MACHINE LAYOUT OF MANUFACTURING CELL WITH FIX-PROPORTION AND VARYING PRODUCT MIX PATTERN

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ABSTRACT

This research study addresses the problem of the cellular layout of machines in static and dynamic environments. Previous researchers focused on either static or dynamic environments. As the static layout is optimized to a planning period, which has particular quantitative demand, it may not be suitable for different quantitative demands in other planning periods. The problem is how to link static and dynamic layouts, and to decide which machine arrangements are most appropriate to a set of quantitative demands in dynamic environments. Therefore, a heuristic algorithm has been developed to tackle machine allocation problems in cellular manufacturing. The proposed heuristic approach is called the MAIN (Machines Allocation INter-relationship) algorithm. This algorithm uses constructive steps to allocate machines into the constrained machine location zones. This works well in a period with fixed quantitative demand and it is referred to the Static Machine Cellular Layout (SMCL). Furthermore, it bases on a pool of SMCLs to select the best one for the Dynamic Machine Cellular Layout (DMCL). The selection of DMCL is dependent on the balance between the rearrangement cost of

machines and the traveling cost of parts. Two extreme cases have been used to verify the MAIN algorithm, namely steady-DMCL and modified multi-DMCLs. The significance of these results is that the average error of SMCL is only 3% compared with the optimal solution. Also, modified multi-DMCLs are ususally better than steady-DMCLs but this depends on the proportion of rearrangement costs.

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1. INTRODUCTION

This research study investigates the Static and Dynamic Machine Cellular Layout (SMCL & DMCL) with fixed proportion and vary quantitative demands in multi-planning periods. Group technology (GT) has been applied to determine machine groups and to identify parts of families to form manufacturing cells. This results in a flow dominance arrangement, and there is often a great similarity between the processes. Nevertheless, each type of part may still have its own operating sequences and, in practice, the quantitative demands of multi-planning periods may also vary. In this project, the layout arrangement is based on fixed quantitative demands in every planning period. This is because the SMCL can have a good solution under a fixed quantitative demand condition. However, this may not be the case when dealing with vary quantitative demands. In fact, Nicol and Hollier have also observed that radical layout changes happen frequently and that management should therefore take this into account in their forward planning [1]. Seifoddini and Djassemi also mention that in real world situation, product mix is a function of demand, and it may well change as demand fluctuates [2]. DMCL an attempt to address the problem of changes in demands without changes in operating sequences within the part family.

In SMCL, if n machines are grouped into a cell, there may be as many as $n!$ possible combinations of layouts. In DMCL, the same machine group in a cell may have *m* periods in a planning horizon. Since, the existing possible layouts are equal to $(n!)^m$ combinations [3, 4], it is clear that the feasible layouts of the cell would also increase exponentially with increase either in the number of machines or the number of periods. Therefore, the purely mathematical approaches would not be the best method of tackling this problem due to a long computation time, etc. [5]. Heuristic approaches can be used to tackle SMCL and DMCL problems. Although heuristic approaches cannot guarantee giving an optimal solution, it requires relatively little time and effort to achieve an acceptable solution [6].

The qualitative flow dominance represents changing attributes in the parts, and the quantitative flow dominance means that the flow frequency of the parts with pair-wise machines is high. Most of the existing approaches pay little attention to qualitative aspects. Therefore, the MAIN (Machines Allocation INter-relationship) algorithm is a specially designed to optimise the machine layout, by considering both the qualitative and the quantitative flows in a cell. It addresses the problem by assuming that the machine location zones are in equal dimension and the load-&-unload points are in the centriods of each machine location zone. The total traveling cost within a cell would be a measuring indicator of the performance of the SMCL. The solution of the DMCL is based on a search for the best layout among the obtained SMCLs over the multi-planning periods. The total rearrangement cost can be minimised by selecting the most suitable layout. The conceptual modelling of MAIN would be described in Chapter 3.

CHAPTER ONE: INTRODUCTION

1.1 Overview of Manufacturing Layouts

Cellular manufacturing (CM) has emerged in recent decades as product-mix becomes increasingly smaller in lot size and a shorter lead time is required. As the result, it may be inefficient to employ the traditional manufacturing layout. CM has proved to be effective for most manufacturers, and involves grouping of part families, putting them to dedicated clusters of machines to form cells. Ideally, entire operations of a part family are completed in a cell, and there is no inter-cell movement involved Therefore, the total traveling distance and time are reduced by implementing CM, the benefits of CM considered to be reduction in setup times, simplification of work flow, reduction in throughput times [7-12].

The flow shop and the job shop layouts are the traditional design of manufacturing layouts for medium to small lot size. A typical flow shop layout is based on the processing sequence of the parts being produced. Typically, the parts move from one machine to next machine in sequence. However, bypassings and backtrackings with movement down the flow would be inevitable [13, 14]. Consequently, the total traveling distance within a flow shop layout would increase.

The job shop layout groups the same function machines together, and the parts and materials flow among these functional groups. It usually takes a relatively longer distance to reach the next machine group. There exists a high degree of inter-machine group flow and obviously, there is little intra-group flow in a functional layout. Normally, it waits for the remaining parts in the batch to be completely processed before the whole batch moves to the next machine group. Indeed, the traveling time (including the idling time) of a batch is a significant factor in view of the throughput. The cellular layout comprises the advantage of flow shop and job shop layout. Each manufacturing cell includes different functions of machines to produce parts in a family.

Illustrative examples of these three types of layouts that have the same processing routes are shown in Figure 1.1a, 1.1b and 1.1c. Eight parts are going to employ four types of machines. In flow shop layout, bypassing and backtracking occurs, it will interpret the flow integrity. In job shop layout, the flow of inter-functional groups will happen frequently. The time effectiveness of part transportation is highly dependent on distances among functional groups. Clearly, cellular layout can be employed to give a good compromise of both the flexibility and the efficiency of a production floor.

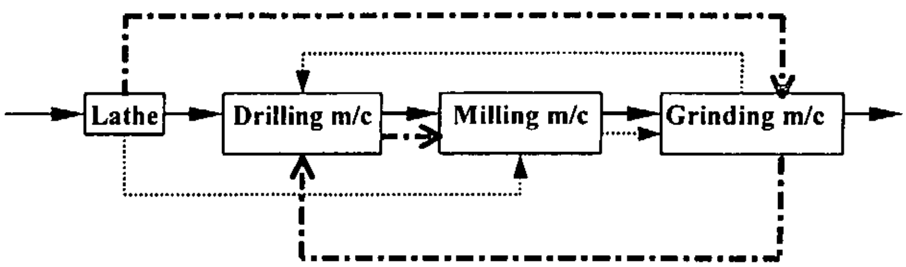


Figure 1.1a Flow shop layout

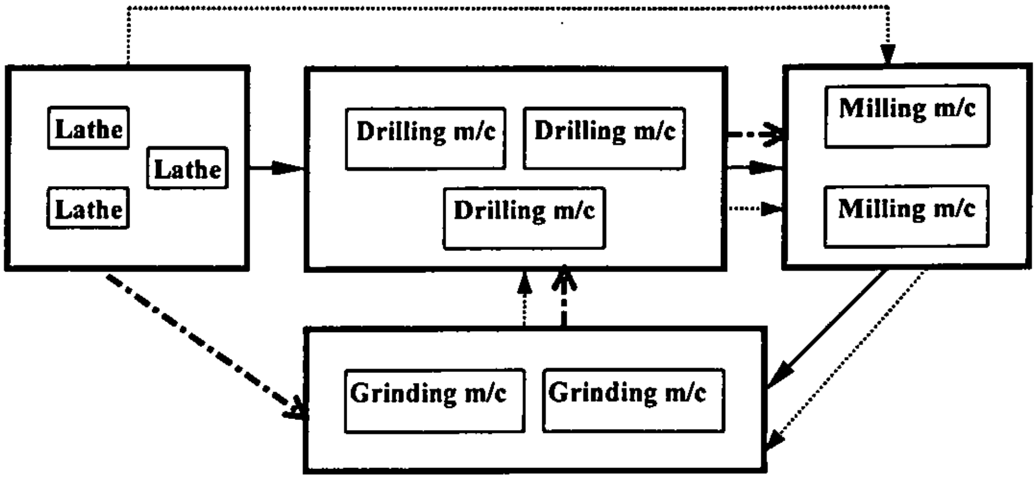


Figure 1.1b Job shop layout

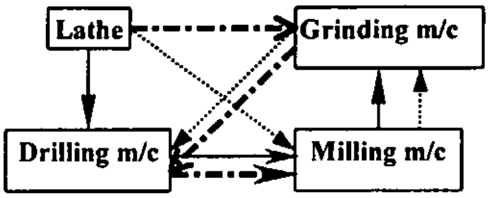


Figure 1.1c Cellular layout

where,

——► (solid)	Route of parts 1,4,6	(lathe→drilling→milling→grinding)
·······► (dotted)	Route of parts 2,3	(lathe→milling→grinding→drilling)
–·–·–> (dash-dot)	Route of parts 5,7,8	(lathe →grinding→drilling→milling)

1.2 Problem Definitions

This research focuses on developing an approach to solving the static and the dynamic machine layout problems. The SMCL tackles the problem in fixed quantitative demand in a given parts family. Most formulations in current machine layouts consider only the quantitative demand of materials and parts flow between machines, such that the higher in-between flow machines would be allocated more closely. However, the changing attributes of parts among processes have not been taken into consideration in many models. Typically, the attributes of a part in an assembly cell would change in size, weight and shape. A significant variation in part attributes is easily noticeable. For example, an initial 5kg weight part may increase to 7kg after some assembly processes, or alternatively, a finished part may become reduced in weight if there are material removal operations involved, such as the metal cutting operations. Even though the quantitative demand of the part is unchanged, the optimal layout could be different if part attributes are taken into consideration.

DMCL is the extension of SMCL. It can be used for layout machines to suit the varying quantitative demand. The DMCL can be classified into two cases: Multi-DMCLs occur over multi-planning periods, the Steady-DMCL occurs over the entire multi-planning periods. In the first case, the machine locations will be rearranged as necessary due to changes in quantitative demands of a part family, meaning that the frequency of part flows between machines would change. The optimal machine layout is only suitable for a particular period but it may be ineffective in the second, and the third periods. Therefore, four possible quantitative demands in four different planning periods would generate four possible SMCLs. Sometimes, it might be the same SMCL over two or three planning periods, but this depends on the variation of quantitative demands in different planning periods. If the proposed algorithm attempts to verify the performance over multi-periods, the total cell layout cost is the best indictor for measuring the performance. It involves the total rearrangement cost, plus the total traveling cost in the cell. For example, nine machines were allocated at the first state, as in Figure 1.2. If machines E & A are going to be rearranged to suit the second planning period, the rearrangement costs ($R_{1\rightarrow 2}$) must be added to the total rearrangement costs at the dynamic state.

In the second case, machine relocation may not be practical, due to prohibitive rearrangement costs on movement of machines. Only one identical machine layout is used for multi-planning periods. Indeed, this machine layout will only be good for one period, and may not be the best solution for other planning periods. The characteristic of this type of layout is that rearrangement costs will be null but the traveling cost of parts may not be kept on optimal level due to maintaining the single layout over multi-planning periods (see Figure 1.3). The detailed procedures of MAIN algorithm will be described in chapter three.

A	B	C
D	E	F
G	H	I

First SMCL

E	B	C
D	A	F
G	H	I

Second SMCL

F	B	C
D	E	A
G	H	I

Third SMCL

A	F	C
D	E	G
B	H	I

Fourth SMCL

Changing in quantitative demands on parts

$$R_{total}=R_{1\rightarrow 2}+R_{2\rightarrow 3}+R_{3\rightarrow 4}$$

The rearrangement cost incurred from first SMCL to fourth SMCL ($R_{1\rightarrow 2}$,$R_{2\rightarrow 3}$,$R_{3\rightarrow 4}$)

Figure 1.2 Multi-DMCL in four planning periods

A	B	C
D	E	F
G	H	I

First SMCL

A	B	C
D	E	F
G	H	I

Second SMCL

A	B	C
D	E	F
G	H	I

Third SMCL

A	B	C
D	E	F
G	H	I

Fourth SMCL

Changing in quantitative demands on parts

$$R_{total}=R_{1\rightarrow 2}+R_{2\rightarrow 3}+R_{3\rightarrow 4}=0$$

There is no machine rearrangement in a cell (R_{total}=0)

Figure 1.3 Steady-DMCL in four planning periods

1.3 Objectives

The main objective of this research is to exploit the machine cellular layout with vary demands in multi-planning periods. Firstly, the methodology is intended to maximize the closeness of machines, based on the part handling effort, the traveling distance and the materials flow frequency in cellular arrangement. Finally, the proposed heuristic approach will be used to minimize the cell layout cost (total rearrangement cost plus total traveling cost) that will be used to justify the best rearrangement for the machine location, whether using single or multiple layouts over successive periods.

1.4 Scope

This project will look into the allocation of machines within a cell, based on the operation sequences, parts flow frequency and quantitative demands of parts to determine the required closeness between machines. Furthermore, the total traveling distance within the cell will be measured by accumulating numerical information between machines, such as the distance between pair-wise machines and the frequency of parts flow. The total traveling distance serves as a measuring indicator, which can reflect the effectiveness of the SMCL. The ultimate goal of this project is to minimize the cell layout cost that needs to balance between the total rearrangement cost and total traveling cost.

1.5 Organization of the Thesis

This thesis is organized into seven chapters. Chapter 1 is an introduction of the project in which various machine layouts and objectives are introduced. In Chapter 2, the current techniques for tackling relevant layout problems are reviewed. The conceptual MAIN algorithm will be formulated and associated with practical constraints in Chapter 3. Chapter 4 illustrates the operation of the MAIN algorithm and various cases in solving machine layout problems are presented. Chapter 5 deals with the experimental design and results and Chapter 6 forms the discussions part. Finally, Chapter 7 gives the overall conclusions of this project.

1.6 Summary

The importance of cellular manufacturing was presented, and the two traditional layouts and cellular layout were illustrated. The concerns of cellular layout problem were described. Based on the problem definitions, the objectives and scope of this project were established.

2. LITERATURE REVIEW

This chapter provides a general review of machine layout problems, in which the difference between static and dynamic states will be identified. The main dissimilarity between these two states is that the static layout is only considered within a specific planning period, whereas the dynamic layout also addresses the requirements over several periods. The plant layout and the facilities layout, the cellular layout will be illustrated, and five existing problem-solving techniques will be described. Among them, the computerized programs and heuristic approaches are often used to solve layout problems. Using expert systems for solving the layout problem is also investigated and the advantages and limitations of various techniques will also be discussed.

2.1 Static and Dynamic Machine Layouts

Static layout problems have been addressed since the past decades and the solution layout is only suitable for one planning period. Currently, most of the available techniques tackle static layout problems by minimizing the total traveling costs of parts. This is usually done by working out a suitable arrangement for machines based on predefined locating zones. For example, the Quadratic Assignment Problem (QAP) technique uses the number of locations as the number of facilities, and Koopmans and Beckmann [15] are the pioneers of QAP. Montreuil [16] developed a static layout solving method using mixed-integer linear programming, which focuses on the load/unload point along aisles. Tam and Li [17] also formulated a three-phase hierarchical approach that attempts to minimize the geometric constraint. The limitation of static layout is that it only focuses on one single planning period. It is not suitable for the requirements of fluctuating customer demand today.

The dynamic layout problem assumes that machines can be economically relocated in order to cope with the new demand profile. Rosenblatt [3] first introduced a layout problem-solving technique for multi-planning periods, in which N machines in T periods has $(N!)^T$ possible combinations of layouts. His dynamic programming model attempts to find out the best layout for each predetermined period. The aim is to minimize the sum of deterministic rearrangement costs through the entire planning periods. One limitation of Rosemblatt's approach is the cost of rearrangement, which does not consider the movement distance from one machine location zone to another. Kouvelis et al. [18] also presented a similar algorithm to determine the best layout, with which the solution layout would be suitable for entire planning periods. Balakrishnan et al. [19] added the constraint of budget for total rearrangement costs over the multi-planning period and solved the problem by using the shortest path algorithm. But, this approach has a drawback of only taking into account of one constraint for determining the dynamic layout. Conway and Venkataramanan [20] applied the genetic search technique to evolve a population with a premature initial solution. Optimal solution layouts were also computed for comparison purpose. Two cases were tested by this approach, and an optimum could be obtained in the case with six machines. Based on the above approaches, it can be seen that the disadvantages of these approaches were not taken into account to the same extent as the relationship between layouts which means that a series of layout were not dependent on each other. So, unnecessary rearrangement cost of machines will be caused to increase the total cell layout cost.

2.2 The Plant Layout

There are two traditional types of layout. A given plant can either be arranged in flow line, or it may be grouped so that machines with similar functions in a production unit, and they are named product layout and process layout respectively. Singleton [21] computed the layout sequence in ascending order of 'demand position'. It attempted to allow a number of operations on the parts with respect to a percentile scale. Hollier [13] proposed a method for the layout of multi-product lines. The objectives were to maximize in-sequence movements and minimize the number of back-flows. Carrie [22] addressed the construction of multi-product flow lines. The workload of each operation and the capacity limit of the machines were evaluated to ascertain whether duplicated machines were needed. The plant layout has brought into the concern of the overall capacity of the plant including the product-mix and jumble of flow. Thus, the drawbacks of plant layout are too concentrated on sequence of parts flow and there is little concern on the requirement of periodical re-layout.

2.3 The Facilities Layout

Most models for facility layout involved the QAP. Sahni and Gonzalez [23] showed that the QAP is NP-complete. Finke, Burkard and Rendl [24] tested the computational results of the QAP, and they obtained optimal results with the maximum number of fifteen machines. Analogously, among the eight test cases reported by Nugent, Vollmann and Ruml [25], optimal solutions were found limited to fifteen facilities or less. In general, getting optimal solutions by tackling all the possible combinations takes very long computational time. Therefore, some researchers have developed heuristic methods which do not guarantee optimality but which provide acceptable solutions within a reasonable time scale [6]. Clearly, the purpose of facilities layout is to focus on how to manipulate the facilities location to improve the overall efficiency, but the characteristics of multi-planning periods makes the approach of going for optimal solution impossible. A simple calculation shows that possible combinations of fifteen machines (15!) are roughly equal to ($1.3x10^{12}$) whilst 9 machines with 4 periods will have ($9!^4 \cong 1.7\ x10^{22}$) arrangements.

2.4 The Cellular Layout

We need to identify part families and machine groups for forming manufacturing cells. The movement towards cellular manufacturing is important in reducing manufacturing costs in medium to small batch production. Material handling cost is a major factor to be considered in cellular layout problems. The material handling cost consists of expenses borne as a result of the intra-cellular and inter-cellular flows of parts. The intra-cellular flow cost occurs as a result of the movement of parts from one machine to another within a cell, while the inter-cellular flow cost occurs as the parts are moved from one cell to another. Typically, material handling is between 20 to 50% of the manufacturing cost [26]. To handle the inter-cellular flow, Seifoddini [27] addressed a machine cell formation model associated with the value of inter-cellular material handling costs, and based on these costs, the inter-cellular layout was selected. However, the total intra-cellular material handling cost is more than the inter-cellular one, because the work flow frequency of intra-cellular flows are normally higher, and this is the reason for forming cells in a plant (see Figure. 2.1). If the total intra-cellular distance were to be minimized, the manufacturing cost would also be reduced [28].

An intra-cellular layout refers to the machine arrangement within a cell. Jacobs [29] showed a three-step heuristic approach for solving the cellular layout problem. The approach attempts to lay down machines on the shop floor by minimizing the number of projection lines that is used in dimension of machine size to allocate into the available spaces. Four criteria can be formulated by this objective function such as distance, adjacency preferences, geometric construction and the utilization of space. The limitation of this approach was that it could not guarantee circulation path connectivity in the final solution. Also, it does not consider the cost factor of layout.

