in level 3 (Fig. 8), the last pattern, pattern 2, is inserted and rotated around these alternatives. A set of candidates is selected as shown in Fig. 9.

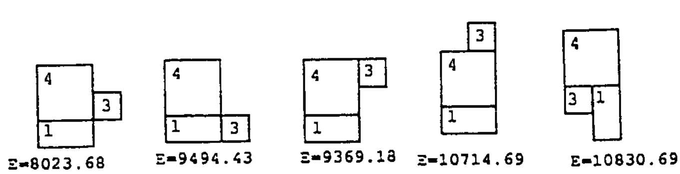
Facility area	Travelling frequency relationships				Facility area dimensions
	Forming	Welding	Cleaning	Storage	
(1) Forming	—	20	10	20	2 × 1
(2) Welding	—	—	20	18	2 × 1
(3) Cleaning	—	—	—	15	1 × 1
(4) Storage	—	—	—	—	2 × 2

Table 2. Travelling frequency relationships and dimensions of the four facility areas.



(*a*) (*b*)

Figure 7. Selected alternatives for the first level.



(*a*) (*b*) (*c*) (*d*) (*e*)

Figure 8. The selected alternatives for the second level.

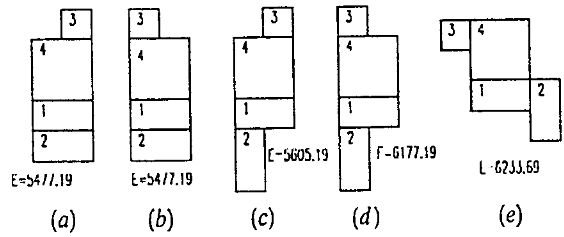


Figure 9. Layout generated by the heuristic.

The user is requested to input the number of alternatives required by including the *n* value. From Fig. 9, the five layouts are given as the output of the system. These layouts are shown on the monitor in graphical representation. On the monitor screen, only one layout is shown one at a time and, when the user presses the tab on the keyboard, the next layout will appear. The user can also save all the layout coordinates in the report file.

7. Concluding remarks

The proposed system integrates a heuristic approach to layouts with a heuristic search using an AI technique to solve the problem. For the heuristic search, the potential energy model is used as a heuristic function. The expert system and certainty factor functions are also used to support the heuristic function in providing the numerical evaluation of facility layout characteristics.

The proposed system is of the construction type. It can handle the problems of general facilities layout with the activity interrelationships and practical limitations of facility, problems in two dimensions, problems involving all kinds of patterns having linear sides and problems with no pre-locations and no orientation restrictions.

The system presented in this paper proposed the method of solving the practical layout limitation problems by allowing the closeness weight to be both positive and negative. Output generated by the system shows that facilities having a positive weight tend to locate at the centre of the layout, whereas facilities having a negative weight tend to locate outside the layout. Two extreme cases are considered here. First, Fig. 10 shows the layout of facilities having all negative W values and Fig. 11 shows the layout of facilities having all positive W values.

By using the proposed technique, not only the closeness weight has been flexibly considered but also the large problem space has been dealt with. The system constructs almost all possible layout alternatives. In selecting the best layout, the designed system uses the advantage of the heuristic function (in the heuristic search) to reduce the size of problem space. This makes it possible to search for the best layout from a large problem space at a reasonable speed. Table 3 shows the run time speed of the program tested on a 120 MHz personal computer (in the last column). The third column in Table 3 shows the number of the improved problem size and the fourth column shows the problem space. It is obvious that the number of alternatives is significantly reduced.

The other advantage of the methods presented is that the system employs the Mycin belief function to reduce the size of the knowledge base. Instead of constructing all rules for combinations of conditions, the system uses the Mycin belief function to calculate the W value for those rules having the combination conditions. Therefore the knowledge engineer constructs one condition for each rule, thus reducing the numbers of rules and therefore the work load.

Number of patterns	Number of candidates in a set	Problem size (candidates)	Problem space (alternatives)	Processing time (min)
5	5	520	$1{\cdot}490 \times 10^7$	00:00·20
5	10	1040		00:00·33
10	5	1120	$2{\cdot}287 \times 10^{18}$	00:01·60
10	10	2240		00:02·70
30	5	3520	$3{\cdot}031 \times 10^{62}$	01:10·64
30	10	7040		02:22·48

Table 3. The approximate processing time and the problem size of the system.

Future research could concentrate on the further development of knowledge to improve the layout solution. In any practical layout, many factors can have an impact on the W value. Therefore providing more details concerning the justification of the W value assigned to a pair of facilities will create a most useful tool for solving the practical facility layout problems in both manufacturing and service industries.

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Appendix 1

The pseudo-code of the procedure described in §3 is as follows.