Triangle Assignment Algorithm (TAA) is another approach, as advanced by Heragu [6]. This algorithm assumes that each of the four possible layout patterns will be used to locating a machine; a pattern being composed of several equally sized sites, with which each site being large enough to accommodate the largest sized machines. It uses a set of heuristic rules to allocate machines to the sites. Mata and Tubaileh [30] also addressed the machine layout served by robotic machinery. It minimizes the total travel time and the total joint displacement, and all possible sequences of operations required by the robot at a given period will be considered. These two approaches are optimized traveling distance/time and computational time but the drawback is that these approaches did not focus on the traveling cost of part movement.

O'Brien and Barr [31] proposed an improved technique for considering different load/unload points of machines. However, here, the user must allocate machines beforehand since this algorithm does not determine the optimal solution for this problem. Welgama and Gibson [32] presented a construction algorithm whereby the machine dimensions and their loading locations are considered. This generation of layout also takes into account the orientation of machines to optimize the material-handling cost. Solutions to these approaches are highly dependent upon the layout construction at the initial stage. In addition, these algorithms are considered as essential the load/unload points of machine location but the limitation is that the position of machines should be located in the cell first in order that the orientation could be worked properly.

Tanchoco [33] showed that the procedure of 'Segmented Flow Topology' (SFT) could give the best machine groups. Following this, the locations of pick up and delivery stations among manufacturing cells were used as parameters to obtain the desired inter-cellular layout. The limitation of this approach is that it may not work if the number of facilities is large.

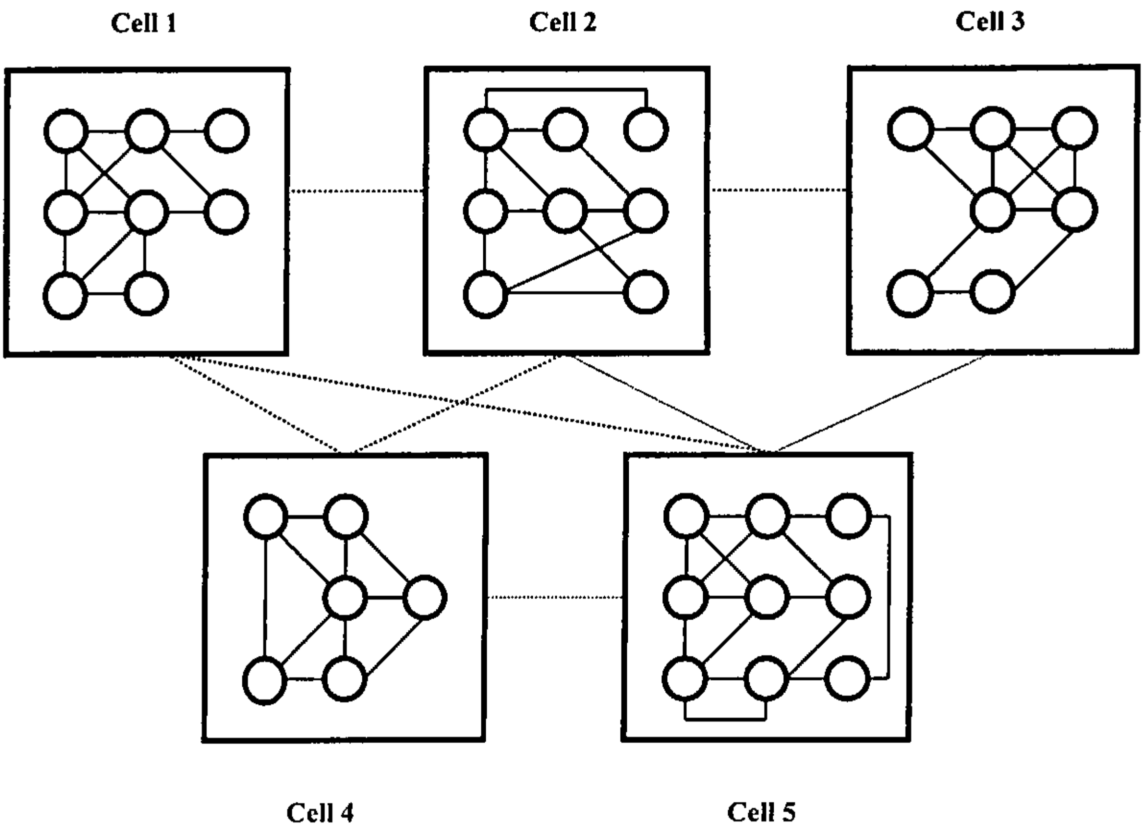


Figure 2.1 Material flows in cellular layout

where:

Cell

Machine

Intra-cellular flow, parts from one machine to another machine

Inter-cellular flow, parts form one cell to another cell

2.5 Computerized Layout Programs

CRAFT (Computerized Relate Allocation of Facilities Technique) [34] is the first successful functional layout program. The algorithm uses a heuristic approach to interchange facility locations. It computes the parts flow, handling cost and distance between the centroid of machines. Following this, it starts to exchange the machine locations, examining two-way and three-way exchanges. Successive interchanges lead to a near-optimum layout. Many researchers made modifications to CRAFT. Such revisions include the biased sampling technique [25], COL [35], CRAFT-M [36] and COFAD [37]. The limitations of CRAFT are that it does not work without an initial layout and cannot handle qualitative relationships between machines in a cell.

CORELAP (COmputerized RElationship Layout Planning) [38] calculates the machines to machine distance. Then, closeness of relationships of the machines are compared, and the machine with the highest score is located first. Other machines are added according to the rated closeness into the plant until all machines have been placed.

ALDEP (Automated Layout DEsign Program) [39] uses a preference table of relationship values to calculate the scores of series of randomly generated layouts. If machine j and k are adjacent, then there is value in separating the relationship between them, which would be added to that layout's score. The first machine is located at random. Subsequent machines are located according to the closeness desired or at random if no significant relationships are found. Obviously, more than one alternative layout can be generated and scored for comparison.

PLANET (a computerized Plant Layout ANalysis and Evaluation Technique) [40] utilizes information about material flow patterns. This technique starts by establishing a layout, and by asking questions such as which machine is placed next, and where the placement is located. Three heuristic algorithms are available for generating alternative layouts, with manual evaluations and adjustments being needed. In the first stage, the part traveling cost between pairs of facilities is determined. The part traveling costs between pairs of facilities are then ranked to facilitate the allocation. Clearly, there are also similar drawbacks as the ALDEP.

Drezner has examined the facility layout approach by using non-convex mathematical programming [41]. He formulated a two-phase algorithm known as the DISCON (DISpersion-Concentration algorithm). In the first phase, the Lagrangean differential gradient method is used to find the best initial layout. In the second, the solution is based on the first phase. It pushes the facilities to an extent that they are as close as possible. Tam and Li [17] also presented the divide-and-conquer strategy for solving the layout problem. This strategy consists of three phases: cluster analysis, initial layout and layout refinement.

Overall, one of the disadvantages of computerized layout program is that all procedures must be coded into the program. If some heuristic rules were included in the algorithm, it would not be easily encoded into the programming steps. Therefore, these approaches may have limitation in development. Furthermore, this approach was not suitable for the large size problem due to the long computational time.

2.6 Mathematical Approaches

In terms of mathematical approaches, one of the most frequently used formulations to solve the machine layout problem is that of the quadratic assignment problem (QAP) [15, 42, 43]. It is NP-complete, and the maximum number of machines with which the optimal solution can be obtained is limited to fifteen [24]. Thus, sub-optimal methods are more appropriate for cases with larger sizes [44]. There are other formulations such as the quadratic set covering formulation [45, 46] and mixed-integer programming formulation [47, 48]. In general, the restrictions of mathematical approaches are that every factor has to be quantified, and in practice, this may not be an easy task.

2.7 Graphical Approaches

Graphical approaches assume that a pair of facilities adjacent is predetermined. Seppanen [49] proposed a graph theoretic approach that uses the maximal planar sub-graphs of a weighted graph. The weighted graph shows the relationship between the facilities. The dual of the maximal planar sub-graph determines the layout of the facilities; the maximal planar sub-graph of a flow graph corresponds to the layout that has the maximal flow between adjacent departments. Since the maximal planar graph is found to be a computationally hard problem, a deltahedron algorithm [50, 51] with an improvement routine was developed, and the results seem to be a successful method. Rosenblatt [52] formulated a model to minimise the transportation cost of material and maximises closeness rating. Hassan and Hogg [53] also developed a method for converting a dual graph into block layout. Here, the dual graph is viewed as a one by one method for placement and construction in the block layout. The advantage of this approach is that it links the graph-theoretical approach and computerised layout approaches. Watson and Giffin [54] presented a new approach to solving the block layout, using the maximal planar graph. It is based on splitting vertices, and the block layout is easily transformed from the maximal planar graph. Wu and Salvendy [55] showed a graphical model (merging-and-breaking heuristic) that can describe part families with respect to the machine types with multiple machines. Thus, identical machines can be assigned to different cells based on part families, without involving complex computation. The restriction of this heuristic method is that it only considers assigning the identical machines to different cells.

2.8 Dynamic Programming Approaches

Dynamic programming approaches are adopted for solving dynamic layout problems. The evolution of these approaches concerns optimization over time periods associated with some constraints in the objective function. The problem must be formulated sequentially. Rosenblatt [3] proposed a dynamic programming approach to determine the best sequence of layouts. Kouvelis and Kiran [56] also developed a dynamic programming approach similar in nature to Rosenblatt's, but pertaining to part demand, process plans and operation assignment. One concern of this approach is that a good static layout is required before the best sequence can be effectively applied.

2.9 Heuristic Approaches

Heuristic approaches solve problems in large solution spaces, and lengthy computational time may be eliminated. These approaches describe a method for finding a good solution in a reasonable time, but do not usually guarantee an optimal solution. Some systematic heuristic approaches were developed in recent decades such as the Simulated Annealing, the Tabu search and the Genetic search, etc..

2.9.1 Simulated Annealing

Simulated annealing, likewise, incorporates randomization, so as to make diversification a function of temperature, whose gradual reduction correspondingly diminishes the directional variation in the objective function trajectory of solutions generated. Kouvelis and Chiang [57] addressed the spine layout problem that machines must be arranged along a straight track with automated guided vehicles moving parts among machines. The solution layout is defined as finding the arrangement of machines that minimize the distance of backtracking done by automated guided vehicle. Tam [58] described a procedure whereby space was allocated to manufacturing cells associated with the area and shape requirements of individual cells. After this minimized inter-cell traffic flow and enforcing geometric constraints were developed. Dissanayake and Gal [59] used a simulated annealing algorithm to optimize the location of the robot in the workshop. The total traveling time is minimized, as based on the sequence of tasks and the location of the robot. Meller and Bozer [60] presented the facility layout problem with single and multiple floors. They also used the simulated annealing algorithm. The disadvantage is that the initial layout is generated by an arbitrary method in order that pair-wise facilities exchanged according to the improvement-type layout algorithm.

2.9.2 Tabu Search

Tabu search (TS) is designed to find a global optimum in a combinatorial optimization problem. The inclusion of long-term memory functions is generally regarded as a way of incorporating diversification. It was proposed by Glover [61] as a technique for overcoming local optimality entrapment in solution processes for hard combinatorial optimization problems.

Lacksonen and Enscore [42] showed that the Tabu-search procedure provided solutions slightly better than the best solutions from other algorithms; the tested problem involved 30 departments over a 5 periods planning. Skorin-Kapov [43] also applied tuba search to solve QAP. Especially, the dynamic Tabu list sizes is changed dynamically associated with moving gaps in it corresponding to clear the memory in next iteration. However, the disadvantage of memory storage is required when running the steps of Tabu search even through the memory clears in each iteration.

2.9.3 Genetic Search

Genetic searches use randomization in component processes such as combining population elements and applying crossover (as well as occasional mutation), thus providing some diversifying. Conway and Venkataramanan [20] used genetic algorithms to develop the CDPLP. The tested problem case consisted of six departments over five periods. The population size consisted of 30 digits, which represented every department in each period. There would be 720 to 800 strings in the population. Here, crossover was manipulated for up to 100 generations, the algorithm performed well compared to dynamic programming for six and nine departments. However, no computation time was shown. Also, details such as crossover and mutation rate were not clearly discussed. Banerjee, Zhou and Montreuil [62] presented a graph with each cell in the layout and flow between stations, corresponding to edges linking the two cell nodes. The locations of the constituent nodes are optimized inside the cells in the problem formulation. The final result could differ substantially from an initial solution in experiments. This implies that this approach is fairly independent of the starting conditions. However, the solution quality and computational time of genetic algorithm are very dependent upon the parameters settings at initial such as the crossover and the mutation rate are of great affect of the algorithm.

2.9.4 Cutting Planes Approach

Bazaraa and Sherali [63] presented a cutting plane algorithm based on Benders' partitioning scheme. Burkard and Bonninger [64] also developed a cutting plane method with an exchange routine in an iterative heuristic to solve the QAP. The initial solution is generated randomly. All departments would be moved to new locations on iterations, to find the best assignment for all departments. The optimal solution is generated by several iterations on each of several starting solutions. This approach is based on the trial-and-error method to obtain the best solution, therefore the limitation is that the overall solution quality will not be consistent, even the initial conditions are identical.

2.9.5 Branch and Bound Approach

The first two branch and bound algorithms were shown by Gilmore [65] and Lawler [66]. Both algorithms implicitly evaluate all potential solutions. Land [67] and Gavett and Plyter [68] also proposed two other branch and bound algorithms. The main difference between these four algorithms is that the last two algorithms allocate pairs of facilities to pairs of locations whereas the first two algorithms allocate only single facility to single location. A parallel branch and bound algorithm was constructed by Pardalos et al. [69]. This algorithm finds the optimal solution to the QAP problem. It uses the cutting plane algorithm to obtain an effective solution to be used as an upper bound on the total cost. Both the memory requirement and the computational time are less than the cutting plane algorithm, but the optimal solution is the same as before. One observation of the branch and bound is that computational time is very dependent on the size of problem.

2.9.6 Cut Trees Approach

Gomory and Hu [70] first formulated a cut trees method. A graphical method is the arc of minimum weight on the path between two nodes in the tree corresponds to the weight of the min-cut separating the two nodes in the original graph. Rinsma

[71] also proposed a method which can always be converted to a layout with rectangular departments. Montreuil and Ratliff [72] observed that the cut tree would minimize the total flow costs for flows in a tree, and using a linear programming model can always generate this layout. The limitation of the cut tree approach is that it requires manual intervention to convert into a cut tree arcs, and also the cut tree arcs transfer to the layout. Therefore, it was a very time consuming process and low efficient on generating the optimal solution.

2.10 Expert System

Expert System can be employed to resolve problems that require reasoning. A typical expert system comprises an inferring engine and a knowledge domain, and it can tackle qualitative problems. Kumara [73] used an augmented transition network of natural language to solve the practical limitations of the alternate layout, such as those generated by heuristic approaches, and WEB grammar to present the pattern allocation knowledge captured from the human expert. Malakooti and Tsurushima [74] built an expert system for multi-criteria decision making. The expert system interacts with the decision maker (DM), reflecting the DM's preferences in the selection of rules and priorities. Heragu and Kusiak [75] proposed a knowledge-based machine layout (KBML), which consists constrains algorithms for the static machine layout problem. Departments would be formulated to hold individual machine. It analyzes the problem sizes and structure, and makes choice based on a penalty function. Abdou and Dutta [76] also used the expert system approach to determine appropriate layout of matching facilities associated with specific manufacturing and material handling systems. The EXSYS expert system shell and the relationship chart were used to construct the knowledge base. Sirinaovakul and Thajchayapong [77] proposed that the closeness relationship weight of objective function could be used to allocate facilities. All the possible potential alternative layouts would be generated. This expert system assists the heuristic search to find out a good layout from the solution spaces with less computational time. The main complication of expert system is the difficulties of develop a knowledge base for the entire scenarios.

2.11 Summary

A comprehensive review of existing methods for tackling the machine layout problems could be categorized either as static or dynamic states. In the static state, most of researchers apply the quadratic assignment problems (QAP) to minimize the total traveling distance between machines or facilities. However, there was little consideration on the changing attributes along the processing route of the parts. The allocations of machines or facilities within a cell were based on the values of the flow frequency. Effectively, machines or facilities with high flow frequency in-between must be put in adjacent locations. In the dynamic state, researchers focused on finding a series of static layout over periods. It implied that if the quantitative demand changes over periods, the existing layout might need to be rearranged correspondingly. The calculation of the total rearrangement cost might become the objective function in dynamic cases. However, the rearrangement cost did not formulate in a distance dependence function, which means that either 1m or 20m of movement of a machine will cost the same rearrangement cost.

Obviously, different types of layouts might have various characteristics and objective functions. The main purpose of the plant layout problem is to minimize the backtracking and bypassing of parts due to the job and the flow shop. However, the cellular layout has different characteristics due to nature of cell formation. The part families and machine groups are identified by group technology. Since, the operational sequences of parts have great similarity in a cell, the flow dominance in cellular layout problem may be less than other types of layout. Thus, the problem solving techniques must be selected carefully. The limitations of computerized layout programs are that they cannot solve the dynamic layout problem. Also, most of the computerized layout programs are dependent on the initial layout. These computerized programs determine the sub-optimal solutions to find out the optimal solution. Therefore, computational time is often very lengthy. The heuristic approach is employed to by-pass the problem. A number of heuristic approaches were described. The simulated annealing and the tabu search could not easily be manipulated due to high memory requirements. The genetic search has been a hot topic in recent years and researchers reported that it could possibly find a global optimal solution. However, little literature shows the parameters settings such as population size, crossover and mutation rate, etc.

CHAPTER TWO: LITERATURE REVIEW

Intra-cellular machine layout problem associated with changing in the flow of parts attributes in both static and dynamic manner would need to be investigated. In addition, factors that significantly affect the layout effectiveness should also be included to reflect the practical situations.

CHAPTER THREE: THE MODELING OF MAIN ALGORITHM

3. THE MODELING OF MAIN ALGORITHM

In this chapter, the three stages of the MAIN algorithm will be presented; it includes two static states and one dynamic state. In the first static stage, the MAIN algorithm covers the data collection and matrix based manipulations. In the second static stage, pair-wise machines are inserted into the space grids according to the ranking of the outputs (flow dominant). The individual SMCL will be evaluated by iterations with negligible rearrangement cost. The total traveling score will be served to indicate the effectiveness of the static machine layout. SMCL can generate a good layout for a single-period while DMCL is a series of layouts for multi-planning periods or for selecting layout in case of machine rearrangement is impractical. In the dynamic stage, eight possible SMCLs at a single-period will be replicated. The modified multi-DMCLs are used to determine the best subsequent layouts among these SMCLs over multi-planning periods. The similarity coefficient technique will be utilized to determine the two successive SMCLs; this is done in a pair-wise manner by picking the highest similarity coefficient. Figure 3.1 shows the skeleton of the MAIN algorithm.

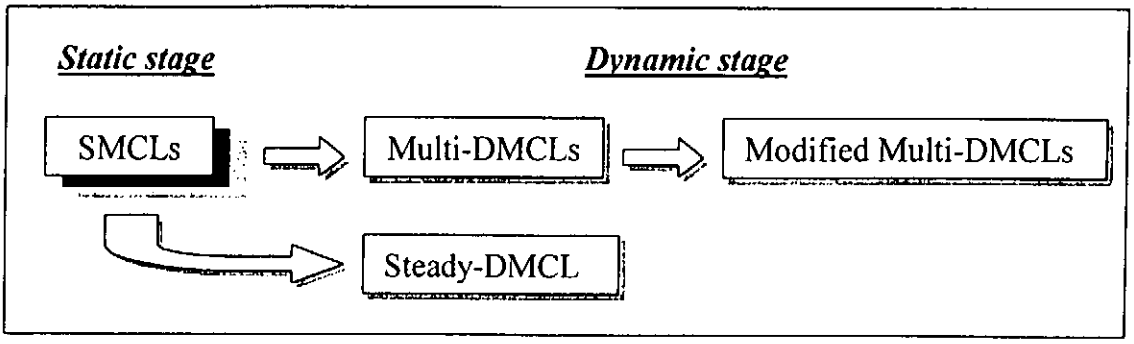


Figure 3.1 Skeleton of the conceptual MAIN model

CHAPTER THREE: THE MODELING OF MAIN ALGORITHM

3.1 Assumption

First, the machine groups and part families are predetermined in a matrix-based method. Parts within a cell are processed in defined sequences. The quantitative demands of each part are fixed in a period, and obstacles that hinder part movement are absorbed by the handling factor. The distance is measured by using the centriod of a machine as a reference point. This implies that the traveling distance between machines would be identical for either parts from machine j to k or k to j. The size of machine location zone (x,y) will be given by the largest machine within a cell (see Figure 3.2). Furthermore, the quantities of parts flow are constants in a period that will not change during the assembly or the disassembly processes. The maximum number of machines, which can be assigned into a 3x3 grid, is limited to 9 machines because there are only 9 potential machine location zones.

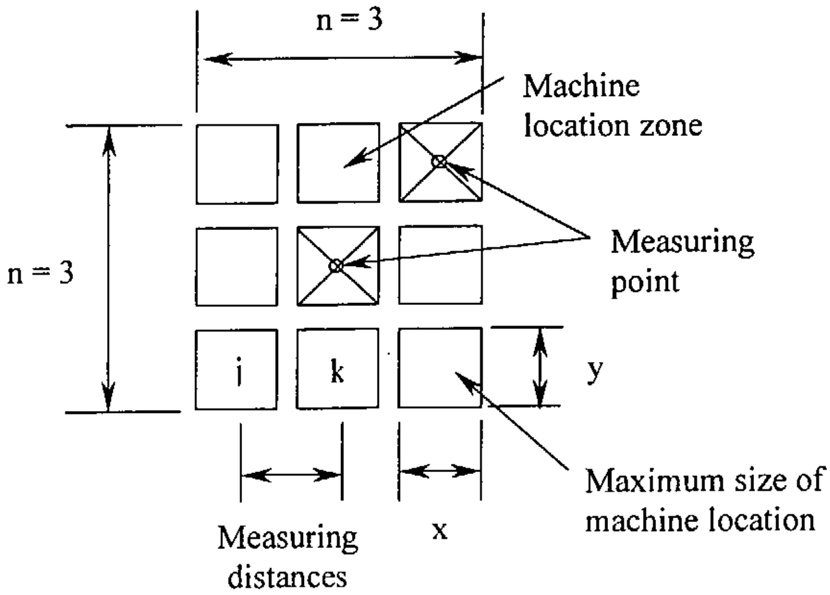


Figure 3.2 Facilities distant measuring

3.2 Notation

In this section, the parameters required for solving the static & dynamic machine layout problem are illustrated and the procedures of MAIN are discussed afterward. The parameters involved are:

(1) $\{i\}$ = Index of parts, $i = 1, \ldots, n$;

(2) $\{j, k\}$ = Index of machines, $j, k = 1, \ldots, m$; $j \neq k$;

(3) $\{j \rightarrow k\}$ = Unidirectional relationship from machine j to machine k;

(4) $\{j \leftrightarrow k\}$ = Bi-directional relationship between machine j and machine k;

(5) $\{t \leftrightarrow s\}$ = Index of replicated layouts between successive SMCLs, $t, s = 1, \ldots, 8$;

(6) $\{p\}$ = Planning period, $p = 1, \ldots, P$;

(7) $\{Q_{p,i}\}$ = Quantitative demand of a part within a period;

(8) $\{H_{i,j \rightarrow k}\}$= Transportation quantity of a part from machine j to machine k;

(9) $\{D_{j \leftrightarrow k}\}$ = Distance between a pair of machines;

(10) $\{X_j, Y_j\}$, $\{X_k, Y_k\}$ = geometric coordinates of machine j and machine k;

(11) $\{\lambda_{i,j \rightarrow k}\}$ = Part handling factor;

(12) $\{T_{p,j \rightarrow k}\}$ = Part flow weight;

(13) $\{F_{p,j \leftrightarrow k}\}$ = Merged part flow weight;

(14) $\{\zeta_p\}$ = Total traveling score of parts in a cell within period p;

(15) $\{\omega\}$ = Cost per unit traveling score (a constant);

(16) $\{R_{p \rightarrow p+1}\}$ = Rearrangement cost for two successive planning periods;

(17) $\{M_j\}$ = Basic cost for machine j relocation (setup/installation, etc.);

(18) $\{C_j\}$ = Cost per unit machine movement of machine j;

(19) $\{SC_{p \rightarrow p+1(t \leftrightarrow s)}\}$ = Similarity Coefficient between two planning periods;

(20) $\{\alpha\}$ = Total cell layout cost over multi-planning periods.

The key objective of the MAIN algorithm in the first two static stages is to minimize the total traveling score in a cell. The role is to minimize the total costs on making parts movement. The objective function is defined as:

$$\text{Minimize } \zeta_P = \sum_{j=1}^{m} \sum_{k=j+1}^{m} D_{j \leftrightarrow k} * F_{p,j \leftrightarrow k} \quad (1)$$

Subject to

$$T_{p,j \rightarrow k} = \sum_{j=1}^{m} \sum_{k=j+1}^{m} \frac{Q_{p,i}}{H_{i,j \rightarrow k}} * \lambda_{i,j \rightarrow k} \quad (2)$$

$$F_{p,j \leftrightarrow k} = T_{p,j \rightarrow k} + T_{p,k \rightarrow j} \quad (3)$$

In the dynamic state, the part traveling cost and the machine rearrangement cost are examined. The interest is to find out a new machine layout that would give the lowest cost in total. The objective function on dynamic state is defined as:

$$Minimize\ \alpha=\sum_{p=1}^{P}(\zeta_p*\omega)+\sum_{p=1}^{P-1}R_{p\rightarrow p+1(t\leftrightarrow s)} \quad (4)$$

Subject to:

$$R_{p\rightarrow p+1(t\leftrightarrow s)}=\sum_{j}^{m}\sum_{k}^{m}(M_j+D_{j\leftrightarrow k}*C_j) \quad (5)$$

$$D_{j\leftrightarrow k}=|X_j-X_k|+|Y_j-Y_k| \quad (6)$$

$R_{p\rightarrow p+1(t\leftrightarrow s)}$ is equal to 0 if all machine are remaining in the same locations because $M_j = 0$ & $D_{j\leftrightarrow k} = 0$.

3.3 The Static Stages - SMCL

In the first two static stages, it is assumed that quantitative demands in parts are fixed within a period. This implies that a fixed proportion of quantitative demands in a part family would be considered. The allocation of machines is based on the inter-relationship between machines, and the inter-relationships are derived from equations (1)-(3). The total traveling score (performance indicator) is used to reflect the effectiveness of the layout. This is done by making use of the objective function. Practical constraints are included in the objective function.

Expert designers impose design constraints. Furthermore, the static machine cellular layout is to develop techniques that are not only capable of providing solutions to problems in a reasonable computational time, but also are able to associate with certain design constraints commonly encountered in cellular manufacturing systems. The design constraints are going to be considered in the following sections.

(a) Size of cell

The machines in a cell are often limited to a certain number. It is because if the numbers of parts in a cell were so large, it would generate too many flow dominances such as jumble flow in a cell. Indeed, the average size of a practical manned cell was 6.2 machines within a cell [8]. Moreover, the number of machines is a crucial factor for cell performance because operators are only capable of monitoring a limited number of machines. Being over stressed would surely affect the efficiency. Here, the testing experiments will be limited to nine machines within a cell.

(b) Part handling factors

The transportation of parts within a cell is unavoidable. The part handling factor is used to reflect the effort used to move a part. For examples, the size, the weight, the shape, parts quantity in a move and the facility available to assist the transportation may affect the outcomes. It is a factor whereby various levels of difficulties of moving parts from one machine to another may be represented. In this research, it uses a simple relative mode. The smallest score is '1', which represents the easiest in transportation in the system, while '2' means double the effort of '1' so on. Obviously, there is no definite highest value, and the existence of one decimal point would appear to be reasonable. Sometimes, parts can be transported in small batches in a single move and in this case, the part handling factors should be carefully assigned to reflect this. Nevertheless, human justification is currently relied on and further studies that could be done to generate a systematic approach.

(c) Transportation quantity

This factor is based on the quantity of parts per move. Some devices may have the ability to carry several parts per transportation. This suggests that the transportation frequency is equal to the quantitative demand of parts divided by the transportation quantity factor. It is different from part handling factors, and a higher value will generally suggest that the transportation device is more effective. In this project, '1' stands for 1 part per transportation, '2' is 2 parts per transportation and so on.

(d) Quantitative demand of parts consideration

The quantitative demand of a part family is often fixed within a period. However, a part family may have its own demands and needs over multi-planning periods. Sometimes, it is possible to follow the seasonal fluctuations. Therefore, the variations in quantitative demands would be induced over multi-planning periods. For example, in Table 3.1, quantitative demands are being increased in part 1 over multi-planning periods but part 3 is constant. In fact, the SMCL can only be applied to determine the optimal solution in one specific period.

Table 3.1 Quantitative demands for parts over multi-planning periods

Part family	Planning period				
	p-1	p-2	p-3	p-4	p-5
Part 1	150	300	550	600	750
Part 2	200	100	100	200	100
Part 3	300	300	300	300	300
Part 4	400	250	200	200	100
Part 5	500	600	100	900	50

p-n is a planning period (n=1,2,3,......)

(e) Parts flow weight consideration

It can be formulated into two types, which are the part flow weights ($T_{p,j\to k}$ & $T_{p,k\to j}$) and the merged part flow weights ($F_{p,j\leftrightarrow k}$). A part flow weight is the mean by which parts are transported from one machine to another within a cell, that is, a unidirectional flow. The merged part flow weight is for bi-directional relationship between a machine pair. In every case, the position of load/unload point should be identical. The characteristics of intra-cellular part flows are that they are usually rush and short distances. These weights directly affect the settings of machines. In other words, a pair of machines with higher part flow weight should be closely allocated. The determination of the basic and the merged part flow weights are related to the quantitative demand, transportation quantity and handling factor of parts. The basic part flow weight is formulated as: (see section 3.2 for explanation of the notations)

$$T_{p,j\to k} = \frac{Q_{p,i}}{H_{i,j\to k}} * \lambda_{i,j\to k}$$

(f) Distance measurement between machines

There are three commonly adopted measuring methods for distance measurement ($D_{j\leftrightarrow k}$) and measuring points between a pair of machines j and k [17, 78]:

1. Distance measure ($D_{j\leftrightarrow k}$):

   (i) Cartesian/ Euclidean measuring method

   $$D_{j\leftrightarrow k} = \{(X_j - X_k)^2 + (Y_j - Y_k)^2\}^{1/2}$$

   (ii)Squared Euclidean measuring method

   $$D_{j\leftrightarrow k} = (X_j - X_k)^2 + (Y_j - Y_k)^2$$

   (iii) Manhattan/ Rectangular measuring method

   $$D_{j\leftrightarrow k} = |X_j - X_k| + |Y_j - Y_k|$$

   Where (X_j, Y_j) and (X_k, Y_k) are the coordinates of the measuring points for machines j and k.

2. Measuring points:

   (i) The centroid displacement between two machines

   The center-to-center distance between machine location zones,

   (i) The shortest distance between machines

   The nearest points between adjacent machines are measured.

3.4 The Dynamic Stage - DMCL

In the dynamic stage, two cases would be involved, namely the multi-DMCLs and the steady-DMCL over multi-planning periods. The multi-DMCLs means that machines may be rearranged to cope with changes in parts demands from period to period, whilst the steady-DMCL keeps machines unmoved. This implies that the steady-DMCL might not be the optimal solution in comparison to individual SMCL. The determination of cell layout cost with the steady-DMCL will be based on aggregated the total traveling cost over all periods. A steady-DMCL will be determined by the same procedures as the SMCL. In other words, it is quite similar to the static machine cellular layout problem. In case of the multi-DMCLs, constraints are described in the coming sections.

The dynamic stage is to take into consideration the machine rearrangement costs. The multi-DMCLs works by including the rearrangement costs between identified SMCLs, each of which represents the optimal solution within a specific period. In terms of the modified multi-DMCLs, a similarity coefficient technique is used to find out the best successive layout by examining the 8 possible replications of a SMCL. A high similarity coefficient means that the two layouts have greater similarity in-between. Thus, the total rearrangement cost can be minimized by the similarity coefficient search.

(a) Rearrangement cost

The machine movement from current location to a new position incurs rearrangement costs. This cost is usually defined as a constant amount [3, 4, 20] but it can be different for different types of machine. For example, in Figure 3.3, the basic relocation cost for machines M_A and M_F is 200 units with reference to Table 3.2. In here, the total rearrangement cost is simply determined by the aggregation of rearrangement costs for machines M_A and M_F. It is understood that moving a machine for a longer distance will be more costly in practice. In the proposed model, we suggest fine turning the system to incorporate the cost associated with distance (see Figure 3.4). Table 3.3 shows that the total cost of rearrangement is involved by two costs: the basic cost and the variable cost. The difference between these costs is that the prior cost is the cost for machine setup and second cost is a distance dependent cost.

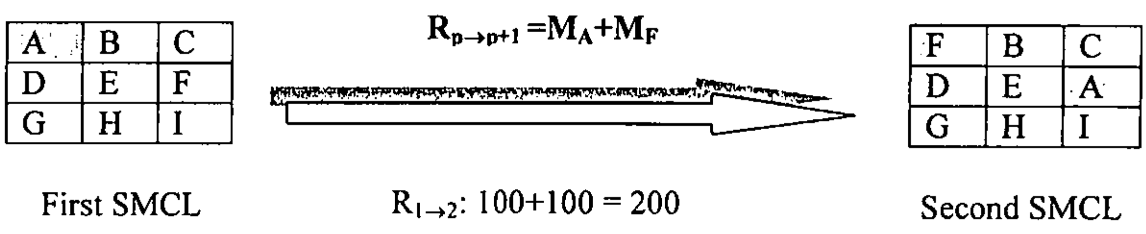


Figure 3.3 Typical rearrangement cost model

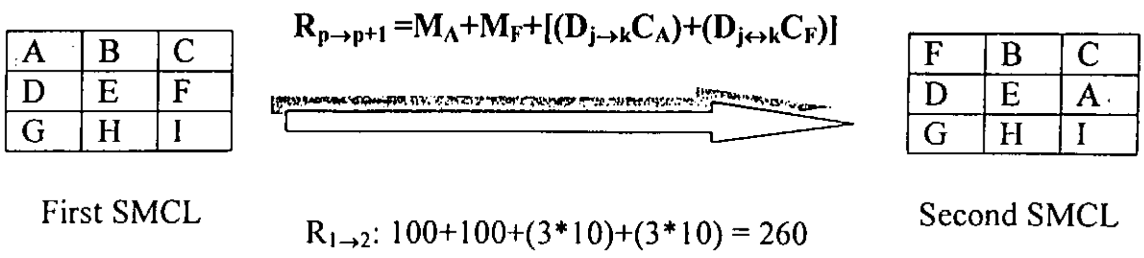


Figure 3.4 Proposed rearrangement cost model

Table 3.2 Basic costs for machine relocation

Basic cost for machines relocation (M_j)									
M/C	A	B	C	D	E	F	G	H	I
$	100	200	150	300	900	100	600	200	100

Table 3.3 Costs per unit machine movement

Cost per unit machine movement (C_j)									
M/C	A	B	C	D	E	F	G	H	I
$	10	20	15	30	90	10	60	20	10

(b) Similarity Coefficient

A Single Linkage Clustering Algorithm (SLCA) [79] tackles the problem of identifying the machine groups. Generally, it used a Similarity Coefficient (SC) to examine a pair of machines in the machine-parts matrix by determining the relationships between the machines and then the parts. SC between all machines can be calculated as:

$$SC_{(j \leftrightarrow k)} = \frac{N_{j \leftrightarrow k}}{N_{j \leftrightarrow k} + U_{j \leftrightarrow k}}$$

where,

$SC_{(j \leftrightarrow k)}$ = Similarity Coefficient between machine j and k

$N_{j \leftrightarrow k}$ = the number of parts visit both machine j and k

$U_{j \leftrightarrow k}$ = the number of parts either visit machine j or k

In Table 3.4, the machine-parts matrix consists of positive (1) and zero (void) entries. The positive entries in the matrix indicate that a part corresponding to the i[th] column is processed by the machine, and the machine corresponding to the j[th] row is employed to the parts with 1's at the columns. SC between machine 01and 02, 01 and 04 are:

$$SC_{(01\leftrightarrow 02)}=\frac{0}{6}=0 \qquad \text{and similarly,} \qquad SC_{(01\leftrightarrow 04)}=\frac{3}{4}=0.75$$

All pairs of machines in Table 3.4 are calculated by the SC equation, and they are shown in Table 3.5. The maximum value of SC represents the strongest inter-relationship between the pair-wise machines.

The SC is modified to select a series of layouts in a DCML problem. The newly formulated SC for DCML is shown as following. The calculations are illustrated in Figure 3.5.

$$SC_{p\rightarrow p+1(t\leftrightarrow s)}=\frac{N_{t\leftrightarrow s}}{U_{t\leftrightarrow s}}$$

where,

$SC_{p,p+1(t\leftrightarrow s)}$ = Similarity Coefficient between planning periods p and p+1;

$N_{t\leftrightarrow s}$ = the number of machines remaining at the same position on both planning periods p and p+1;

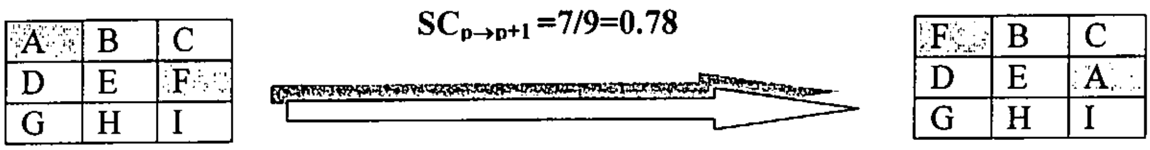
$U_{t\leftrightarrow ,s}$ = the number of machines within cell.

Table 3.4 Machine-parts matrix

		Parts						
		1	2	3	4	5	6	7
M/C	01	1			1		1	
	02		1	1		1		
	03			1		1		
	04	1			1		1	1
	05		1	1		1		
	06	1			1			

Table 3.5 SCs between machine pairs

		M/C					
		01	02	03	04	05	06
M/C	01						
	02	0					
	03	0	0.67				
	04	0.75	0	0			
	05	0	1	0.67	0		
	06	0.67	0	0	0.50	0	



First SMCL Second SMCL

Figure 3.5 Proposed SC model for DMCL

3.5 Procedures of the MAIN Algorithm

The procedures of the proposed MAIN algorithm involve three stages, and there are several steps to each stage: Stage 1 involves data collection and data manipulation. Stage 2 deals with constructing the machine layout, by which the allocation of machines will be based on the ranking of part flow weights. The SMCL for each planning period would be determined by the above two stages. In Stage 3, the modified SC model is used to find out the best layout for successive planning periods, such that the total cell layout cost will be minimized. Details of these three stages are illustrated in the following sections.

Stage 1

Step 1: Data collection

Five sets of production information should be captured first, and then put into matrices for later manipulation (see Table 3.6). The five sets of data are:

(a) Parts and machines involve in the target cell. The number of machines will be limited to a maximum of nine machines in a cell as mentioned in section 3.3-a. To certain extend, this also restricts the number of parts.

(b) Operational sequences of various types of parts are also needed. In a part family, it may contain various parts. Although the operational sequences of each part may not be same, they often have great similarity.

(c) Quantitative demand of each part per planning period. A period is often four or six months in practice or associates with seasonal fluctuations (see section 3.3-d).

(d) Transportation quantity represents the number of parts to be transported in a time. The maximum value of transportation is equal to quantitative demand in a planning period and the minimum value is obviously one part a time (see section 3.3-c).

(e) Part handling factors are concerned with the difficulty of transporting the part between machines during manufacturing processes. These factors should incorporate the obstacles in handling (see section 3.3-b).