Program alternative generation (q:number of patterns);
No. of patterns: $q > 2$;
Pattern: $P_1, P_2, P_3, \ldots, P_q$;
Integer: x, y;

Procedure Allocation (input A,B: Pattern);
Angle: Pattern A: $A_1, A_2, A_3, \ldots, A_n$
        Pattern B: $B_1, B_2, B_3, \ldots, B_n$;
No. of sides: Pattern A: m;
        Pattern B: n;
Integer: i, j, k, l, m, n;
Call procedure: OVERLAP
Begin
  (For $i = 1$ to m;
    (For $j = 1$ to n;
    $k = i$;
    $l = j$;
      (Repeat the following steps twice;
      if $i = m$ then $i + 1 = 1$;
      if $j = n$ then $j + 1 = 1$;
      Adjoin side B_jB_{j+1} with side A_iA_{i+1} by
      adjoining the angle B_l with A_k;
      if the adjoined pattern NOT_OVERLAP with other patterns

```
        Then (Assign this adjoined pattern as an alternative;
          if l=n then l=1 else l=l+1;
          if k=m then k=1 else k=k+1;)
        else (if l=n then l=1 else l=l+1;
          if k=m then k=1 else k=k+1;))
    Next j;)
  Next i;)
End;
{Main Program}
Begin
(For x=2 to q-1;
  (For y=1 to x-1;
   Allocation(P_y, P_x);
   Next y;)
Next x;)
End.
```

Appendix 2

The algorithm of the modified heuristic is as follows.

Step 1. Let OPEN be a list of unallocated patterns and CLOSE be a list of allocated patterns.
Step 2. Select a pair of the start patterns P_i and P_j from OPEN for which W_{ij} is a maximum.
Step 3. If OPEN is empty, exit with failure.
Step 4. Remove P_i and P_j from OPEN and place on CLOSE.
Step 5. Allocation (P_i, P_j) (see Appendix 1).
Step 6. Calculate costs E_{ij} for every generated layout.
Step 7. Select the n candidate layouts for which costs E_{ij} of the layouts are lowest.
Step 8. Name the layouts in (6) as P_i. {There are n layouts of P_i and each P_i is an accumulation of the adjoined patterns P_i and P_j}.
Step 9. If OPEN is empty, P_i is the solution.
Step 10. Otherwise, select the next pattern P_j, from OPEN for which W_{ij} is a maximum.
Step 11. Remove P_j from OPEN and place on CLOSE.
Step 12. Go to step 4.

Appendix 3

The procedure inference related to § 5.1 is as follows.

```
Begin
Read GOAL;
Go to topmost rule;
(For all rules;
 Go to topmost condition;
 (For all conditions;
  (IF the condition is not concluded before;
   THEN Check the condition by asking question;
   ELSE Check the condition with the concluded value;)
```

```
(IF the condition is true;
(THEN
    (IF there is no more condition;
     THEN rule:=TRUE;
     ELSE go to next condition;)
 ELSE rule:=FAIL;))
(If rule:=TRUE;
 THEN
    (IF there is no rule and GOAL is concluded;
     THEN CALCULATE weight; (see also equations (9)-(12))
     ELSE go to next rule;)
 ELSE
    (IF there is no rule;
     THEN use DEFAULT value;
     ELSE go to next rule;)))
END.
```

Appendix 4

The following is the knowledge base used in the system. It is composed of five questions and 26 rules. The default of the knowledge is 0 and the goal is weight.

Question (Hazard):
'What is the condition apparent between, this pair of departments?',
'Hazard such as fire hazard or vibration',
'None of the above conditions.'.
Question (Density):
'What is the density or bulkiness of the item?',
'Very light and empty.',
'Light and bulky.',
'Reasonably solid.',
'Fairly heavy and dense.',
'Heavy and dense.',
'Very heavy and dense.',
Question (Shape):
'How can you define the shape of material flowing between departments?',
'Very flat and stackable.',
'Readily stackable or nestable.',
'Fairly stackable or slightly nestable.',
'Basically square with some stacking quality.',
'Long, rounded or somewhat irregular.',
'Very long, spherical or irregular.',
'Extra long, curved or particularly irregular.',
Question (Damage):
'How do you define the risk of damage to material?',
'Not susceptible to damage at all.',
'Susceptible to negligible or almost no damage.',
'Slightly susceptible to some damage.',
'Susceptible to damage by crushing, breaking and scratching.',
'Very susceptible to some damage.',

'Highly susceptible to some damage.',
'Highly fragile.'.
Question (Condition):
'What is the condition of the item?',
'Clear, firm and stable.',
'Oily, flimsy and unstable or awkward to handle.',
'Covered with grease, hot and very flimsy or slippery.'.
Goal:weight
DEFAULT:'0'.
1:IF Hazard ='Hazard such as fire hazard or vibration'
THEN weight='−10'.
2:IF Density ='Very light and empty.'
THEN weight ='−5'.
3:IF Density ='Light and bulky.'
THEN weight ='−3'.
4:IF Density ='Reasonably solid.'
THEN weight ='0'.
5:IF Density ='Fairly heavy end dense.'
THEN weight ='3'.
6:IF Density ='Heavy and dense.'
THEN weight ='5'.
7:IF Density ='Very heavy and dense.'
THEN weight ='7'.
8:IF Shape ='Very flat and stackable.'
THEN weight ='−7'.
9:IF Shape ='Readily stackable or nestable.'
THEN weight ='−5'.
10:IF Shape ='Fairly stackable or slightly nestable.'
THEN weight ='−3'.
11:IF Shape ='Basically square with some stacking quality.'
THEN weight ='0'.
12:IF Shape ='Long, rounded or somewhat irregular.'
THEN weight ='3'.
13:IF Shape ='Very long, spherical or irregular.'
THEN weight ='5'.
14:IF Shape ='Extra long, curved or particularly irregular.'
THEN weight ='7'.
16:IF Damage ='Not susceptible to damage at all.'
THEN weight ='−5'.
17:IF Damage ='Susceptible to negligible or almost no damage.'
THEN weight ='−3'.
18:IF Damage ='Slightly susceptible to some damage.'
THEN weight ='0'.
19:IF Damage ='Susceptible to damage by crushing, breaking and scratching.'
THEN weight ='3'.
20:IF Damage ='Very susceptible to some damage.'
THEN weight ='5'.
21:IF Damage ='Highly susceptible to some damage.'
THEN weight ='7'.

22:IF Damage ='Highly fragile.'
THEN weight ='9'.
23:IF Condition ='Clear, firm and stable.'
THEN weight ='0'.
25:IF Condition ='Oily, flimsy and unstable or awkward to handle.'
THEN weight ='3'.
26:IF Condition ='Cover with grease, hot and very flimsy or slippery.'
THEN weight ='5'.

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AN ANALYSIS OF COMPUTER AIDED FACILITY LAYOUT TECHNIQUES

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ABSTRACT

This paper presents a new approach for classifying the facility layout techniques. The classification is based on the analysis of facility layout process as layout improvement, entire layout and partial layout model. This classification contributes two important concepts. First, it gives the idea of how the facility layout algorithm can be constructed; and second, it provides the idea of how the quality of facility layout algorithm can be improved. The previous researches of facility layout algorithms are also analyzed to support the classification concept.

1. Introduction

Computerized facility layout algorithms are characterized by one of the two distinct semantics modes; (1) they construct the layout by building up a solution from initial layout, or (2) they construct the layout by building up a solution from scratch. These semantic models are called *improvement algorithm* and *construction algorithm* respectively. In the later classification, two more models are added; hybrid and graph theory algorithm (Kusiak and Heragu 1987). The hybrid algorithm generates the layout from scratch and improves it by regeneration. The graph-theory algorithm generates the layout by employing graph-theory.

This paper presents a new method for classifying the facility layout algorithm which is done based on the analysis of facility layout process structure as *layout improvement*, *entire layout* and *partial layout* model. The presentation of the paper is divided into; analysis of computer aided facility layout techniques, facility placing order, facility allocation and alternative selection strategy. Few well-known algorithms are also presented as examples. The conclusion and comment are given in the conclusion remark section.

2. Analysis of Computer Aided Facility Layout Techniques

By analyzing the facility layout algorithm, it is found that there are three major processes; *facility placing order, facility allocation* and *alternative selection* process. The facility placing order determines the ordering of facilities to be located onto the layout area. The facility allocation process allocates facilities onto the layout area and, for some models, generates layout alternative(s). The alternative selection process selects the best layout from the generated alternative(s). However, not all algorithms consist all of these processes. Some algorithms have only two processes. From the different components of processes in constructing the layout algorithm, the facility layout can be classified as *layout improvement*, *entire layout* and *partial layout* model.

Table 1 shows the components of facility layout processes for each model.

Table 1 Analysis of facility layout model.

Layout model	Facility placing order	Facility allocation	Alternative selection
Layout improvement		O	O
Entire layout	O	O	
Partial layout	O	O	O

The *layout improvement* model uses *facility allocation process* to improve the existing layout by relocating the facilities to generate the new alternative layout. Then, the *alternative selection process* tests the newly generated alternative. If it gives the better cost, then it is selected as an improved layout and used as the initial layout for another improvement iteration. Otherwise the algorithm generates another alternative. The process is repeated until no further improvement can be made. The examples are CRAFT (Buffa, Armour and Vollmann 1964), and Moore's algorithm (Moore 1976).

The *entire layout* model selects and places a seed facility onto the given layout area. Then, another facility is selected by *facility placing order process*, one at a time, and placed by *facility allocation*. The processes are repeated until all facilities are located. The examples are the algorithms proposed by (Fortenberry and Cox 1985 Hassan and Hogg 1991).