Step 2: Establishment of operational matrices

The processing information of parts is inserted into matrices, which include data of part transportation frequency and corresponding part handling factors (see Table 3.7 and Table 3.8). All these are unidirectional information and there are cases where two or more entities are in the same slot. This implies that the machine indicated in the first column of the matrix may process more than one part types in a family before these parts have been transferred to the machine labeled at the first row. Indeed, every period to be tackled will need a set of operation matrices.

Step 3: Formulation of the part flow weight matrix

Within a period, entities within the part flow weight matrix such as $T_{p,j \rightarrow k}$ and $T_{p,k \rightarrow j}$ are derived from equation (2). This matrix combines information from two sub-matrices; the sub-matrices of transportation frequencies and handling factors. Each entities ($Q_{p,i}/H_{i,j \rightarrow k}$) in the transportation frequency matrix are multiplied by the corresponding part handling factor ($\lambda_{i,j \rightarrow k}$). The idea is to normalize the figures for further processing purpose. Also see Table 3.9.

Step 4: Determination of the merged part flow weight matrix

The entities ($F_{p,j\leftrightarrow k}$) are derived from equation (3) for every period. This matrix is used to conclude the bi-directional relationship of all machine pairs. In Table 3.10, the upper right side of this matrix shows the combined results of the unidirectional part flow weights.

Step 5: Ranking of the merged part flow weight matrix

Based on the values of entities in a part flow weight matrix, ranks them in descending order. Table 3.11 shows some pretended values since there are no actual figures in the previous matrices. The higher value would have the higher rank in the ranked merged part flow weight matrix; 1 is the highest rank. If there are equal values in the part flow weight matrix, then these will have the equal ranking level. For example, if $F_{1,(1\leftrightarrow 2)}$ and $F_{1,(3\leftrightarrow 4)}$ are both equal to 70, then they will fall into the same rank .

Table 3.6 Basic parts & materials information

Type of parts (i)	Processing sequence of parts (M/c)	Quantity demand ($Q_{p,i}$)	No. of parts per transportation ($H_{i,j\rightarrow k}$)	Parts handling factor ($\lambda_{i,j\rightarrow k}$)
1	m1→m3→m2→m1	$Q_{1,1}$	$H_{1,m1\rightarrow m3}$, $H_{1,m3\rightarrow m2}$, $H_{1,m2\rightarrow m1}$	$\lambda_{1,m1\rightarrow m3}$, $\lambda_{1,m3\rightarrow m2}$, $\lambda_{1,m2\rightarrow m1}$
2	m3→m1→m2→m1	$Q_{1,2}$	$H_{2,m3\rightarrow m1}$, $H_{2,m1\rightarrow m2}$, $H_{2,m2\rightarrow m1}$	$\lambda_{2,m3\rightarrow m1}$, $\lambda_{2,m1\rightarrow m2}$, $\lambda_{2,m2\rightarrow m1}$
: :	: :	: :	: :	: :
i	j→k→l ...	$Q_{p,i}$	$H_{i,j\rightarrow k}$, $H_{i,k\rightarrow l}$, ...	$\lambda_{i,j\rightarrow k}$, $\lambda_{i,k\rightarrow l}$, ...

Table 3.7 Part transportation frequency matrix

M/c	m1	m2	m3	m
m1		$Q_{1,2}/H_{2,m1\rightarrow m2}$	$Q_{1,1}/H_{1,m1\rightarrow m3}$	
m2	$Q_{1,2}/H_{2,m2\rightarrow m1}$ $Q_{1,1}/H_{1,m2\rightarrow m1}$			
m3	$Q_{1,2}/H_{2,m3\rightarrow m1}$	$Q_{1,1}/H_{1,m3\rightarrow m2}$		
m				

Table 3.8 Part handling factors

M/c	m1	m2	m3	m
m1		$\lambda_{2,m1\rightarrow m2}$	$\lambda_{1,m1\rightarrow m3}$	
m2	$\lambda_{2,m2\rightarrow m1}$ $\lambda_{1,m2\rightarrow m1}$			
m3	$\lambda_{2,m3\rightarrow m1}$	$\lambda_{1,m3\rightarrow m2}$		
m				

Table 3.9 Part flow weight matrix

M/c	m1	m2	m3	m
m1		$T_{1,m1\rightarrow m2}$	$T_{1,m1\rightarrow m3}$	
m2	$T_{1,m2\rightarrow m1}$			
m3	$T_{1,m3\rightarrow 1}$	$T_{1,m3\rightarrow m2}$		
m				

Table 3.10 Merged part flow weight matrix

M/c	m1	m2	m3	m
m1		$F_{1,m1\leftrightarrow m2}$	$F_{1,m1\leftrightarrow m3}$	
m2			$F_{1,m3\leftrightarrow m2}$	
m3				
m				

Table 3.11 Ranked merged part flow weight matrix

M/c	m1	m2	m3	m
m1		1	2	
m2			3	
m3				
m				

Stage 2

Step 6: Allocation of pair-wise machines according to the ranking levels

Initially, the pair of machines j and k with the highest $F_{p,j\leftrightarrow k}$ would be picked out and put onto a space area as the primary parent. If there are more than one $F_{p,j\leftrightarrow k}$ with the same value in the 'ranked merged part flow weight matrix', then one is assigned to be the primary parent and the another becomes the temporary parent. A temporary parent is formed when they have no link to the others on the space area.

Furthermore, the temporary parent(s) may be adopted by the primary parent cluster in the merging processes. For example, if $F_{p,(j\leftrightarrow k)}$, $F_{p,(j+1\leftrightarrow k+1)}$ and $F_{p,(j+1\leftrightarrow k+2)}$ are having the same maximum ranking value, only one pair of machines, say machines j and k, will be allocated first. Machines j+1 and k+1 or j+1 and k+2 will become temporary parents (see Figure 3.6). The parent cluster(s) keeps growing until the merging processes have finished.

Step 7: Pulling the machines based on the ranking order

Select the $F_{p,j\leftrightarrow k}$ with highest value that is remaining in the matrix. It becomes a 'related or unrelated son'. The related son means that the machine j or k has link to the primary parent. The unrelated son represents that the pulled machines do not link to the primary parent. However, it may or may not link to the temporary parent. For example, the primary parent is machine j and k, and two of the merged part flow weights are having the same value. The first is $F_{p,k\leftrightarrow k+2}$ and the second is $F_{p,j+2\leftrightarrow k+1}$. Obviously, the first son possesses machine k and k+2 whilst the second son possesses machine j+2 and k+1. Only the machine k of the first son links to the primary parent so that related son $F_{p,k\leftrightarrow k+2}$ is connecting with the primary parent. On the other hand, the unrelated son $F_{p,j+2\leftrightarrow k+1}$ would be allocated to the temporary parent since It has the term 'k+1' that is also found in the temporary parent. Whatever a new son is born, one should also check that parents might need to be united due to the new son (see Figure. 3.7).

Step 8: Machines positioning consideration

In Figure 3.8, let the grayed positions be possible 'sites'. A parent $F_{p,j\leftrightarrow k}$ has three sites for direct linking to another machines. If the son ($F_{p,k\leftrightarrow k+2}$) is pulled into the space area of the parent, then it can be allocated arbitrarily into these three sites. This is because these sites give minimum distance between machine k and k+2. In Figure 3.9, it has only two sites if there is a new son ($F_{(j+1\leftrightarrow k+2)}$) pulled into space because we use a 3x3 grid for machine allocation and the maximum number of rows and columns in layout are limited to three machines at most. Therefore, the machine j+1 could only be put into either the top or bottom of machine k+2.

Step 9: Repeat Step 7 and 8 until all machines are allocated into the space area.

Step 10: Calculation of total traveling score

The total traveling score (ζ_p) within a cell is derived from equation (1) after machines have been allocated into the space area.

Step 11: Evaluation of traveling scores

Evaluate the traveling scores ($F_{p,j\rightarrow k}$ x $D_{j\leftrightarrow k}$) for all machine pairs to seek for improvement. If 'yes', repeat steps 6-11. Otherwise, stop the iteration. The rule of thumb is that one should always examine those with high traveling scores and $D_{j\leftrightarrow k}$ = 3 or 4.

Figure 3.6 Generation of primary and temporary parents

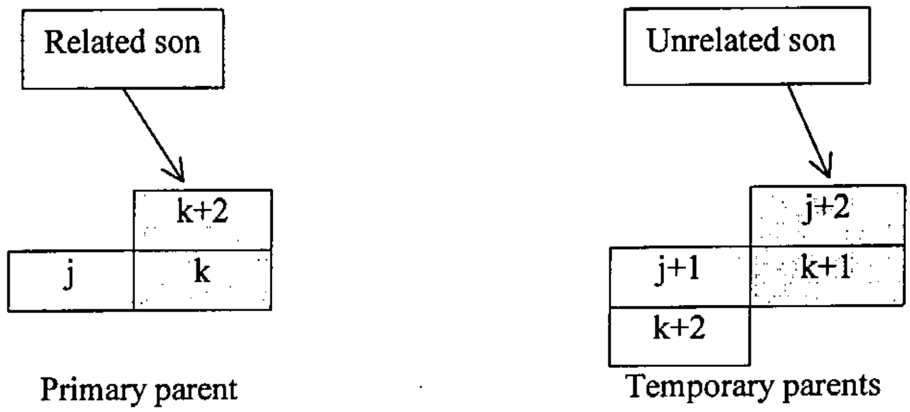


Figure 3.7 Generation of related and unrelated sons

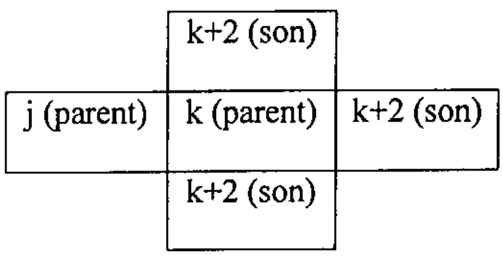


Figure 3.8 Minimum distance between machines

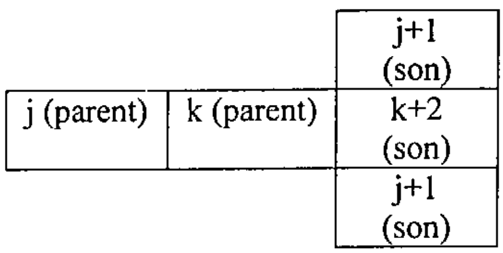


Figure 3.9 Constraint of cell size (3x3 grid)

Stage 3

Step 12a: Determination of the multi-DMCLs

The multi-DMCLs means that successive SMCLs are taken on directly to fit for various periods (see Figure 3.10). Since each SMCL is only good in a specific planning period; therefore, this approach may have some concerns. The reason is that there are possibly high machine rearrangement costs involved.

Step 12b: Determination of the Steady-DMCL throughout planning periods

This is to select a Steady-DMCL from the established SMCLs. Each SMCL attempts to fit into various planning periods to determine the traveling costs in different periods. The summation of traveling costs of a given SMCL over the entire periods provides a value for comparison purpose. Among the possible SMCLs, the one with the minimum total cell layout cost will be the Steady-DMCL. As same layout is used for all planning periods, the total rearrangement cost must be zero (see Table 3.12).

Step 12c: Determination of the modified multi-DMCL

The SMCL for each planning period would be determined by the first two static stages of the proposed MAIN algorithm. However, any original SMCL can also be replicated to eight similar layouts, which are generated by:

(1) original SMCL from stage two;

(2) flip the original SMCL about the diagonal axis that lies from left top to bottom right;

(3) flip the original SMCL about vertical axis though the centre of the matrix;

(4) rotate the original SMCL by 90° counter-clockwise;

(5) rotate the original SMCL by 270° counter-clockwise.

(6) flip original SMCL about center horizontal axis through the centre of the matrix;

(7) flip original SMCL about diagonal axis that lies form right top to bottom left;

(8) rotate the original SMCL by 180° counter-clockwise.

In all these layouts, only the machine at the center of the cell does not change. Figure 3.11 shows eight possible replications of a SMCL.

Step 13: Similarity coefficient calculation

A similarity coefficient is used to find out the pair of most appropriate successive layouts among the replicated SMCLs in two periods (see Figure 3.11 and 3.12). The valves of entities in the similarity coefficient matrix are derived from the proposed equation (see section 3.4-b). In Table 3.13, the second row and second column numbers on the similarity coefficient matrix represent the replicated layouts from first and second planning periods respectively. For example, $SC_{1\rightarrow 2(1,01)}$ means that two layouts at left-top corner is evaluated for the similarity. Obviously, both of machines A and B do not change location but the other machines C, D, E, F, G, H and I will be rearranged. As the result, the entity (1,01) in similarity coefficient matrix is equal to 0.22.

Step 14: Minimization of total rearrangement costs

This is done by selecting maximum value entities in the similarity coefficient matrix. In Table 3.13, the maximum value in the similarity coefficient matrix is equal to 0.22, which involve 16 entities (1,01), (1,03), (2,02) and (2,04), etc. Although the value of similarity coefficient is the same, the basic cost for machines relocation and cost per unit machine movement may not be identical (see Table 3.14 and 3.15). This implies that the total cell layout cost will be different for layouts. For example, total rearrangement cost in entity (1,01) is \$1391 and in entity (2,04) is \$1331 (see Figure 3.13 and Figure 3.14). Since the purpose of this step is to minimize the total rearrangement cost, so that entity (2,04) will be the best for two successive layouts. In fact, there are 16 entities with the SC values equal to 0.22, and each of them will need to be examined.

Step 15: Repeat steps 12-14 until successive layouts are identified for all periods.

Step 16: Comparing steps 12a (multi-DMCLs), 12b (Steady-DMCL) and 12c (modified multi-DMCLs) to decide the best layout

The total cell layout cost (α) is determined by the equation 5, which involves total traveling costs ($\zeta_p*\omega$) and total rearrangement costs ($R_{P\to P+1(t\leftrightarrow s)}$) in all periods.

I	H	G
E	F	D
C	B	A
ζ=2400		
SMCL-1		

G	C	H
F	E	I
D	B	A
ζ=3200		
SMCL-2		

A	H	E
C	F	D
G	I	B
ζ=2750		
SMCL-3		

A	H	E
I	G	B
C	D	F
ζ=3850		
SMCL-4		

G	A	I
B	D	C
H	F	E
ζ=2630		
SMCL-5		

Figure 3.10 Determination of the multi-DMCL from successive SMCLs

Table 3.12 Determination of the Steady-DMCL

Planning period / Total traveling cost (ζ x ω) ($)	p=1	p=2	p=3	p=4	p=5	Total (a)
SMCL-1	2400	3340	2870	4490	2930	16030
SMCL-2	2530	3200	2960	4300	2810	15800
SMCL-3	2680	3480	2750	4240	2770	15920
SMCL-4	2540	3320	3230	3850	2790	15730
SMCL-5	2730	3450	2840	4270	2630	15920
Minimum of total cell layout cost (α)	α = (a) + (b) (b) = total rearrangement cost is zero					**15730**

* ω = $10/unit traveling score

I	H	G
E	F	D
C	B	A
ζ_1=2400		
(1)		

I	E	C
H	F	B
G	D	A
ζ_1=2400		
(2)		

G	H	I
D	F	E
A	B	C
ζ_1=2400		
(3)		

G	D	A
H	F	B
I	E	C
ζ_1=2400		
(4)		

C	E	I
B	F	H
A	D	G
ζ_1=2400		
(5)		

C	B	A
E	F	D
I	H	G
ζ_1=2400		
(6)		

A	D	G
B	F	H
C	E	I
ζ_1=2400		
(7)		

A	B	C
D	F	E
G	H	I
ζ_1=2400		
(8)		

Figure 3.11 Eight replicated SMCLs on the first planning period

G	C	H
F	E	I
D	B	A
ζ_2=3200		
(01)		

G	F	D
C	E	B
H	I	A
ζ_2=3200		
(02)		

H	C	G
I	E	F
A	B	D
ζ_2=3200		
(03)		

H	I	A
C	E	B
G	F	D
ζ_2=3200		
(04)		

D	F	G
B	E	C
A	I	H
ζ_2=3200		
(05)		

D	B	A
F	E	I
G	C	H
ζ_2=3200		
(06)		

A	I	H
B	E	C
D	F	G
ζ_2=3200		
(07)		

A	B	D
I	E	F
H	C	G
ζ_2=3200		
(08)		

Figure 3.12 Eight replicated SMCLs on the second planning period

Table 3.13 Similarity coefficient matrix

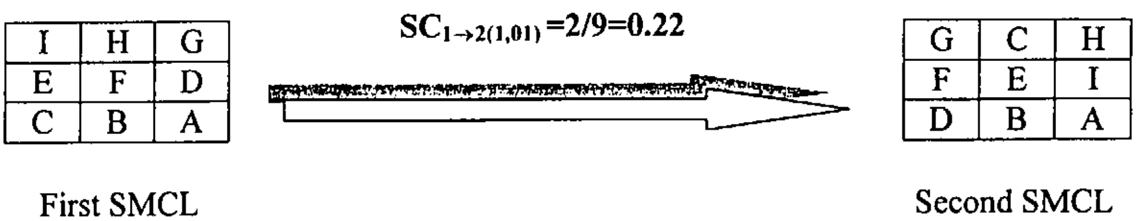
(SMCLs)		P-2							
		01	02	03	04	05	06	07	08
P-1	1	0.22	0.11	0.22	0	0.11	0	0	0
	2	0.11	0.22	0	0.22	0	0.11	0	0
	3	0.22	0.11	0.22	0	0.11	0	0	0
	4	0.11	0.22	0	0.22	0	0.11	0	0
	5	0	0	0.11	0	0.22	0	0.22	0.11
	6	0	0	0	0.11	0	0.22	0.11	0.22
	7	0	0	0.11	0	0.22	0	0.22	0.11
	8	0	0	0	0.11	0	0.22	0.11	0.22

Table 3.14 Basic cost for machine relocation

	Basic cost for machine relocation (M_j)								
M/C	A	B	C	D	E	F	G	H	I
($)	150	100	200	320	180	90	240	130	90

Table 3.15 Cost per unit machine movement

	Cost per unit machine movement (C_j)								
M/C	A	B	C	D	E	F	G	H	I
($)	15	10	20	32	18	9	24	13	9



$M_C+M_D+M_E+M_F+M_G+M_H+M_I$ = \$1120

$C_C*3+C_D*3+C_E*1+C_F*1+C_G*2+C_H*1+C_I*3$ = \$271

$R_{1\rightarrow 2(1,1)} = \Sigma M_j + \Sigma C_j*D_{j,k}$ = \$1391

Figure 3.13 Similarity coefficient matrix - entity (1,01)

$SC_{1\rightarrow 2(2,04)}=2/9=0.22$

I	E	C
H	F	B
G	D	A

First SMCL

H	I	A
C	E	B
G	F	D

Second SMCL

$M_A+M_C+M_D+M_E+M_F+M_H+M_I = \$1160$

$C_A*3+C_C*3+C_D*1+C_E*1+C_F*2+C_H*1+C_I*3 = \$171$

$R_{1\rightarrow 2(1,1)} = \Sigma M_j + \Sigma C_j*D_{j,k} = \$1331$

Figure 3.14 Similarity coefficient matrix - entity (2,04)

3.6 Summary

In this chapter, three stages of the MAIN algorithm were described. These heuristic steps of the MAIN algorithm were introduced whereas the SMCL was determined in Stage 1 and Stage 2. In stage 3, three techniques for examining the DMCL were illustrated. To enhance this algorithm, the modified similarity coefficient model was established to assist the search for the best successive layouts over multi-planning periods in the dynamic case.

4. CASES FOR NUMERICAL ANALYSIS

In this chapter, some numerical information provided by a number of research cases in machine layout will be used to investigate the proposed MAIN algorithm. The results obtained by the proposed MAIN algorithm will also be compared with some other approaches.