In the *partial layout* model, the *facility placing order* selects a to-be-located facility and locates it to all possible locations, by *facility allocation*, to generate partial layout alternatives. Then, *alternative selection* selects the best partial layout alternative and adds another facility onto it by repeating the same processes until all facilities are located. The examples are CORELAP (Lee and Moore 1967) and Sirinaovakul and Thajchayapong's algorithm (Sirinaovakul and Thajchayapong 1994).

3. Facility Placing Order Strategy

The strategy is applied for *entire layout* and *partial layout* model. It considers the basis for the order in which the facilities enter the layout. The purpose of this strategy is to limit the problem space of the layout algorithm which means that the strategy reduces the search for a good layout effort. The followings are some possible strategies:

- Among all unallocated facilities, the next facility to-be-placed is selected at random. ALDEP (Seehof and Evans 1967) use this strategy.

- Among all unallocated facilities, the facility that has the highest weight relationship with the located facilities is selected. The examples are CRAFT and CORELAP.

- Among all unallocated facilities, the facility that has the highest weight relationship with the located facilities is selected. If there is no highest relationship weight occurred, the facility with highest area is selected. Sirinaovakul and Thajchayapong's algorithm employ this strategy.

4. Facility Allocation Strategy

According to the facility layout model, there are three strategies for allocating facilities onto the layout area. The facility allocations for layout improvement, entire layout and partial layout model are layout alternative generation, pattern allocation and partial layout alternative generation respectively. The details are as follows:

4.1 Layout Alternative Generation

The layout alternative generation is done by interchanging the facility location of the initial layout. Normally, the methods are designed for layout improvement model. CRAFT is the first model to present the way of generating the layout alternative. It divides the initial layout into an array of matrix. There are three required conditions for exchange; the facilities with common borders, the facilities with same area and the fixed out line of layout area. An exchange involving the greatest cost reduction is made and is used as a new layout. Figure 1 shows the pattern allocation of CRAFT algorithm.

```
(a)                    (b)                    (c)
A A B B C C C C C C    C C B B A A A A A A    A A B B D D D D D D
A A B B C C C C C C    C C B B A A A A A A    A A B B D D D D D D
A A B B C C C C C C    C C B B A A A A A A    A A B B D D D D D D
A A A A D D D D D D    C C C C D D D D D D    A A A A C C C C C C
A A A A D D D D D D    C C C C D D D D D D    A A A A C C C C C C
A A A A D D D D D D    C C C C D D D D D D    A A A A C C C C C C
```

Figure 1 (a) initial layout (b) facilities A and C exchange by the same area condition and (c) C and D exchange by the common border condition.

Another technique used in layout alternative generation is graph theory layout which is also done by exchanging of facility location. Cutting Point Interchange Approach (Oten 1982) uses four operators to represent the slicing structure, "L" (left cut), "R" (right cut), "U" (up cut) and "B" (bottom cut).

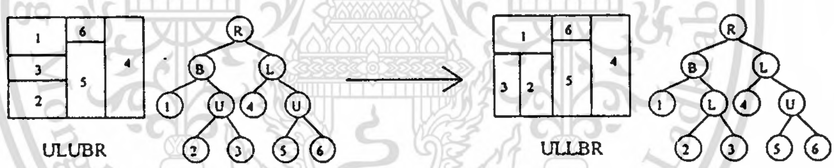


Figure 2 the slicing structure and its transformations

Figure 2 shows the slicing structure and its slicing tree and the structure transformation. The slicing structure can be represented by slicing tree in short form as 65U4L32U1BR or ULUBR. The representation of this form is similar to the way operators and operands are stated in post order arithmetic expressions. The algorithm relocates the facilities by changing the two opposite operators along each dimension (e.g. "L" and "R", "U" and "B"). The change of operator means that the facility location is relocated.

4.2 Pattern allocation

This approach generates the layout by locating a facility to the unique position which is considered from the relation between a to-be-located facility and located facilities. No alternative is generated for this approach. ALDEP places a facility onto grid array of matrix. It uses a vertical scan routine and places the facilities in the layout in a manner analogous to placement of strips of tape from left to right. The placement of this model must specify the length, width, and area requirements for each facility. Then, the unit area for each grid is calculated from the required area of all facilities. Figure 3 shows the example of facility allocation using ALDEP algorithm.

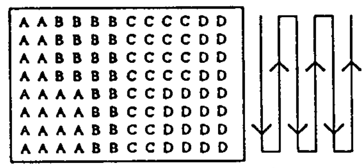
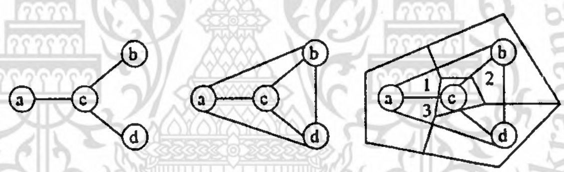


Figure 3 ALDEP facility allocation method.

Planar graph approach (Seppanen and Moore 1970) utilizes the properties of planar graph. The facility areas, in this algorithm, are considered as the vertices of the planar graph and then the layout is constructed by the dual graph created from this planar graph. The algorithm consists of three steps. First, the algorithm creates the maximal spanning tree of the facilities from the given relationship weights. Second, the high relationship weight edges are added to the maximal spanning tree to construct the maximal planar graph. Lastly, the dual graph is constructed from this maximal planar graph. This dual graph is considered to be the output of the facility design. The planar graph algorithm was later developed and called Detahedron Heuristic (Foulds and Robinson 1978 and Hassan and Hogg 1991). Figure 4 is the planar graph algorithm.



Maximal spanning tree   Planar graph   Dual graph

Figure 4 Dual graph construction

4.3 Partial layout alternative generation

This technique allocates a facility onto all possible locations. When a facility is placed, the alternatives are generated, called partial layout alternatives, by locating a to-be-located facility to all possible location. Sirinaovakul and Thajchayapong's algorithm is an example of this technique.

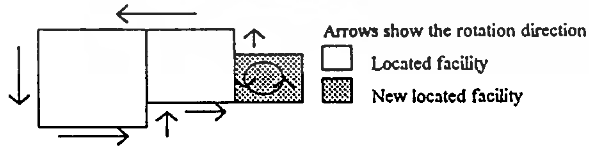


Figure 5 Sirinaovakul and Thajchayapong allocation method.

The process generates the partial layout alternative by locating a to-be-located facility onto a side of located facilities. This combined area is proposed as a first alternative. Next, a to-be-located facility is rotated around itself and placed so that its perpendicular side adjoins the same side of located facility and this combined area is also proposed as an alternative. Then, a to-be-located facility moves to another side of located facilities. The method repeats the above procedures until all possible combinations (or alternatives) of these facilities have been considered. Figure 5 shows the facility allocation method.

5. Alternative Selection

Normally, the alternative selection process is the heuristic search which is composed of heuristic search and objective function. The heuristic search searches for a good alternative and the objective function guides the search direction.

5.1 Heuristic Search

Three most popular heuristic searches are presented in this section.; hill climbing, beam search and simulated annealing.

Hill climbing method generates a set of alternatives and evaluates these alternative choices by using objective function. An alternative that appears to be the better solution is then chosen. No further reference to parent of other alternatives is retained. This process continues from node-to-node with previously expanded nodes being discarded. An example algorithm that uses hill climbing as a search process is CRAFT.

Beam search generates all possible alternatives for each level and the alternatives are evaluated by objective function. The n most promising alternatives are selected for further expansion. When n, called beam width, is an adjustable number. This process continues from level-to-level until no further alternatives can be generated. The examples of algorithm using beam search are AILAY (Shih, Enkawa and Itoh 1992) and Sirinaovakul and Thajchayapong algorithm.

Simulated annealing is a variation of hill climbing in which, at the beginning of the process, some downhill moves may be made. The idea is to do enough exploration of the whole space. Its computational process is patterned after the physical process of annealing. There is a probability that a transition to the higher energy state will occur. This probability is given by Eq. (1);

$$p = e^{-\Delta E/kT} \tag{1}$$

Where, ΔE is the positive change in the energy level, T is the temperature and k is Boltzmann's constant. In the algorithm, the moves that worsen the current solution by an amount, E, are accepted with probability p. T is a control parameter analogous to temperature in the annealing of physical systems. The examples of facility layout algorithm using simulated annealing are CLASS (Jajodia, Minis, Harhalakis and Proth 1992) and Tam algorithm (Tam 1992).

5.2 Objective Function

On searching for the best alternative, along the way the objective function calculates the costs in consideration of all alternatives. The following topics are some popular objective functions.

Total cost is defined as:

$$TR = \sum_{i=1}^{n} \sum_{j=1}^{n} f_{ij} d_{ij} \quad (2)$$

Where n is the number of facilities, f_{ij} is the flow data between facilities i and j and d_{ij} is the distance between facilities i and j. The flow data are expressed in terms of the number of trips per time period. Therefore, TC, total cost, reflects the total material-handling cost required to move one unit of distance between combination of departments. The examples of algorithm using total cost are CRAFT and CLASS.

Total closeness rating uses closeness relationships for considering a pair of facilities for every combination. The vowel-letters are enumerated as fixed numerical values. Then the total cost is calculated by:

$$TCR = \sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij} \quad (3)$$

Where c_{ij} is the numerical value of the relationship weight rating between facilities i and j and n is the number of facilities. The examples of algorithm using total cost are ALDEP and CORELAP.