4.1 Example Cases

In this section, the procedures of MAIN algorithm are evaluated with the numerical figures. The basic data were obtained from Yaman et al. [80] and Tang et al. [81]. They gave information such as the operational sequences and the quantitative demands on each part, but did not provide the movement costs for machines. Therefore, the author will assign a fixed cost for all machines to simulate the need of the MAIN algorithm without distributing the results of the comparison. Conway et al. [20] and Rosenblatt [3] only offered the from-to matrix and movement cost for each machine, but no operational sequence and quantitative demand on each part was supplied. Therefore, the author combined two sets of data to validate the MAIN algorithm.

CHAPTER FOUR: CASES FOR NUMERICAL ANALYSIS

4.1.1 Yaman's and Tang's Approaches

These cases used the same set of data and a 3x3 grid for the purpose of locating machines. Yaman's approach will be examined first and then Tang's approach becomes next.

(a) Case 1: Yaman approaches

Yaman developed 'a sorting methods' to solve the layout problem. The overall methods can be divided into three stages:

(1) Data entry;

(2) Calculations;

(3) Arrangement of the sorted elements.

Yaman's layout example involved five parts, which were processed by nine machines. For each part, operation sequence and quantitative demands in five planning periods were proposed (see Table 4.1 & 4.2). He used two spiral types of physical arrangement methods to allocate machines into a 3x3 grid (see Figure 4.1) according to the ranking of part flow frequencies. The two spiral types generated fairly good layout results.

Table 4.1 Original data of Yaman's & Tang's cases

Type of parts	Operation sequence of parts
1	01→03→05→07→02→07→09
2	01→04→02→05→06→08→09
3	01→05→07→08→05→06→02→09
4	01→02→04→06→07→08→02→03→09
5	01→07→06→04→02→08→03→05→06→09

Table 4.2 Demands in Yaman's & Tang's cases

Type of parts	P-1	P-2	P-3	P-4	P-5
1	10	35	90	40	55
2	30	50	25	65	20
3	45	15	40	70	15
4	70	80	55	90	85
5	85	60	70	20	30

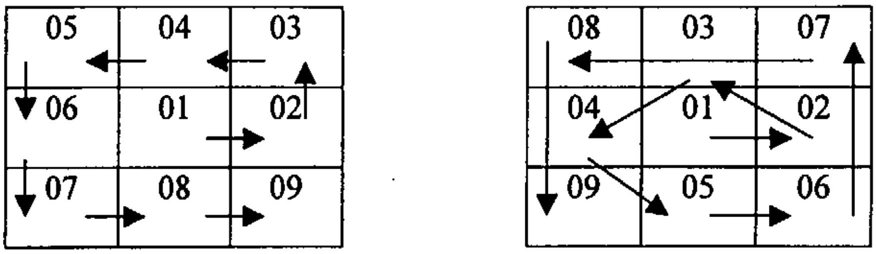


Figure 4.1 Yaman's approaches (spiral type one and two)

(b) Case 2: Tang approach

Tang proposed the hierarchical interactive approach for solving the layout problem. This approach generates improved results in comparison with Yaman's algorithm but the procedures are also more complicated. This approach consists of three major phases:

(1) Clustering procedure to rationalize the master flow network;

(2) Planned flow pattern which take into account the aisle designation;

(3) Allocating machines and storage areas around the designated aisle.

The quantitative demands and profile of parts during various planning periods being used in this study were the same as Yaman's problem. As a result, all the generated layouts have a lower total traveling score (ζ) than the Yaman's approach.

4.1.2 Conway's Approach

Conway presented the use of the genetic algorithm to evolve an initial population of solutions into a population of superior solutions. Two tests were used to investigate the approach, where the population was 400 and the generations attempted were 50 and 100. However, the optimal layouts are not guaranteed. Obviously, the result is very dependent on conditions such as the population size, the number of generations, the crossover and mutation rate, etc. Five planning periods were also involved with nine machines. The parts flow data is shown in the from-to chart in Table 4.3. The rearrangement cost per machine is in Table 4.4.

Table 4.3 Original part flow data of Conway's case

Planning period (p-1)									
	To								
From	0	3622	258	493	697	296	627	552	287
	991	0	316	443	570	684	334	283	1043
	673	6522	0	484	114	324	611	762	762
	791	4369	203	0	170	1031	598	923	788
	867	5146	56	203	0	1121	309	154	361
	894	3264	71	62	769	0	664	343	282
	714	3113	240	506	831	1183	0	1144	311
	588	1319	319	161	826	1194	744	0	773
	1096	6521	335	317	459	439	416	1222	0

Planning period (p-2)									
	To								
From	0	136	6371	886	1596	213	499	1378	476
	657	0	3461	1275	567	254	405	263	449
	590	528	0	488	498	273	311	1277	486
	179	684	1305	0	1748	101	462	1008	559
	772	550	6113	478	0	261	53	1134	1285
	511	822	2046	1105	1404	0	384	405	875
	577	690	2362	925	944	139	0	847	312
	300	461	3343	514	676	128	487	0	214
	291	560	6306	397	235	243	466	963	0

Planning period (p-3)									
	To								
From	0	265	720	3275	361	230	580	221	1433
	695	0	816	5276	636	683	637	1877	203
	901	1535	0	2322	323	592	129	857	979
	1138	298	987	0	400	1051	163	238	924
	619	478	856	4205	0	615	81	991	990
	647	1373	441	722	608	0	128	603	1040
	1008	1383	772	3552	497	836	0	1795	211
	1348	682	233	892	206	600	448	0	679
	1291	2281	595	3972	89	840	257	348	0

Planning period (p-4)									
	To								
From	0	753	632	1686	722	241	192	510	63
	840	0	897	795	3331	1274	426	611	442
	2138	895	0	1277	3019	693	88	470	514
	561	445	1444	0	1123	385	523	2015	428
	335	421	1549	560	0	820	251	1480	455
	636	515	776	1590	5257	0	781	504	416
	571	625	765	1304	5312	954	0	647	82
	1675	297	176	1137	1240	1313	715	0	321
	1187	1550	751	441	840	336	252	1695	0

Planning period (p-5)									
	To								
From	0	1017	663	1460	1118	804	256	1291	246
	854	0	1102	1476	1109	2931	975	1032	403
	850	1017	0	1503	412	4102	613	1083	140
	525	205	792	0	1060	3647	196	591	981
	1653	113	1133	1501	0	2160	203	706	695
	981	686	184	852	450	0	155	560	962
	781	1010	353	319	648	2043	0	914	185
	2031	701	930	755	1113	1883	772	0	175
	867	580	377	478	284	4879	106	325	0

Table 4.4 Original machine rearrangement cost in Conway's case

Rearrangement cost									
M/C	01	02	03	04	05	06	07	08	09
Cost	802	985	517	500	736	910	768	564	923

4.1.3 Rosenblatt's Approach

Rosenblatt proposed a dynamic programming formulation for solving the dynamic layout problem. Both optimal and heuristic procedures were developed for this problem. Furthermore, it assumed that the rearrangement cost was independent of the distances between original and new locations. Five planning periods and six machines were involved. The parts flow data is shown in the from-to chart in Table 4.5, and the rearrangement cost are given in Table 4.6.

Table 4.5 Original part flow data of Rosenblatt's case

Planning period (p-1)						
	To					
From	0	63	605	551	116	136
	63	0	625	941	50	191
	104	71	0	569	136	55
	65	193	622	0	77	90
	162	174	607	591	0	179
	156	13	667	611	175	0

Planning period (p-2)						
	To					
From	0	175	804	904	56	176
	63	0	743	936	45	177
	168	85	0	918	138	134
	51	94	962	0	173	39
	97	104	730	634	0	144
	95	115	983	597	24	0

Planning period (p-3)						
	To					
From	0	90	77	553	769	139
	168	0	114	653	525	185
	32	35	0	664	898	87
	27	166	42	0	960	179
	185	56	44	926	0	104
	72	128	173	634	687	0

Planning period (p-4)						
	To					
From	0	112	15	199	665	649
	153	0	116	173	912	671
	10	28	0	182	855	542
	29	69	15	0	552	751
	198	71	42	24	0	758
	62	109	170	90	973	0

Planning period (p-5)						
	To					
From	0	663	23	128	119	50
	820	0	5	98	141	66
	822	650	0	137	78	91
	826	570	149	0	93	151
	915	515	53	35	0	177
	614	729	178	10	99	0

Table 4.6 Original machine rearrangement cost in Rosenblatt's case

Rearrangement cost						
M/C	01	02	03	04	05	06
Cost	887	964	213	367	289	477

4.1.4 Self-developed Test Cases

We randomly generate two more test cases. Ten parts in the part family are processed by nine machines in the cell. Five periods with varying quantitative demands are generated to reflect the actual production environment (see Table 4.7 & 4.8). In Table 4.9, different parts are possessed by different operation sequences and part handling factors may also vary. The basic costs and costs per unit machine movements for various machines are given in Table 4.10 & 4.11.

Table 4.7 Data for self-developed case five

	Planning periods					
Part no.	p-1	p-2	p-3	p-4	p-5	Total
1	10	20	30	70	90	220
2	20	61	80	44	65	270
3	34	30	98	67	32	261
4	45	45	45	45	45	225
5	59	37	74	87	110	367
6	50	21	18	12	8	109
7	77	80	90	53	79	379
8	112	150	140	160	121	683
9	96	30	20	72	53	271
10	44	11	68	9	88	220

Table 4.8 Data for self-developed case six

	Planning periods					
Part no.	p-1	p-2	p-3	p-4	p-5	Total
1	120	145	167	189	194	815
2	40	52	46	93	21	252
3	98	46	27	38	74	283
4	45	45	45	45	45	225
5	61	22	100	88	37	308
6	27	16	15	34	13	105
7	65	79	53	46	23	266
8	172	144	138	169	213	836
9	81	15	13	24	117	250
10	41	32	6	70	53	202

Table 4.9 The operational sequences and part handling factors (case five & six)

Part no	Operational sequences	Part handling factors
1	01→04→06→04→05→03→09	5→5→4→3→2→1
2	01→06→04→07→08→09	4→2→2→1→1
3	01→05→03→02→05→09	1→1→2→3→4
4	01→02→03→05→04→06→09	1→2→3→3→4→4
5	01→08→04→06→05→02→03→05→09	1→1→1→1→1→2→2→2
6	01→03→04→07→09	7→6→5→4
7	01→06→05→02→06→08→03→09	1→1→1→2→2→3→3
8	01→02→04→06→05→03→05→09	1→1→1→1→1→2→2
9	01→04→05→07→03→08→09	4→3→2→1→1→1
10	01→07→08→02→06→04→05→03→09	5→4→3→2→1→2→3→4

Table 4.10 Machine rearrangement cost for case five

Basic cost for machine relocation (M_j) for case five									
M/C	01	02	03	04	05	06	07	08	09
($)	780	650	930	820	620	670	770	910	860
Cost per unit machine movement (C_j) for case five									
($)	78	65	93	82	62	67	77	91	86

Table 4.11 Machine rearrangement cost for case six

Basic cost for machine relocation (M_j) for case six									
M/C	01	02	03	04	05	06	07	08	09
($)	940	640	1100	450	390	780	990	420	520
Cost per unit machine movement (C_j) for case six									
($)	94	64	110	45	39	78	99	42	52

4.2 Application of the MAIN Algorithm

The proposed MAIN algorithm addresses the layout problem by examining the relationship between pairs of machines. If two machines have certain connections, then $F_{p,j\leftrightarrow k}$ would be obtained by comparing these machines. As mentioned before, the overall operations are separated into three stages. Referring to the product information given by Yaman, the details about using the MAIN algorithm are illustrated in below.

<u>Stage 1</u>

Step 1: Data collection

Information relating to production is collected in Table 4.1 & 4.2 for planning period 1 (p-1); the operations for other periods are similar. In here, both transportation quantities, $H_{i,j\rightarrow k}$ and part handling factors, $\lambda_{i,j\rightarrow k}$ are equal to "1". It is because Yaman and Tang did not consider part handling factors, and the reason for doing this is to enable subsequent comparison to be made.

Step 2: Establishment of operational matrices

In period 1 (p-1), five matrices are used to summarize the part transportation frequencies for five parts. As mentioned before, the part handling factors and transportation quantities are set to '1', therefore the operations are quite straightforward here.

To (Part 1)

	M/C	01	02	03	04	05	06	07	08	09
	01			10						
	02							10		
	03					10				
	04									
From	05							10		
	06									
	07		10							10
	08									
	09									

To (Part 2)

	M/C	01	02	03	04	05	06	07	08	09
	01				30					
	02					30				
	03									
	04		30							
From	05						30			
	06								30	
	07									
	08									30
	09									

To (Part 3)

	M/C	01	02	03	04	05	06	07	08	09
	01					45				
	02									45
	03									
	04									
From	05						45	45		
	06		45							
	07								45	
	08					45				
	09									

To (Part 4)

	M/C	01	02	03	04	05	06	07	08	09
	01		70							
	02			70	70					
	03									70
	04						70			
From	05									
	06							70		
	07								70	
	08		70							
	09									

To (Part 5)

	M/C	01	02	03	04	05	06	07	08	09
	01							85		
	02								85	
	03					85				
	04		85							
From	05						85			
	06				85					85
	07						85			
	08			85						
	09									

A sorted set of matrices (p-1)

Step 3: Formulation of the part flow weight matrix

The part flow weight matrix is obtained by summing up all the numbers in the same slots in the five operational matrices above. Basically, these are the normalized unidirectional relationship of machine pairs.

		To								
	M/C	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**
	01		70	10	30	45		85		
	02			70	70	30		10	85	45
	03					95				70
	04		115				70			
From	**05**						160	55		
	06		45		85			70	30	85
	07		10				85		115	10
	08		70	85		45				30
	09									

Part flow weight matrix (p-1)

Step 4: Determination of the merged part flow weight matrix

The merged part flow weight matrix is obtained by combining the unidirectional data of every machine pair. Since the figures from the part flow weight matrix are merged, one can make a summation to get the bi-directional know-how of a machine pair.

M/C	01	02	03	04	05	06	07	08	09
01		70	10	30	45		85		
02			70	185	30	45	20	155	45
03					95			85	70
04						155			
05						160	55	45	
06							155	30	85
07								115	10
08									30
09									

Merged part flow weight matrix (p-1)

Step 5: Ranking of the merged part flow weight matrix

Based on the results in the last step, one can rank the machine pairs accordingly.

M/C	01	02	03	04	05	06	07	08	09
01		7	12	10	9		6		
02			7	1	10	9	11	3	9
03					5			6	7
04						3			
05						2	8	9	
06							3	10	6
07								4	12
08									10
09									

Ranked merged part flow weight matrix

<u>Stage 2</u>

Step 6: Allocation of pair-wise machines according to the ranking levels.

Readers can refer to Table 4.12 for the initial allocation of maximum $F_{p,j \to k}$.

Primary parents

2	4

Step 7: Pulling the machines based on the ranking order

The second machine pair is (5,6) in Table 4.12. Since there is no connection to the primary parents, temporary parents will be generated.

2	4

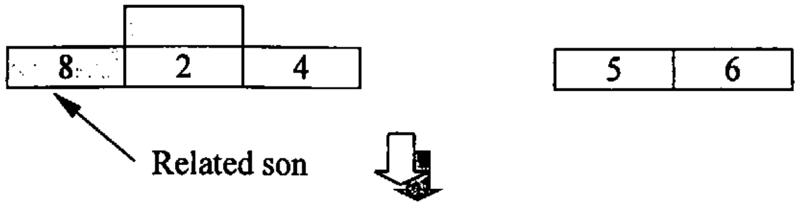
Primary parents

5	6

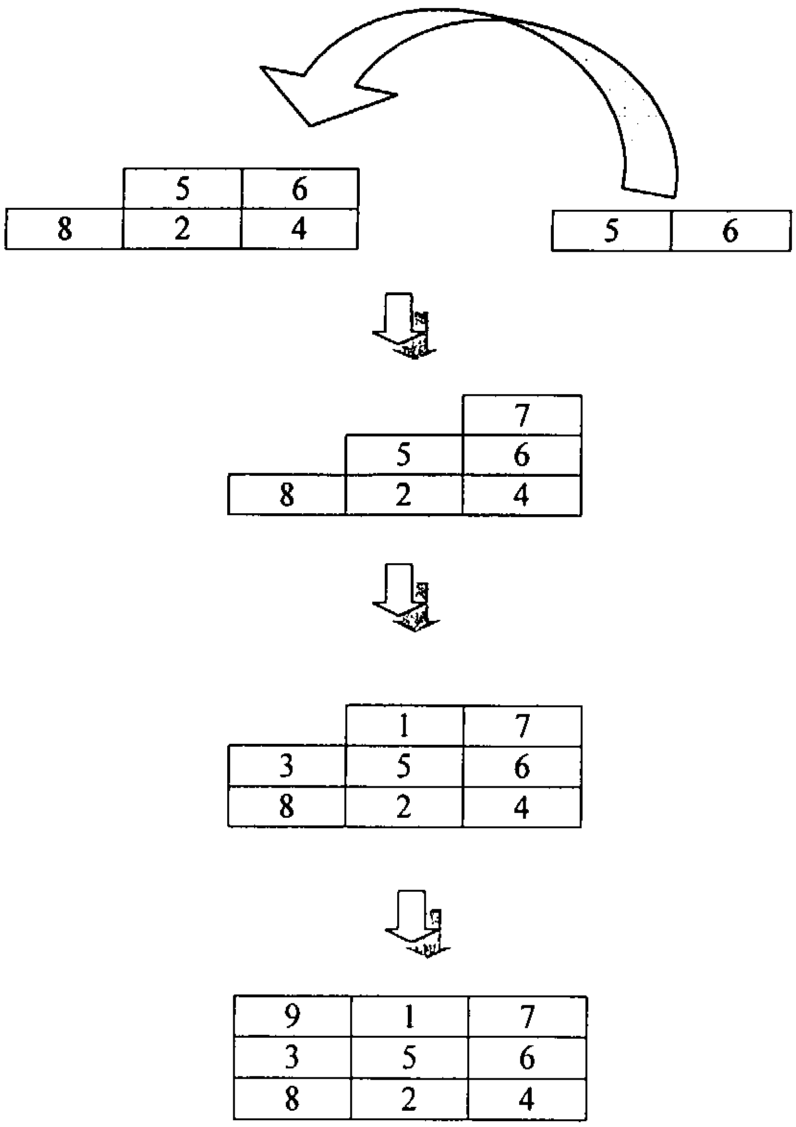
Temporary parents

Step 8: Machines positioning consideration

In this case, machine 8 links to machine 2 from the primary parents. Although there are two possible locations for machine 8, we just select either one arbitrarily.



Step 9: Repeat Step 7 and 8 until all machines are allocated into the space area.



First iteration, $\zeta_1 = 2980$

Step 10: Calculation of total traveling score

Determine the total traveling score at the first iteration ($\zeta_1 = 2980$) and this acts as the datum for improvement. See Table 4.12.

Step 11: Evaluation of traveling scores

As $F_{1,(7\leftrightarrow 8)} \times D_{7\leftrightarrow 8} = 115 \times 4 = 460$ is quite a large value. Second iteration is target at this by repeating Steps 6 to 11. These machines can be placed more closely, so as to reduce the distance. Referring to Table 4.12, in second iteration $\zeta_1 = 2850$.

2	4	1
8	6	7
3	5	9

Second iteration, $\zeta_1 = 2850$

All preliminary results generated by the proposed MAIN algorithm are better than Yaman's approaches (see Table 4.13 & 4.14). Although some results may not be better than Tang's approach, there are improvements in planning period 2, 3 and 5 in Table 4.15. Among all tested heuristics, the proposed MAIN algorithm is the best in overall performance and the average error is the least.