Multiple criteria defined by Fortenberry and Cox is

$$\text{nin } Z = \sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{k=1}^{n} \sum_{l=1}^{n} a_{ijkl}\, b_{ijkl}\, X_{ij}\, X_{kl} \quad (4)$$

subject to

$$\sum_{i=1}^{n} X_{ij} = 1,\ j = 1, 2, .. n \quad \text{and} \quad \sum_{j=1}^{n} X_{ij} = 1,\ i = 1, 2, ...n \quad (5)$$

X_{ij} equals to 1 if facility i is assigned to location j or equals to 0 otherwise. The value of $a_{ijkl} = f_{ik}\, d_{jl}$. Where d_{jl} is a distance from location j to location l, f_{ik} is work flow from facility i to facility k, and b_{ijkl} (or r_{ik}) is vowel-value closeness weight of facility i and k.

There are two more alternative formulations. First, the formulation presented by (Rosenblatt 1979) is

$$\text{nin } Z = \sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{k=1}^{n} \sum_{l=1}^{n} (a_2 a_{ijkl} - a_1 w_{ijkl}) X_{ij} X_{kl} \quad (7)$$

Where a_1, a_2 and w are weight assigned to total material handling cost, total rating score and relationship cost respectively. The other formulation was proposed by (Dutta and Sahu 1982) is

$$\text{nim } C' = W_2 C - W_1 R \quad (8)$$

Where W_1,W_2, C and R are weights assigned to closeness rating score, material handling cost, material handling objective function and closeness rating objective function.

Potential energy is defined as a potential field of two blocks that produces a force tending to separate them, when two blocks overlap. On the other hand, this force is tending to pull the two blocks closer when two connected blocks are separated. Without separation or overlap, blocks are said to be in equilibrium condition (Sirinaovakul and Thajchayapong 1994)

$$E_{ij} = {}^{1}/_{2}*(w_{ij}*(d_{ij})^2) \qquad (9)$$

Where w_{ij} is the closeness weight between facilities i and j, E_{ij} is the energy done by an external force in moving the facility from equilibrium position to d_{ij} which is obeying Hooke's law and d_{ij} is the length from the center of facility i to the center of facility j.

The alternative model of this approach is attractive force (Tam & Li 1991). The formulation is:

$$f_{ij} = {}^{1}/_{2}*(w_{ij}*(d_{ij})^2) + \alpha \min\{0, d_{ij} - r_i - r_j\} \qquad (10)$$

Where w_{ij}, d_{ij}, r_j, r_j and α are closeness weight, distance, radius of i, radius of j and coefficient of overlapping degree respectively.

6. Concluding Remarks

This paper has presented a new approach for analyzing the facility layout algorithms. Three major processes, facility placing order, facility allocation and alternative selection, are described. Based on these processes, the layout algorithms are classified as layout improvement, entire layout generation and partial layout generation algorithm. The results from this classification makes the researchers understand the facility layout programs structure and know the way to improve them. The comments for further research will be made on three points as follows:

1. The quality of the final layout can be measured by the number of generated alternatives in the algorithm. The more alternatives are generated, the better final layout can be carried out. On the other word, the higher number of alternatives provides the higher possibilities to result the better solution.

2. Efficiency of layout algorithms for each classification can be considered as;

The efficiency of layout improvement model depends on the number of iterations since the model generates only one alternative for each iteration. Therefore, more alternatives can be created by generating more iterations.

The final layout of entire layout model can be improved by changing the seed facility and the related parameters and then regenerating the final layout. This final layout can also be improved by using layout improvement algorithm.

The efficiency of the partial layout model depends on the alternative selection process since enough alternatives have already been generated. However, the problem of partial layout model is the speed of the processing time. The improvement of the model efficiency can be done by either improving the heuristic search performance or increasing the processing speed.

3. The processing speed of facility layout algorithm can be increased by systolic algorithm. The systolic algorithm not only reduces the processing time in facility layout

algorithm, but also increases the number of alternative layouts for the entire layout generation model (Narue-domkul 1994).

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A BEAM SEARCH TECHNIQUE FOR VLSI BLOCK LAYOUT

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ABSTRACT

The paper presents the partial layout model of block layout. An artificial intelligence technique has been used for solving the problems. The designed system consists of the block allocation, beam search and heuristic function. The system first generates the alternative layouts by using the block allocation. Then, the beam search searches for the n best layouts from the generated alternatives. Next, the heuristic function directs the search process to the most profitable direction. It is used for calculating the layout cost. A good layout is supposed to have a low cost value. In the proposed system three processes (block allocation, beam search and heuristic function) are worked together as one process. The system repeats these three main steps as cycle loop and will be stopped when all blocks are located. An experimental system is constructed based on the method for testing purpose. The results from the system show the potential applications to solve the complex facility layout problems.

INTRODUCTION

The main function of block layout is to allocate the blocks onto the layout template under the interrelationship and their space requirement optimization. The object is to design an efficient arrangement of space required by a block into an integrated whole, which is called area allocation. In fact, the area allocation technique has been studied in various contexts including stock cutting, VLSI design, as well as facility layout. In each context, problem formulation remains largely the same.