Table 4.12 The traveling scores within the first planning period

Ranking	(j↔k)	$F_{p,j\leftrightarrow k}$	$D_{j\leftrightarrow k}$	Iteration 1 (ζ)	$D_{j\leftrightarrow k}$	Iteration 2 (ζ)
1	2,4	185	1	185	1	185
2	5,6	160	1	160	1	160
3	2,8	155	1	155	1	155
	4,6	155	1	155	1	155
	6,7	155	1	155	1	155
4	7,8	115	4	460	2	230
5	3,5	95	1	95	1	95
6	1,7	85	1	85	1	85
	3,8	85	1	85	1	85
	6,9	85	3	255	2	170
7	1,2	70	2	140	2	140
	2,3	70	2	140	2	140
	3,9	70	1	70	2	140
8	5,7	55	2	110	2	110
9	1,5	45	1	45	3	135
	2,6	45	2	90	2	90
	2,9	45	3	135	4	180
	5,8	45	2	90	2	90
10	1,4	30	3	90	1	30
	2,5	30	1	30	3	90
	6,8	30	3	90	1	30
	8,9	30	2	60	3	90
11	2,7	20	3	60	3	60
12	1,3	10	2	20	4	40
	7,9	10	2	20	1	10
				ζ_1=2980		ζ_1=2850

Table 4.13 First iterative results of the proposed MAIN algorithm

9	1	7
3	5	6
8	2	4
ζ_1=2980		

9	3	5
1	7	6
8	2	4
ζ_2=2880		

9	8	6
1	3	5
4	2	7
ζ_3=3710		

7	5	6
8	2	4
9	1	3
ζ_4=3165		

5	7	6
8	2	4
3	1	9
ζ_5=2275		

Table 4.14 Second iterative results of the proposed MAIN algorithm

2	4	1
8	6	7
3	5	9
ζ_1=2850		

2	4	1
8	6	7
3	5	9
ζ_2=2790		

1	8	3
2	7	5
4	9	6
ζ_3=3160		

1	2	4
9	8	6
3	7	5
ζ_4=3225		

1	2	4
9	8	6
3	5	7
ζ_5=2475		

Table 4.15 Best results generated by tested approaches

Methods	**Profile 1** (ζ_1)	**Profile 2** (ζ_2)	**Profile 3** (ζ_3)	**Profile 4** (ζ_4)	**Profile 5** (ζ_5)	**Total** ($\Sigma\zeta$)	**% of error**
Optimal	2780	2640	2950	3020	2200	13590	--
Yaman (1)	3630	3180	3690	3975	3045	17520	28.9
Yaman (2)	3470	3350	3570	4065	2975	17430	28.3
Tang	2820	2980	3200	3100	2355	14455	6.4
MAIN	2850	2790	3160	3165	2275	14240	4.8

Stage 3:

Step12a: Determination of the multi-DMCLs

In terms of multi-DMCLs, all formulated SMCLs will be used exactly with machine rearrangement costs will be involved.

p-1		
2	4	1
8	6	7
3	5	9
ζ_1=2850		

p-2		
2	4	1
8	6	7
3	5	9
ζ_2=2790		

p-3		
1	8	3
2	7	5
4	9	6
ζ_3=3160		

p-4		
7	5	6
8	2	4
9	1	3
ζ_4=3165		

p-5		
5	7	6
8	2	4
3	1	9
ζ_5=2275		

Step12b: Determination of the Steady-DMCL throughout planning periods

Sometimes, it is good to have a consistent layout and a SMCL will be adopted for all periods. Since there are five periods involved, five generated SMCLs will be examined. Naturally, the one with minimum overall total traveling cost should be chosen and it is SMCL-5 in this case.

Planning period / Total traveling cost (ζ x ω)($)	p=1	p=2	p=3	p=4	p=5	Total (a)
SMCL-1	28500	27900	35100	36100	25300	152900
SMCL-2	28500	27900	35100	36100	25300	152900
SMCL-3	31400	29700	31600	35150	24650	152500
SMCL-4	32600	30200	35900	31650	24550	154900
SMCL-5	29400	28200	31700	33650	22750	145700
Minimum of total cell layout cost (α)	(b) total rearrangement cost is zero α = (a) + (b)					145700

Step12c: Determination of the modified multi-DMCL

There are eight possible replications for a SMCL. In below, the replications for periods 2 and 3 are presented.

t = 1		
2	4	1
8	6	7
3	5	9
ζ_2=2790		

t = 2		
2	8	3
4	6	5
1	7	9
ζ_2=2790		

t = 3		
1	4	2
7	6	8
9	5	3
ζ_2=2790		

t = 4		
1	7	9
4	6	5
2	8	3
ζ_2=2790		

t = 5		
3	8	2
5	6	4
9	7	1
ζ_2=2790		

t = 6		
3	5	9
8	6	7
2	4	1
ζ_2=2790		

t = 7		
9	7	1
5	6	4
3	8	2
ζ_2=2790		

t = 8		
9	5	3
7	6	8
1	4	2
ζ_2=2790		

s = 01		
1	8	3
2	7	5
4	9	6
ζ_3=3160		

s = 02		
1	2	4
8	7	9
3	5	6
ζ_3=3160		

s = 03		
3	8	1
5	7	2
6	9	4
ζ_3=3160		

s = 04		
3	5	6
8	7	9
1	2	4
ζ_3=3160		

s = 05		
4	2	1
9	7	8
6	5	3
ζ_3=3160		

s = 06		
4	9	6
2	7	5
1	8	3
ζ_3=3160		

s = 07		
6	5	3
9	7	8
4	2	1
ζ_3=3160		

s = 08		
6	9	4
5	7	2
3	8	1
ζ_3=3160		

Step 13: Similarity coefficient calculation

Modified SC is utilized to calculate values in this matrix. People can refer to section 3.4 for details.

SC		p-3							
		01	02	03	04	05	06	07	08
p-2	1	0	0.33	0.11	0.11	0.22	0	0	0.11
	2	0.33	0	0.11	0.11	0	0.22	0.11	0
	3	0.11	0.22	0	0	0.33	0.11	0.11	0
	4	0.22	0.11	0	0	0.11	0.33	0	0.11
	5	0.11	0	0.33	0.11	0	0	0.11	0.22
	6	0	0.11	0.11	0.33	0	0	0.22	0.11
	7	0	0.11	0.22	0	0.11	0.11	0	0.33
	8	0.11	0	0	0.22	0.11	0.11	0.33	0

Step 14: Minimization of total rearrangement costs

Eight entities in the similarity coefficient matrix have the maximum value of 0.33 for periods 2 to 3. These are (1,02), (2,01), (3,05), (4,06), (5,03), (6,04), (7,08) and (8,07). Remember, the rearrangement costs in eight entities may not be the same. For example, the rearrangement cost for (1,02) is $M_1+M_2+M_4+M_6+M_7+M_9$ $+C_1*2+C_2*1+C_4*1+C_6*2+C_7*1+C_9*1$ = \$1113 (also see Table 3.14 & 3.15).

Step 15: Repeat steps 12-14

Five successive modified multi-DMCLs are determined as below. The rearrangement costs from one planning period to next are: $R_{1\to 2(1,1)}$=\$0, $R_{2\to 3(1,2)}$=\$1113, $R_{3\to 4(2,6)}$=\$812 and $R_{4\to 5(6,6)}$=\$462.

P-1		
2	4	1
8	6	7
3	5	9
ζ_1=2850		

P-2		
2	4	1
8	6	7
3	5	9
ζ_2=2790		

P-3		
1	2	4
8	7	9
3	5	6
ζ_3=3160		

P-4		
9	1	3
8	2	4
7	5	6
ζ_4=3165		

P-5		
3	1	9
8	2	4
5	7	6
ζ_5=2275		

Step 16: Comparing steps12a, 12b and 12c to determine the best layout

Multi-DMCLs (In step12a):

Total traveling cost ($\Sigma\zeta_p*\omega$) is 14240*10 = $142400

Total rearrangement cost ($\Sigma R_{p\rightarrow p+1}$) is $1829+$1660+$462 = $3951

Total cell layout cost (α) is **$146,351**

Steady-DMCL (In step 12b):

Total traveling cost ($\Sigma\zeta_p*\omega$) is $29400+$28200+$31700+$33650+$22750=

$145700

Total rearrangement cost ($\Sigma R_{p\rightarrow p+1}$) is = $0

Total cell layout cost (α) is **$145,700**

Modified mult-DMCLs (In step 12c):

Total traveling cost ($\Sigma\zeta_p*\omega$) is 14240*10 = $142400

Total rearrangement cost ($\Sigma R_{p\rightarrow p+1}$) is $1113+$812+$462 = $2387

Total cell layout cost (α) is **$144,787**

Therefore, the modified multi-DMCLs is the best layout in this case.

4.3 Summary

In this chapter, the proposed MAIN algorithm was evaluated, and was able to supply positive cellular machine layouts both cases one and two. Also, the SMCLs associated with the modified similarity coefficient technique to search the best two successive SMCL over multi-planning periods were shown. This helped to determine the machine reallocation pattern to be used from a planning period to the succeeding planning period with the least cost.

5. EXPERIMENTS AND RESULTS

Four experiments will be conducted to test the performance of the MAIN algorithm in various conditions. The first experiment is used to evaluate the performance of SMCLs by using the first two stages of the proposed MAIN algorithm. The second experiment evaluates the performance of multi-DMCLs, in which the total cell layout cost is calculated and was used as an indicator for reflecting the effectiveness of the machine layout. The third experiment is similar to the second experiment. In the third experiment, we assume that the machines will be rearranged to adopt new conditions according to the results of the modified SC and Step 12c of the MAIN algorithm. The last experiment is used to determine the best steady-DMCL among the existing SMCLs. The best is the one with minimum total cell layout cost over entire planning periods. In section 5.1, methods for evaluating the solution quality and measuring the performance of the proposed MAIN algorithm are introduced. Then, the design of experiments is described in detail. The results of the experiments are showed in section 5.3-5.7.

5.1 Establishment of Performance Indicators

Performance of the MAIN algorithm will be evaluated by looking into the solution quality. The study will be primarily divided into two stages. First, the total traveling cost and the percentage of errors are compared with optimum results in different planning periods. Second, the dynamic stage would be measured by total cell layout cost and total rearrangement cost. All these methods require some calculations, and these will be described in the following sections.

5.1.1 Absolute Solution Quality

Absolute solution quality is to measure the solution by checking the closeness of a solution to the optimal solution. Therefore, the performance of the proposed MAIN algorithm and other machine layout approaches can be compared.

In the DMCL state, α_m will be the solution calculated by the proposed MAIN algorithm (see section 3.2), and α_c is solution obtained by any other existing approaches. α_a is the best solution offers by searching the n! solution spaces and a computer program is used to calculate α_a. The absolute solution qualities (QA_c & QA_m) are defined as:

$$QA_c = \frac{\alpha_a}{\alpha_c} \tag{7}$$

$$QA_m = \frac{\alpha_a}{\alpha_m} \tag{8}$$

The quality of a solution is degrading if either the QA_c or the QA_m are moving away from 1 to a smaller value.

5.1.2 Relative Solution Quality

One of the main disadvantages of the absolute solution quality measurement is that it is very time consuming to get the optimal solution. This is especially true of problems with large solution spaces. To overcome this difficulty, the relative solution quality (QR) is formulated as follows:

$$QR = \frac{\alpha_c - \alpha_m}{\alpha_c} \times 100\% \qquad (9)$$

The relative quality solution shows the difference between the current approaches and the proposed MAIN algorithm.

5.2 Experiments Design

MATLAB running in a Pentium Pro 233MHz personal computer is used to program the software. Furthermore, the software can operate some proposed heuristic steps. In this research, four experiments will be conducted in order to validate the performance of the MAIN algorithm at different stages. Experiment one is used to evaluate the performance of the first two stages of the MAIN algorithm, while the next three experiments are used to evaluate the third stage of the algorithm. The details of each experiment are illustrated in the following sections. Generally, each experiment is divided into two parts. The first shows the optimal results generated by software program, while the second gives the outcomes from the MAIN algorithm. Moreover, each part will be separated into two divisions. In the first division, the part handling factor is neglected. The second division assumes that the effort of parts transportation is highly dependent on the sizes, shapes and weights, etc. Therefore, the part handing factors would be significant. Additionally, the results of some existing approaches are shown in Appendix II. Figure 5.1 also shows the overall experiment design in this project.

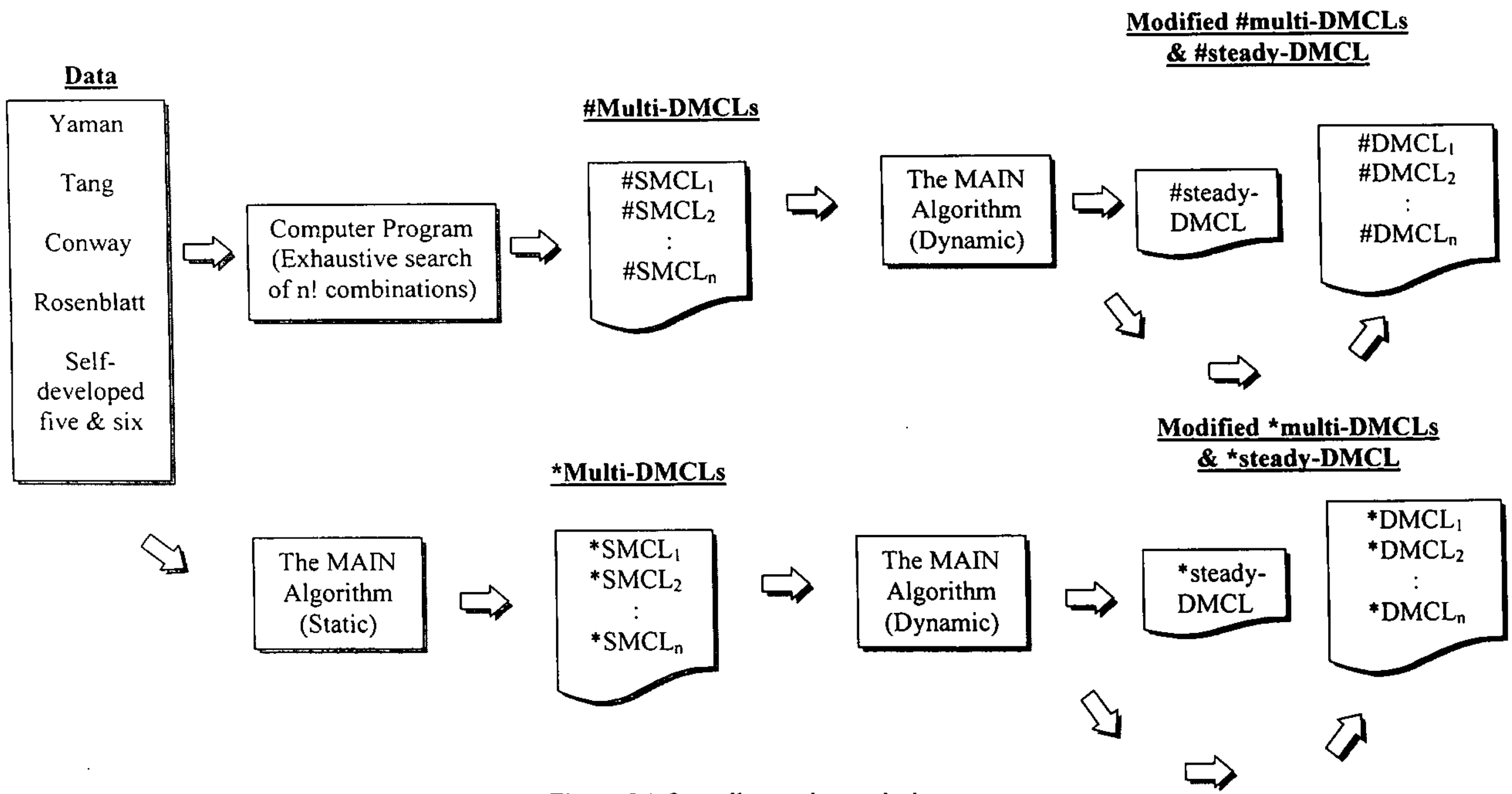


Figure 5.1 Overall experiment design

#SMCLn – Optimal solution obtained by computer program
*SMCLn – Solution obtained by MAIN algorithm (Static state)
n – Planning Period with varying demands

CHAPTER FIVE: EXPERIMENTS AND RESULTS

(a) Experiment1

The first experiment does not take into consideration the dynamic layout between successive periods. It only determines a particular SMCL and evaluates the performance of this SMCL in a specific planning period. Meanwhile, if the quantitative demands vary over planning periods, the machine locations will need to be rearranged to suit the new demands.

Optimal solutions are generated for four cases (see section 4.1.1 & 4.1.4) by software programs (see Appendix I). The initial part of the first experiment is to obtain the #SMCL(s) in the n! solutions, and the second part is to determine the *SMCL by using the first two stages of the MAIN algorithm. Firstly, we assume that all part handling factors are equal to 1, and next, that the part handling factors vary in cases 1, 2, 5 and 6 (see Table 4.9 & Table 5.1). The data sets of cases 3 & 4 do not give operational sequences. Therefore, we cannot assign varying part handling factors.

Table 5.1 Proposed part handling factors for case 1 and case 2

Type of parts	Part handling factors
1	6→5→4→3→2→1
2	1→2→3→4→5→6
3	6→5→4→4→3→2→1
4	1→1→2→2→2→3→3→4
5	1→2→3→4→5→5→5→5→6

(b) Experiment 2

Broadly, the second experiment used information from the previous experiment, but case 4 is not considered here. This experiment is used to evaluate the total cell layout cost from successive non-replicated SMCLs known as the multi-DMCLs. The total cell layout cost of multi-DMCLs involves two costs: the total traveling cost of parts and the total rearrangement cost of machines. The total traveling cost is determined by the total traveling score, and multiplied by the cost per unit traveling score (we assume that it is \$10/unit). The total rearrangement cost is the summation of the rearrangement cost over multi-planning periods. This cost involves two sub-costs, which are the basic cost for machine relocation and the cost per unit machine movement. The cost per unit machine movement is assumed ten per cent of the basic cost for machine relocation. Different cases would be assigned various costs for calculating the relocation of machines (see Table 4.10 & 4.11).

(c) Experiment 3

The third experiment is used to evaluate the total cell layout cost from successive replicated SMCLs, and is called the modified multi-DMCLs. The modified multi-DMCLs means that the original SMCLs undergo the Step 12c in the third stage of the MAIN algorithm, and is encoded by the MATLAB programming language (see Appendix I). The possible arrangements and the Similarity Coefficients between successive SMCLs can be determined by this program (see Appendix III). Each SMCL in a fixed planning period will be replicated by eight possible layouts where the total traveling cost is identical. The maximum value of similarity coefficient will be selected between two successive planning periods so that the total cell layout cost can be minimized (also see Step 12c - Step 14 of the MAIN algorithm).

(d) Experiment 4

The last experiment is to determine the minimum total cell layout cost from existing SMCLs and is called the steady-DMCL; in fact, there is no actual machine reshuffle involved. The steady-DMCL means that a selected layout is used in all planning periods and the SMCLs for different periods will be aimed at. The steady-DMCL gives a permanent machine layout over multi-planning periods, and therefore the total rearrangement cost is always zero. Obviously, the one with minimum total traveling cost should be chosen to layout machines and the total cell layout cost depends on the total traveling cost only.

5.3 Results of Experiment 1 - SMCLs

There are five sets of data to be evaluated by the software program and to be manipulated by the first two stages of the MAIN algorithm. In each case, the #SMCLs are determined by an exhaustive search (n! combinations) of the total traveling scores. On the other hand, *SMCLs are manipulated by the first two stages of the MAIN algorithm based on the solution procedures. Part handling factors constitute a new idea in considering the attributes of parts for transportation. Therefore, there is no existing data, which could be compared with our results.

CHAPTER FIVE: EXPERIMENTS AND RESULTS

The software program manipulates data in different cases to obtain #SMCLs. We set the part handling factors to 1 and to those in Table 5.1 respectively. In part one, the part handling factors are equal to 1s, which means that the attributes of parts do not take into consideration in this experiment. In part two, the importance of part handling factors takes place to reflect the changing attributes of parts during transportation between machines. The results of minimum value of total traveling scores and the best #SMCLs for all five periods are shown in Figure 5.2-5.9.