In the conventional analysis of computerized block layout, the algorithms are characterized as improvement algorithm and construction algorithm. The later classification has added two more models as hybrid and graph theory algorithm[4]. The hybrid algorithm generates the layout from scratch and improves it by regeneration. The graph-theory algorithm generates the layout by employing graph-theory. The reviews of these algorithm techniques can be seen in [5].

The latest classification[7] is done based on the analysis of block layout process as layout improvement, entire layout and partial layout model. The layout improvement model improves the existing layout by relocating the blocks to generate the new alternative layout. The *entire layout* model selects and places a seed block onto the given layout area, one at a time, until all blocks are located. In the *partial layout* model, the system selects a to-be-located block and locates it to all possible locations to generate partial layout alternatives. Then, the system selects the best partial layout alternative and adds another block onto it until all blocks are located.

In the partial layout model, the number of generated alternatives is a large number. It is considered to be an NP-complete problem. Therefore, the search technique must be used to improve the process of the best alternative selection process. The examples of search techniques used in the layout process can be seen in [3], [6], [8].

The paper presents the partial layout model for cell placement. An artificial intelligence technique has been used for solving the problems. The designed system consists of Block Allocation process, Beam Search and Heuristic Function. Pattern allocation process generates the alternative layouts. Beam search searches for the best layout from these generated alternatives. Heuristic Function is used for directing the search process to the most profitable direction.

SYSTEM DESIGN

The system is designed as shown in figure 1. It consists of two major processes; block allocation and beam search.

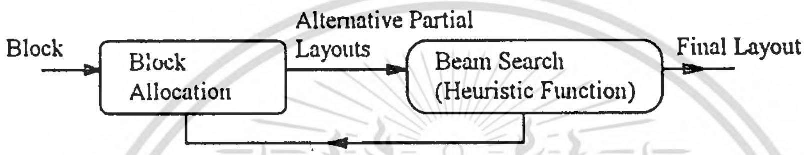


Figure 1 the design of the system.

The procedure starts by the block allocation process which is adapted from the heuristic approach to two-dimensional stock cutting problems[1]. It arbitrarily selects and locates a pair of blocks, a so called major and minor, to generate the alternative layouts. In the generation process a side of minor is put to adjoin a side of major. Next, the process rotates minor around itself and places its next side onto the same side of major. When all sides of minor are placed onto a side of major, minor will be moved to next side of major. The method repeats the above procedure until all sides of major and minor are adjoined. During the rotation of minor around major process the combined areas of adjoined blocks are proposed as alternative layouts. The overlapping of the combined area is checked. If the patterns overlap, the alternative is rejected.

In order to select the best layout out of these alternatives, the system uses the beam search technique. This means that cost of all alternatives has to be calculated. The function of cost calculation is designed based on the potential energy model[2] as:

$$E_{ij} = 1/2\ \omega_{ij}\ d_{ij}^2$$

Where E_{ij} is potential energy done on blocks i and j, ω_{ij} is closeness weight assigned for blocks i and j and d_{ij} is the distance between blocks i and j. In assigning the closeness weight, the functional characteristic, interrelationship among the blocks and practical limitation must be taken into account. After all layout costs are calculated, the n numbers of lowest cost layouts are selected. This n number is known as 'beamwidth' and can be any number. The system then searches for next to-be-located block. If there is no more pattern then the system uses the selected layouts as proposed layouts. If there exists any pattern, the system selects next to-be-located block and locates it.

The closeness weight, ω_{ij}, is defined the same way as stiffness coefficient of the potential energy. The value can be both positive and negative values. If the closeness weight is positive value, blocks i and j tend to move closer together. On the other hand, if the closeness weight value is negative, blocks i and j tend to move apart. A zero value of closeness weight represents no connection between blocks i and j. Since the closeness weight represents relative measure of a system, it can be any number. In the design system, the closeness weight is ranked from -10 to 10.

The next to-be-located block is considered from one of the following two strategies. First, among all unallocated patterns, the system selects the one for which the sum of its ω value between this pattern and each of all located patterns is maximum. Second, if the summation of ω-values in the first step are all equal then the system selects the one that has the biggest area.

After the next to-be-located block is selected, it is treated as minor and is located around all selected alternatives, or majors, to generate a new set of alternatives. The n numbers of lowest cost alternatives are selected again. The process will be stopped when there is no more to-be-located block.

ILLUSTRATIVE EXAMPLE

The following example will demonstrate the system working process for four quadrangle patterns. The layout processes will repeat the following three steps; the next to-be-located block selection, block allocation and beam search. Actually, the next to-be-located block selection and the block allocation processes are embedded in the beam search process. The steps are the next to-be-located block selection, block allocation and selection of the good alternatives. The process will be terminated when all blocks have been located.

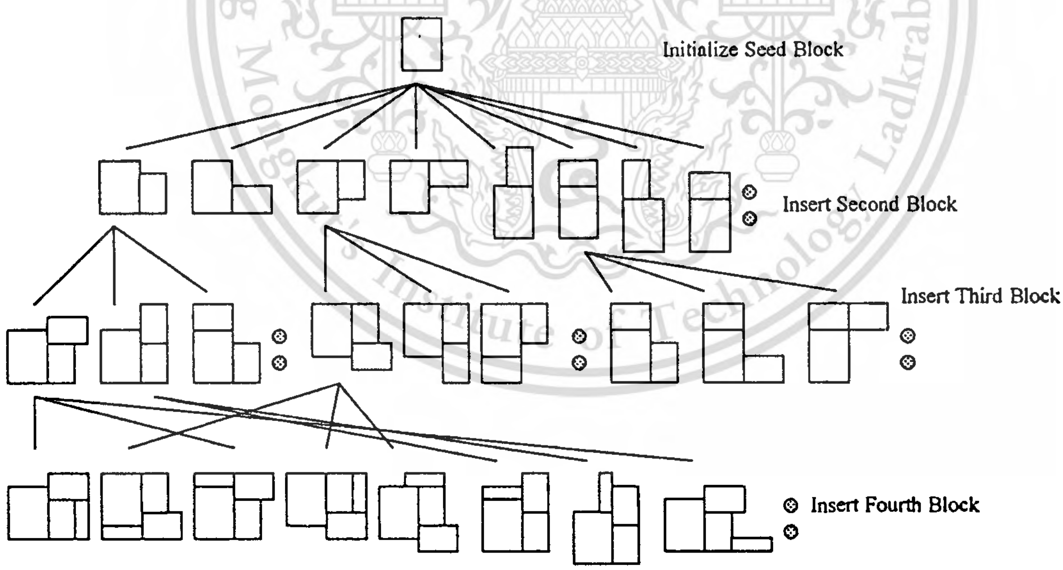


Figure 2 Block Allocation and Beam Search.

Figure 2 shows steps of block allocation and beam search working processes. As we see from the figure, these two processes work together as a single process. The block allocation is processed a long the way with the beam search process. The system first selects and initializes the seed block. Then, the second block is selected to insert and rotate around the seed block. The alternative partial layouts are generated and the best three of them, given n = 3, are selected for the further generation as shown in level one of the tree. Next, the third block is selected to insert and rotate around the three selected alternatives. Their generated alternatives are shown in level two. Again, the best three of them are selected. Finally, the fourth block is selected and the alternatives are generated as shown in level three. If there is no further block to locate, the best alternative of this level is selected as the final layout.

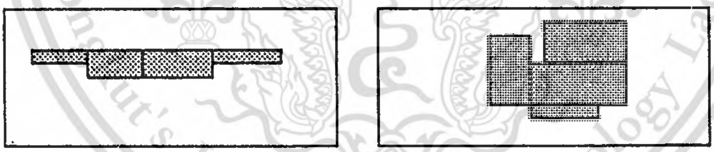
Figure 2 shows only some generated alternatives. In the real process all possible alternative layouts are generated. In level one, for example, the numbers of generated alternatives are 4*8 (32) alternatives. In level two the numbers of generated alternatives are 4*13*3 (156) alternatives. Table 1 shows the number of generated alternatives for quadrangle blocks which have beam width equal to three.

Level	Beam Width	Alternatives
1		32
2	3	4*13*3 = 156
3	3	4*18*3 = 216
:	:	:
n	x	4*[(8*n)-3*(n-1)]*x

Table 1 shows the number of generated alternatives.

EXPERIMENTAL TEST AND CONCLUSION

An experimental system is constructed based on the method for testing purpose. In fact, the efficiency of the partial layout model depends on the alternative selection process. This can be done by either improving the heuristic search performance. The results from the system show the potential applications to solve the complex block layout problems. The system can handle the layout of 30 blocks on 120 MHz personal computer with in 2:22 minutes when the beamwidth of the beam search is set to ten.



(a) (b)

Figure 3 the example of the layout results.

Figure 3 shows the results of the layout done by the prototype program. The two extreme cases have been presented. For figure 3(a) all values of ω have minus values. Therefore, all blocks tend to be located apart. On the other hand, in figure 3(b) all values of ω are positive values and the blocks tend to be located as close as possible.

The proposed system presents the use of beam search accompanying with block allocation algorithm to solve the problem. For the proposed system there are some points that can be discussed as follows:

1. The quality of the final layout is depending directly on the beam width. The larger number of the beamwidth is selected, the better the final layout is resulted.

2. If the beamwidth is set to one, the beam search becomes the depth-first-search.

3. The advantage of the system is that it considered the condition that blocks have to be located apart.

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