(a) Part handling factors equal to 1

9	8	3
6	7	5
4	2	1
ζ_1=2780		
#SMCL$_1$		

9	8	3
6	7	5
4	2	1
ζ_2=2640		
#SMCL$_2$		

9	8	3
6	7	5
4	2	1
ζ_3=2950		
#SMCL$_3$		

7	5	6
8	2	4
9	3	1
ζ_4=3020		
#SMCL$_4$		

9	8	3
6	7	5
4	2	1
ζ_5=2200		
#SMCL$_5$		

Figure 5.2 #SMCLs - Yaman's and Tang's cases (λ=1)

8	7	6
9	2	5
4	3	1
ζ_1=116288		
#SMCL$_1$		

8	9	6
1	3	5
7	2	4
ζ_2=115795		
#SMCL$_2$		

6	5	3
2	4	9
8	7	1
ζ_3=120172		
#SMCL$_3$		

8	4	7
1	3	5
9	2	6
ζ_4=119004		
#SMCL$_4$		

9	2	7
6	3	8
4	5	1
ζ_5=120770		
#SMCL$_5$		

Figure 5.3 #SMCLs - Conway's case (λ=1)

2	4	6
5	3	1
ζ_1=12822		
#SMCL$_1$		

6	3	5
2	4	1
ζ_2=14853		
#SMCL$_2$		

6	4	2
3	5	1
ζ_3=13172		
#SMCL$_3$		

3	5	2
4	6	1
ζ_4=13032		
#SMCL$_4$		

5	1	4
6	2	3
ζ_5=12819		
#SMCL$_5$		

Figure 5.4 #SMCLs - Rosenblatt's case (λ=1)

8	9	6
3	5	4
7	2	1
ζ_1=6988		
#SMCL$_1$		

9	3	5
8	2	6
7	1	4
ζ_2=5276		
#SMCL$_2$		

9	8	7
5	6	4
3	2	1
ζ_3=5502		
#SMCL$_3$		

9	3	5
8	2	6
7	1	4
ζ_4=7140		
#SMCL$_4$		

8	9	6
3	5	4
7	2	1
ζ_5=6908		
#SMCL$_5$		

Figure 5.5 #SMCLs - Self-developed case five (λ=1)

9	5	6
8	3	4
7	2	1
ζ_1=5530		
#SMCL$_1$		

9	8	7
5	6	4
3	2	1
ζ_2=4450		
#SMCL$_2$		

9	8	7
5	6	4
3	2	1
ζ_3=6192		
#SMCL$_3$		

7	3	8
6	5	9
4	2	1
ζ_4=5773		
#SMCL$_4$		

9	3	5
8	2	6
7	1	4
ζ_5=6719		
#SMCL$_5$		

Figure 5.6 #SMCLs - Self-developed case six (λ=1)

(b) Part handling factors vary

9	8	3
6	7	5
4	2	1
ζ_1=9085		
#SMCL$_1$		

6	7	5
9	8	3
4	2	1
ζ_2=8360		
#SMCL$_2$		

6	7	5
9	8	3
4	2	1
ζ_3=9780		
#SMCL$_3$		

7	8	9
6	5	3
4	2	1
ζ_4=9375		
#SMCL$_4$		

6	7	5
9	8	3
4	2	1
ζ_5=6545		
#SMCL$_5$		

Figure 5.7 #SMCLs - Yaman's and Tang's cases (λ vary)

8	9	6
3	5	4
7	2	1
ζ_1=14799		
#SMCL$_1$		

7	6	9
1	4	5
8	2	3
ζ_2=11938		
#SMCL$_2$		

7	6	9
1	4	5
8	2	3
ζ_3=11312		
#SMCL$_3$		

8	2	6
7	1	4
9	3	5
ζ_4=16145		
#SMCL$_4$		

8	9	6
3	5	4
7	2	1
ζ_5=14871		
#SMCL$_5$		

Figure 5.8 #SMCLs - Self-developed case five (λ vary)

8	9	7
6	5	4
2	3	1
ζ_1=11775		
#SMCL$_1$		

9	8	7
5	6	4
3	2	1
ζ_2=8952		
#SMCL$_2$		

7	4	9
1	6	5
8	2	3
ζ_3=12989		
#SMCL$_3$		

8	9	6
3	5	4
7	2	1
ζ_4=10935		
#SMCL$_4$		

9	3	5
8	2	6
7	1	4
ζ_5=13872		
#SMCL$_5$		

Figure 5.9 #SMCLs - Self-developed case six (λ vary)

CHAPTER FIVE: EXPERIMENTS AND RESULTS

In this section, the MAIN algorithm is used to generate the *SMCLs in different cases. The data is identical. The results are shown in Figure 5.10-5.17. It is not difficult to observe that the results generated by the first two stages of the MAIN algorithm are very close to the corresponding optimal solutions (#SMCLs).

(a) Part handling factors equal to 1

2	4	1
8	6	7
3	5	9
ζ_1=2850		
*SMCL$_1$		

2	4	1
8	6	7
3	5	9
ζ_2=2790		
*SMCL$_2$		

1	8	3
2	7	5
4	9	6
ζ_3=3160		
*SMCL$_3$		

7	5	6
8	2	4
9	1	3
ζ_4=3165		
*SMCL$_4$		

5	7	6
8	2	4
3	1	9
ζ_5=2275		
*SMCL$_5$		

Figure 5.10 *SMCLs - Yaman's & Tang's cases (λ=1)

6	5	1
4	2	9
7	3	8
ζ_1=117043		
*SMCL$_1$		

2	9	6
1	3	5
7	8	4
ζ_2=116053		
*SMCL$_2$		

8	1	7
2	4	5
3	9	6
ζ_3=121757		
*SMCL$_3$		

9	7	8
2	5	6
1	3	4
ζ_4=119792		
*SMCL$_4$		

5	4	1
3	6	9
8	2	7
ζ_5=121403		
*SMCL$_5$		

Figure 5.11 *SMCLs - Conway's case (λ=1)

1	4	2
6	3	5
ζ_1=12896		
*SMCL$_1$		

5	4	2
1	3	6
ζ_2=14883		
*SMCL$_2$		

3	5	1
2	4	6
ζ_3=13488		
*SMCL$_3$		

4	6	1
3	5	2
ζ_4=13032		
*SMCL$_4$		

3	2	6
4	1	5
ζ_5=12819		
*SMCL$_5$		

Figure 5.12 *SMCLs - Rosenblatt's case (λ=1)

1	4	7
2	6	8
3	5	9
ζ_1=7074		
*SMCL$_1$		

7	8	9
1	2	3
4	6	5
ζ_2=5276		
*SMCL$_2$		

1	2	3
4	6	5
8	7	9
ζ_3=5512		
*SMCL$_3$		

3	1	2
5	4	6
9	7	8
ζ_4=7504		
*SMCL$_4$		

8	9	6
3	5	4
7	2	1
ζ_5=6908		
*SMCL$_5$		

Figure 5.13 *SMCLs - Self-developed case five (λ=1)

8	9	7	3	5	9	4	6	1	7	6	4	1	2	3
3	5	6	1	6	8	3	5	2	3	5	2	4	6	5
1	2	4	2	4	7	8	9	7	8	9	1	7	8	9
ζ_1=5619			ζ_2=4493			ζ_3=6695			ζ_4=5773			ζ_5=6824		
*$SMCL_1$			*$SMCL_2$			*$SMCL_3$			*$SMCL_4$			*$SMCL_5$		

Figure 5.14 *SMCLs - Self-developed case six (λ=1)

(b) Part handling factors vary

4	1	7	7	8	2	1	7	2	1	4	2	9	6	4
2	5	6	5	6	4	3	5	8	5	6	3	3	5	8
8	3	9	3	9	1	9	6	4	7	8	9	1	7	2
ζ_1=9590			ζ_2=8975			ζ_3=9840			ζ_4=9885			ζ_5=6775		
*$SMCL_1$			*$SMCL_2$			*$SMCL_3$			*$SMCL_4$			*$SMCL_5$		

Figure 5.15 *SMCLs - Yaman's & Tang's cases (λ vary)

1	4	6	9	7	8	3	5	9	9	7	8	2	3	8
2	5	9	5	4	6	2	4	6	5	4	6	7	5	9
7	3	8	3	1	2	7	1	8	3	1	2	1	4	6
ζ_1=14799			ζ_2=12153			ζ_3=11456			ζ_4=16156			ζ_5=14997		
*$SMCL_1$			*$SMCL_2$			*$SMCL_3$			*$SMCL_4$			*$SMCL_5$		

Figure 5.16 *SMCLs - Self-developed case five (λ vary)

3	5	9	2	1	6	8	4	6	3	5	9	1	4	6
1	4	7	3	5	4	3	5	2	2	4	6	7	5	2
2	6	8	8	9	7	7	9	1	8	1	7	8	3	9
ζ_1=11895			ζ_2=9097			ζ_3=14135			ζ_4=11201			ζ_5=13992		
*$SMCL_1$			*$SMCL_2$			*$SMCL_3$			*$SMCL_4$			*$SMCL_5$		

Figure 5.17 *SMCLs - Self-developed case six (λ vary)

5.4 Results of Experiment 2 - Multi-DMCLs

In experiment 2, multi-DMCLs are determined on the basis of experiment 1. The best SMCL in each period is selected to construct the multi-DMCLs (see Figure

5.2-5.17). The results of multi-DMCLs are divided into two branches according to #SMCLs and *SMCLs that lead to #multi-DMCLs and *multi-DMCLs respectively (see Figure 5.1). This experiment will consider the changing of quantitative demands over different planning periods. Each #SMCL has its own total traveling score, and this score is converted into monetary base, here we assume that the cost per unit traveling score (ω) is $10/unit. The total rearrangement cost is the summation of rearrangement costs among all planning periods. The total cell layout cost is equal to the summation of the above two costs. Basically, #multi-DMCLs serve as datum for the verifications of *multi-DMCLs.

First, unique part handling factors are used. Table 5.2 to Table 5.5 show the results of different cases. Although the quantitative demands of parts affects the machine locations in a cell, minimum re-layout effort between two successive layouts should be targeted. Sometimes, if a same layout can be maintained in two successive periods, then the rearrangement cost is zero (see Table 5.2). Second, the part handling factors vary. Based on the results in experiment 1, the total traveling cost is enlarged due to the values of the part handling factors are larger than one. As some cases did not show the operational sequences of parts, they would not be used here. In fact, only three cases show the operational sequences of parts (see Table 4.1 & 4.9). All the results of the #multi-DMCLs in various cases are presented in Table 5.2 to Table 5.8.

(a) Part handling factors equal to 1

Table 5.2 Cost of #multi-DMCLs - Yaman's and Tang's cases (λ=1)

Yaman's and Tang's cases						
Planning period	p=1	p=2	p=3	p=4	p=5	Total (a)
Total traveling cost (ζ x ω) ($)	27800	26400	29500	30200	22000	135900
Successive periods	$R_{1\to2}$	$R_{2\to3}$	$R_{3\to4}$	$R_{4\to5}$		Total (b)
Rearrangement cost ($R_{p\to p+1}$) ($)	0	0	1671	1671		3342
Total cell layout cost (α) ($)	α = (a) + (b)					139242

Table 5.3 Cost of #multi-DMCLs - Conway's case (λ=1)

Conway's case						
Planning period	p=1	p=2	p=3	p=4	p=5	Total (a)
Total traveling cost (ζ x ω) ($)	116288	115795	120172	119004	120770	592029
Successive periods	$R_{1\to2}$	$R_{2\to3}$	$R_{3\to4}$	$R_{4\to5}$		Total (b)
Rearrangement cost ($R_{p\to p+1}$) ($)	5401	8050	8428	6781		28660
Total cell layout cost (α) ($)	α = (a) + (b)					620689

Table 5.4 Cost of #multi-DMCLs -Self-developed case five (λ=1)

Self-developed case five						
Planning period	p=1	p=2	p=3	p=4	p=5	Total (a)
Total traveling cost (ζ x ω) ($)	69880	52760	55020	71400	69080	318140
Successive periods	$R_{1\to2}$	$R_{2\to3}$	$R_{3\to4}$	$R_{4\to5}$		Total (b)
Rearrangement cost ($R_{p\to p+1}$) ($)	7019	7397	7397	7019		28832
Total cell layout cost (α) ($)	α = (a) + (b)					346972

Table 5.5 Cost of #multi-DMCLs - Self-developed case six (λ=1)

Self-developed case six						
Planning period	p=1	p=2	p=3	p=4	p=5	Total (a)
Total traveling cost (ζ x ω) ($)	55300	44500	61920	57730	67190	286640
Successive periods	$R_{1\to2}$		$R_{2\to3}$	$R_{3\to4}$	$R_{4\to5}$	Total (b)
Rearrangement cost ($R_{p\to p+1}$) ($)	4614		0	5628	6902	17144
Total cell layout cost (α) ($)	α = (a) + (b)					303784

(b) Part handling factors vary

Table 5.6 Cost of #multi-DMCLs - Yaman's and Tang's cases (λ vary)

Yaman's and Tang's cases						
Planning period	p=1	p=2	p=3	p=4	p=5	Total (a)
Total traveling cost (ζ x ω) ($)	90850	83600	97800	93750	65450	431450
Successive periods	$R_{1\to2}$		$R_{2\to3}$	$R_{3\to4}$	$R_{4\to5}$	Total (b)
Rearrangement cost ($R_{p\to p+1}$) ($)	1023		0	839	839	2701
Total cell layout cost (α) ($)	α = (a) + (b)					434151

Table 5.7 Cost of #multi-DMCLs - Self-developed case five (λ vary)

Self-developed case five						
Planning period	p=1	p=2	p=3	p=4	p=5	Total (a)
Total traveling cost (ζ x ω) ($)	147990	119380	113120	161450	148710	690650
Successive periods	$R_{1\to2}$		$R_{2\to3}$	$R_{3\to4}$	$R_{4\to5}$	Total (b)
Rearrangement cost ($R_{p\to p+1}$) ($)	7506		7506	8152	5541	28705
Total cell layout cost (α) ($)	α = (a) + (b)					719355

Table 5.8 Cost of #multi-DMCLs - Self-developed case six (λ vary)

Self-developed case six						
Planning period	p=1	p=2	p=3	p=4	p=5	Total (a)
Total traveling cost ($\zeta \times \omega$) ($)	117750	89520	129890	109350	138720	585230
Successive periods	$R_{1\to2}$	$R_{2\to3}$	$R_{3\to4}$	$R_{4\to5}$		Total (b)
Rearrangement cost ($R_{p\to p+1}$) ($)	4235	5908	6821	6135		23099
Total cell layout cost (α) ($)	α = (a) + (b)					608329

Seven *multi-DMCLs are formulated. Each of these *multi-DMCLs consists of five *SMCLs as there are five planning periods involved; *SMCLs are determined by the first two stages of the MAIN algorithm. Table 5.9 to Table 5.12 shows the results of *multi-DMCLs that the effect of the part handling factor is somehow disregarded. Table 5.13 to 5.15 involves part handling factors in associated *SMCLs. One should notice that these *multi-DMCLs should be compared with those using unique part handling factors because we are not intend to investigate the affect of the part handling factor here.

(a) Part handling factors equal to 1

Table 5.9 Cost of *Multi-DMCLs - Yaman's and Tang's case (λ =1)

Yaman's and Tang's case						
Planning period	p=1	p=2	p=3	p=4	p=5	Total (a)
Total traveling cost (ζ x ω) ($)	28500	27900	31600	31650	22750	142400
Successive periods	$R_{1\to2}$	$R_{2\to3}$	$R_{3\to4}$	$R_{4\to5}$		Total (b)
Rearrangement cost ($R_{p\to p+1}$) ($)	0	1829	1660	462		3951
Total cell layout cost (α) ($)	α = (a) + (b)					146351

Table 5.10 Cost of *Multi-DMCLs - Conway's case (λ=1)

Conway's case						
Planning period	p=1	p=2	p=3	p=4	p=5	Total (a)
Total traveling cost (ζ x ω) ($)	117043	116053	121757	119792	123903	595548
Successive periods	$R_{1\to2}$	$R_{2\to3}$	$R_{3\to4}$	$R_{4\to5}$		Total (b)
Rearrangement cost ($R_{p\to p+1}$) ($)	7147	7274	6742	8447		29610
Total cell layout cost (α) ($)	α = (a) + (b)					625158

Table 5.11 Cost of *Multi-DMCLs - Self-developed case five (λ=1)

Self-developed case five						
Planning period	p=1	p=2	p=3	p=4	p=5	Total (a)
Total traveling cost (ζ x ω) ($)	70740	52760	55120	75040	69080	322740
Successive periods	$R_{1\to2}$	$R_{2\to3}$	$R_{3\to4}$	$R_{4\to5}$		Total (b)
Rearrangement cost ($R_{p\to p+1}$) ($)	8315	8133	7196	8442		32086
Total cell layout cost (α) ($)	α = (a) + (b)					354826

Table 5.12 Cost of *Multi-DMCLs - Self-developed case six (λ=1)

Self-developed case six						
Planning period	p=1	p=2	p=3	p=4	p=5	Total (a)
Total traveling cost (ζ x ω) ($)	56190	44930	66950	57730	68240	294040
Successive periods	$R_{1\to2}$	$R_{2\to3}$	$R_{3\to4}$	$R_{4\to5}$		Total (b)
Rearrangement cost ($R_{p\to p+1}$) ($)	7036	6358	3054	7608		24056
Total cell layout cost (α) ($)	α = (a) + (b)					318096

(b) Part handling factors vary

Table 5.13 Cost of *Multi-DMCLs - Yaman's and Tang's cases (λ vary)

Yaman's and Tang's cases						
Planning period	p=1	p=2	p=3	p=4	p=5	Total (a)
Total traveling cost (ζ x ω) ($)	95900	89750	98400	98850	67750	450650
Successive periods	$R_{1\to2}$	$R_{2\to3}$	$R_{3\to4}$	$R_{4\to5}$		Total (b)
Rearrangement cost ($R_{p\to p+1}$) ($)	1814	1598	1529	1735		6676
Total cell layout cost (α) ($)	α = (a) + (b)					457326

Table 5.14 Cost of *Multi-DMCLs - Self-developed case five (λ vary)

Self-developed case five						
Planning period	p=1	p=2	p=3	p=4	p=5	Total (a)
Total traveling cost (ζ x ω) ($)	147990	121530	114560	161560	149970	695610
Successive periods	$R_{1\to2}$	$R_{2\to3}$	$R_{3\to4}$	$R_{4\to5}$		Total (b)
Rearrangement cost ($R_{p\to p+1}$) ($)	8414	5830	5830	7340		27414
Total cell layout cost (α) ($)	α = (a) + (b)					723024

Table 5.15 Cost of *Multi-DMCLs - Self-developed case six (λ vary)

Self-developed case six						
Planning period	p=1	p=2	p=3	p=4	p=5	Total (a)
Total traveling cost (ζ x ω) ($)	118950	90970	141350	112010	139920	603200
Successive periods	$R_{1\rightarrow2}$	$R_{2\rightarrow3}$	$R_{3\rightarrow4}$		$R_{4\rightarrow5}$	Total (b)
Rearrangement cost ($R_{p\rightarrow p+1}$) ($)	7313	4286	7162		7113	25874
Total cell layout cost (α) ($)	α = (a) + (b)					629074

5.5 Results of Experiment 3 - Modified Multi-DMCLs

In experiment 3, the modified multi-DMCLs are investigated. This involves the third stage of the MAIN algorithm. For each SMCL, eight replicated SMCLs can be generated according to the orientating method shown in Step 12c. (Also see Figure 3.11-3.12). The purpose is to minimize the rearrangement costs between two successive periods without affecting the total traveling costs; therefore, the total traveling costs do not change in experiments 2 and 3.

We note that a SMCL can be replicated without affecting the total traveling cost. However, an initial arrangement is required for the MAIN algorithm to sort out the new machine locations in a cell. For instance, the machine at the centre of the 3x3 grid remains but relocations of surrounding machines to cope with demands changes will be optimized by the MAIN algorithm. Subsequently, the total rearrangement cost can be reduced. The anticipated machines locations of #multi-

DMCLs are shown in Figure 5.18-5.24, and the total cell layout costs are given in Table 5.16-5.22.

(a) Part handling factors equal to 1

Table 5.16 Cost of modified #multi-DMCLs - Yaman's and Tang's cases (λ=1)

Yaman's and Tang's cases						
Planning period	p=1	p=2	p=3	p=4	p=5	Total (a)
Total traveling cost (ζ x ω) ($)	27800	26400	29500	30200	22000	135900
Successive periods	$R_{1\to2}$	$R_{2\to3}$	$R_{3\to4}$	$R_{4\to5}$		Total (b)
Rearrangement cost ($R_{p\to p+1}$) ($)	0	0	1307	1307		2614
Total cell layout cost (α) ($)	α = (a) + (b)					138514

9	8	3
6	7	5
4	2	1
ζ_1=2780		

9	8	3
6	7	5
4	2	1
ζ_2=2640		

9	8	3
6	7	5
4	2	1
ζ_3=2950		

9	8	7
3	2	5
1	4	6
ζ_4=3020		

9	8	3
6	7	5
4	2	1
ζ_5=2200		

Figure 5.18 Modified #multi-DMCLs - Yaman's & Tang's cases (λ=1)

Table 5.17 Cost of modified #multi-DMCLs - Conway's case (λ=1)

Conway's case						
Planning period	p=1	p=2	p=3	p=4	p=5	Total (a)
Total traveling cost (ζ x ω) ($)	116288	115795	120172	119004	120770	592029
Successive periods	$R_{1\to2}$	$R_{2\to3}$	$R_{3\to4}$	$R_{4\to5}$		Total (b)
Rearrangement cost ($R_{p\to p+1}$) ($)	5401	4716	4927	5313		20357
Total cell layout cost (α) ($)	α = (a) + (b)					612386

8	7	6
9	2	5
4	3	1
ζ_1=116288		

8	9	6
1	3	5
7	2	4
ζ_2=115795		

1	9	3
7	4	5
8	2	6
ζ_3=120172		

8	4	7
1	3	5
9	2	6
ζ_4=119004		

4	5	1
6	3	8
9	2	7
ζ_5=120770		

Figure 5.19 Modified #multi-DMCLs - Conway's case (λ=1)

Table 5.18 Cost of modified #multi-DMCLs - Self-developed case five (λ=1)

Self-developed case five						
Planning period	p=1	p=2	p=3	p=4	p=5	Total (a)
Total traveling cost (ζ x ω) ($)	69880	52760	55020	71400	69080	318140
Successive periods	$R_{1\to2}$	$R_{2\to3}$	$R_{3\to4}$	$R_{4\to5}$		Total (b)
Rearrangement cost ($R_{p\to p+1}$) ($)	7019	4917	4917	7019		23872
Total cell layout cost (α) ($)	α = (a) + (b)					342012

8	9	6
3	5	4
7	2	1
ζ_1=6988		

9	3	5
8	2	6
7	1	4
ζ_2=5276		

9	5	3
8	6	2
7	4	1
ζ_3=5502		

9	3	5
8	2	6
7	1	4
ζ_4=7140		

8	9	6
3	5	4
7	2	1
ζ_5=6908		

Figure 5.20 Modified #multi-DMCLs - Self-developed case five (λ=1)

Table 5.19 Cost of modified #multi-DMCLs - Self-developed case six (λ=1)

Self-developed case six data						
Planning period	p=1	p=2	p=3	p=4	p=5	Total (a)
Total traveling cost (ζ x ω) ($)	55300	44500	61920	57730	67190	286640
Successive periods	$R_{1\to2}$	$R_{2\to3}$	$R_{3\to4}$	$R_{4\to5}$		Total (b)
Rearrangement cost ($R_{p\to p+1}$) ($)	3564	0	5374	4626		13564
Total cell layout cost (α) ($)	α = (a) + (b)					300204

9	5	6	9	5	3	9	5	3	8	9	1	9	8	7
8	3	4	8	6	2	8	6	2	3	5	2	3	2	1
7	2	1	7	4	1	7	4	1	7	6	4	5	6	4
ζ_1=5530			ζ_2=4450			ζ_3=6192			ζ_4=5773			ζ_5=6719		

Figure 5.21 Modified #multi-DMCLs - Self-developed case six (λ=1)

(b) Part handling factors vary

Table 5.20 Cost of modified #multi-DMCLs - Yaman's and Tang's cases (λ vary)

Yaman's and Tang's cases						
Planning period	p=1	p=2	p=3	p=4	p=5	Total (a)
Total traveling cost (ζ x ω) ($)	90850	83600	97800	93750	65450	431450
Successive periods	$R_{1\to2}$	$R_{2\to3}$	$R_{3\to4}$		$R_{4\to5}$	Total (b)
Rearrangement cost ($R_{p\to p+1}$) ($)	1023	0	839		839	2701
Total cell layout cost (α) ($)	α = (a) + (b)					434151

9	8	3	6	7	5	6	7	5	7	8	9	6	7	5
6	7	5	9	8	3	9	8	3	6	5	3	9	8	3
4	2	1	4	2	1	4	2	1	4	2	1	4	2	1
ζ_1=9085			ζ_2=8360			ζ_3=9780			ζ_4=9375			ζ_5=6545		

Figure 5.22 Modified #multi-DMCLs - Yaman's & Tang's cases (λ vary)

Table 5.21 Cost of modified #multi-DMCLs - Self-developed case five (λ vary)

Self-developed case five						
Planning period	p=1	p=2	p=3	p=4	p=5	Total (a)
Total traveling cost (ζ x ω) ($)	147990	119380	113120	161450	148710	690650
Successive periods	$R_{1\to2}$	$R_{2\to3}$	$R_{3\to4}$	$R_{4\to5}$		Total (b)
Rearrangement cost ($R_{p\to p+1}$) ($)	6576	0	6401	5541		18518
Total cell layout cost (α) ($)	α = (a) + (b)					709168

8	9	6	8	2	3	8	2	3	6	4	5	6	4	1
3	5	4	1	4	5	1	4	5	2	1	3	9	5	2
7	2	1	7	6	9	7	6	9	8	7	9	8	3	7
ζ_1=14799			ζ_2=11938			ζ_3=11312			ζ_4=16145			ζ_5=14871		

Figure 5.23 Modified #multi-DMCLs - Self-developed case five (λ vary)

Table 5.22 Cost of modified #multi-DMCLs - Self-developed case six (λ vary)

Self-developed case six						
Planning period	p=1	p=2	p=3	p=4	p=5	Total (a)
Total traveling cost (ζ x ω) ($)	117750	89520	129890	109350	138720	585230
Successive periods	$R_{1\to2}$	$R_{2\to3}$	$R_{3\to4}$	$R_{4\to5}$		Total (b)
Rearrangement cost ($R_{p\to p+1}$) ($)	4235	2120	6001	5913		18269
Total cell layout cost (α) ($)	α = (a) + (b)					603499

8	9	7	9	8	7	7	4	9	1	2	7	4	1	7
6	5	4	5	6	4	1	6	5	4	5	3	6	2	8
2	3	1	3	2	1	8	2	3	6	9	8	5	3	9
ζ_1=11775			ζ_2=8952			ζ_3=12989			ζ_4=10935			ζ_5=13872		

Figure 5.24 Modified #multi-DMCLs - Self-developed case six (λ vary)

In the following, the modified *multi-DMCLs will be obtained by the *SMCLs in Figure 5.10-5.17. The manipulating procedures of this part are same as those of the previous ones (modified #multi-DMCLs). We can see that the total traveling cost does not change while the machines are relocated according to Step 12c and Step 13 of the MAIN algorithm in all cases. The results of the modified *multi-DMCLs is presented in Figure 5.25-5.31, and the total cell layout costs are in Table 5.23-5.29.

(a) Part handling factors equal to 1

Table 5.23 Cost of modified *multi-DMCLs - Yaman's & Tang's cases (λ=1)

Yaman's and Tang's cases						
Planning period	p=1	p=2	p=3	p=4	p=5	Total (a)
Total traveling cost (ζ x ω) ($)	28500	27900	31600	31650	22750	142400
Successive periods	$R_{1\to2}$	$R_{2\to3}$	$R_{3\to4}$	$R_{4\to5}$		Total (b)
Rearrangement cost ($R_{p\to p+1}$) ($)	0	1113	812	462		2387
Total cell layout cost (α) ($)	α = (a) + (b)					144787

2	4	1
8	6	7
3	5	9
ζ_1=2850		

2	4	1
8	6	7
3	5	9
ζ_2=2790		

1	2	4
8	7	9
3	5	6
ζ_3=3160		

9	1	3
8	2	4
7	5	6
ζ_4=3165		

3	1	9
8	2	6
5	7	6
ζ_5=2275		

Figure 5.25 Modified *multi-DMCLs - Yaman's & Tang's cases (λ=1)

Table 5.24 Cost of modified *multi-DMCLs - Conway's case (λ=1)

Conway's case						
Planning period	p=1	p=2	p=3	p=4	p=5	Total (a)
Total traveling cost (ζ x ω) ($)	117043	116053	121757	119792	121403	596048
Successive periods	$R_{1\to2}$	$R_{2\to3}$	$R_{3\to4}$	$R_{4\to5}$		Total (b)
Rearrangement cost ($R_{p\to p+1}$) ($)	5168	4809	6742	4099		20818
Total cell layout cost (α) ($)	α = (a) + (b)					616866

6	5	1
4	2	9
7	3	8
ζ_1=117043		

4	5	6
8	3	9
7	1	2
ζ_2=116053		

7	5	6
1	4	9
8	2	3
ζ_3=121757		

8	6	4
7	5	3
9	2	1
ζ_4=119792		

8	3	5
2	6	4
7	9	1
ζ_5=121403		

Figure 5.26 Modified *multi-DMCLs - Conway's case (λ=1)

Table 5.25 Cost of modified *multi-DMCLs - Self-developed case five (λ=1)

Self-developed case five						
Planning period	p=1	p=2	p=3	p=4	p=5	Total (a)
Total traveling cost (ζ x ω) ($)	70740	52760	55120	75040	69080	322740
Successive periods	$R_{1\to2}$	$R_{2\to3}$	$R_{3\to4}$	$R_{4\to5}$		Total (b)
Rearrangement cost ($R_{p\to p+1}$) ($)	4917	6765	3212	7184		22078
Total cell layout cost (α) ($)	α = (a) + (b)					344818

1	4	7
2	6	8
3	5	9
ζ_1=7074		

4	1	7
6	2	8
5	3	9
ζ_2=5276		

1	4	8
2	6	7
3	5	9
ζ_3=5512		

2	6	8
1	4	7
3	5	9
ζ_4=7504		

7	3	8
2	5	9
1	4	6
ζ_5=6908		

Figure 5.27 Modified *multi-DMCLs - Self-developed case five (λ=1)

Table 5.26 Cost of modified *multi-DMCLs - Self-developed case six (λ=1)

Self-developed case six						
Planning period	p=1	p=2	p=3	p=4	p=5	Total (a)
Total traveling cost (ζ x ω) ($)	56190	44930	66950	57730	68240	294040
Successive periods	$R_{1\to2}$	$R_{2\to3}$	$R_{3\to4}$	$R_{4\to5}$		Total (b)
Rearrangement cost ($R_{p\to p+1}$) ($)	5764	5854	3054	5374		20046
Total cell layout cost (α) ($)	α = (a) + (b)					314086

8	9	7
3	5	6
1	2	4
ζ_1=5619		

9	8	7
5	6	4
3	1	2
ζ_2=4493		

8	9	7
3	5	2
4	6	1
ζ_3=6695		

8	9	1
3	5	2
7	6	4
ζ_4=5773		

9	5	3
8	6	2
7	4	1
ζ_5=6824		

Figure 5.28 Modified *multi-DMCLs - Self-developed case six (λ=1)

(b) Part handling factors vary

Table 5.27 Cost of modified *multi-DMCLs -Yaman's & Tang's cases (λ vary)

Yaman's and Tang's cases						
Planning period	p=1	p=2	p=3	p=4	p=5	Total (a)
Total traveling cost (ζ x ω) ($)	95900	89750	98400	98850	67750	450650
Successive periods	$R_{1\to2}$	$R_{2\to3}$	$R_{3\to4}$	$R_{4\to5}$		Total (b)
Rearrangement cost ($R_{p\to p+1}$) ($)	1442	1344	1465	1465		5716
Total cell layout cost (α) ($)	α = (a) + (b)					456366

4	1	7
2	5	6
8	3	9
ζ_1=9590		

2	8	7
4	6	5
1	9	3
ζ_2=8975		

2	8	4
7	5	6
1	3	9
ζ_3=9840		

7	8	9
5	6	3
1	4	2
ζ_4=9885		

2	8	4
7	5	6
1	3	9
ζ_5=6775		

Figure 5.29 Modified *multi-DMCLs - Yaman's & Tang's cases (λ vary)

Table 5.28 Cost of modified *multi-DMCLs - Self-developed case five (λ vary)

Self-developed case five						
Planning period	p=1	p=2	p=3	p=4	p=5	Total (a)
Total traveling cost (ζ x ω)($)	147990	121530	114560	161560	149970	695610
Successive periods	$R_{1\to2}$	$R_{2\to3}$	$R_{3\to4}$	$R_{4\to5}$		Total (b)
Rearrangement cost ($R_{p\to p+1}$) ($)	7184	3456	3456	6392		20488
Total cell layout cost (α) ($)	α = (a) + (b)					716098

1	4	6
2	5	9
7	3	8
ζ_1=14799		

3	5	9
1	4	7
2	6	8
ζ_2=12153		

3	5	9
2	4	6
7	1	8
ζ_3=11456		

3	5	9
1	4	7
2	6	8
ζ_4=16156		

1	4	6
7	5	9
2	3	8
ζ_5=14997		

Figure 5.30 Modified *multi-DMCLs - Self-developed case five (λ vary)

Table 5.29 Cost of modified *multi-DMCLs - Self-developed case six (λ vary)

Self-developed case six						
Planning period	p=1	p=2	p=3	p=4	p=5	Total (a)
Total traveling cost ($\zeta \times \omega$) ($)	118950	90970	141350	112010	139920	603200
successive periods	$R_{1\to2}$	$R_{2\to3}$	$R_{3\to4}$	$R_{4\to5}$		Total (b)
Rearrangement cost ($R_{p\to p+1}$) ($)	5029	4286	5666	6483		21464
Total cell layout cost (α) ($)	α = (a) + (b)					624664

3	5	9
1	4	7
2	6	8
ζ_1=11895		

6	4	7
1	5	9
2	3	8
ζ_2=9097		

6	2	1
4	5	9
8	3	7
ζ_3=14135		

3	2	8
5	4	1
9	6	7
ζ_4=11201		

9	2	6
3	5	4
8	7	1
ζ_5=13992		

Figure 5.31 Modified *multi-DMCLs - Self-developed case six (λ vary)

5.6 Results of Experiment 4 - Steady-DMCL

In experiment 4, the steady-DMCL will be selected from various SMCLs associated with their planning periods (see Figure 5.2-5.17). The steady-DMCL attempts to find a single layout to fit all quantitative demands over multi-planning periods. In other wards, the total rearrangement cost must be zero because it only uses one SMCL as the permanent layout for the production and therefore, there is no need to reallocate the machines within a cell. The total traveling cost of this layout may be higher than multi-DMCL as the steady-DMCL may not be the best way to cope with the fluctuating quantitative demands of parts. The total cell layout costs will be determined by this experiment.

First, every #SMCL will be tested against all related periods and the total traveling costs can thus be determined. The parts flow frequencies and the part handling factors are important elements to machine allocation so they will also be explored. Finally, the #steady-DMCL will be chosen among the five #SMCLs by seeking the one with a minimum total cell layout cost (see Table 5.30-5.36).

(a) Part handling factors equal to 1

Table 5.30 Minimum cost of #steady-DMCL - Yaman's & Tang's cases (λ=1)

Yaman's & Tang's cases						
Planning period / Total traveling cost (ζ x ω)($)	**p=1**	**p=2**	**p=3**	**p=4**	**p=5**	**Total (a)**
SMCL-1	27800	26400	29500	31300	22000	137000
SMCL-2	27800	26400	29500	31300	22000	137000
SMCL-3	27800	26400	29500	31300	22000	137000
SMCL-4	31100	28100	33900	30200	22800	146100
SMCL-5	27800	26400	29500	31300	22000	137000
Minimum of total cell layout cost (α) ($)	(b) total rearrangement cost is zero α = (a) + (b)					137000

Table 5.31 Minimum cost of #steady-DMCL - Conway's case (λ=1)

Conway's case						
Planning period / Total traveling cost (ζ x ω)($)	**p=1**	**p=2**	**p=3**	**p=4**	**p=5**	**Total (a)**
SMCL-1	116288	132999	143154	128143	136117	656701
SMCL-2	132999	115795	134935	138849	135311	657889
SMCL-3	143154	138488	120172	131893	145521	679228
SMCL-4	128143	122200	135306	119004	138849	643502
SMCL-5	136117	123872	141774	143023	120770	665556
Minimum of total cell layout cost (α) ($)	(b) total rearrangement cost is zero α = (a) + (b)					643502

Table 5.32 Minimum cost of #steady-DMCL - Self-developed case five (λ=1)

Self-developed case five						
Planning period / Total traveling cost (ζ x ω)($)	**p=1**	**p=2**	**p=3**	**p=4**	**p=5**	**Total (a)**
SMCL-1	69880	55340	58640	77720	69080	330660
SMCL-2	71280	52760	56220	71400	73420	325080
SMCL-3	70740	52860	55020	71420	74320	324360
SMCL-4	71280	52760	56220	71400	73420	325080
SMCL-5	69880	55340	58640	77720	69080	330660
Minimum of total cell layout cost (α) ($)	(b) total rearrangement cost is zero α = (a) + (b)					324360

Table 5.33 Minimum cost of #steady-DMCL - Self-developed case six (λ=1)

Self-developed case six						
Planning period / Total traveling cost (ζ x ω)($)	p=1	p=2	p=3	p=4	p=5	Total (a)
SMCL-1	55300	46340	65880	58160	70760	296440
SMCL-2	56320	44500	61920	58920	68240	289900
SMCL-3	56320	44500	61920	58920	68240	289900
SMCL-4	56270	46030	67270	57730	73890	301190
SMCL-5	56370	46310	63030	60850	67190	293750
Minimum of total cell layout cost (α) ($)	(b) total rearrangement cost is zero α = (a) + (b)					289900

(b) Part handling factors vary

Table 5.34 Minimum cost of #steady-DMCL - Yaman's & Tang's cases (λ vary)

Yaman's & Tang's cases						
Planning period / Total traveling cost (ζ x ω)($)	p=1	p=2	p=3	p=4	p=5	Total (a)
SMCL-1	90850	85200	98050	95800	68050	437950
SMCL-2	91150	83600	97800	98450	65450	436450
SMCL-3	91150	83600	97800	98450	65450	436450
SMCL-4	98350	87900	111050	93750	69900	460950
SMCL-5	91150	83600	97800	98450	65450	436450
Minimum of total cell layout cost (α)($)	(b) total rearrangement cost is zero α = (a) + (b)					436450

Table 5.35 Minimum cost of #steady-DMCL - Self-developed case five (λ vary)

Self-developed case five						
Planning period / Total traveling cost (ζ x ω)($)	p=1	p=2	p=3	p=4	p=5	Total (a)
SMCL-1	147990	121040	116680	174240	148710	708660
SMCL-2	148000	119380	113120	162540	150750	693790
SMCL-3	148000	119380	113120	162540	150750	693790
SMCL-4	154640	121880	122830	161450	155700	716500
SMCL-5	147990	121040	116680	174240	148710	708660
Minimum of total cell layout cost (α)($)	(b) total rearrangement cost is zero α = (a) + (b)					693790

Table 5.36 Minimum cost of #steady-DMCL - Self-developed case six (λ vary)

Self-developed case six						
Planning period / Total traveling cost (ζ x ω)($)	p=1	p=2	p=3	p=4	p=5	Total (a)
SMCL-1	117750	96960	142740	121710	160290	639450
SMCL-2	122230	89520	130320	112350	143940	598360
SMCL-3	129330	93030	129890	120100	147320	619670
SMCL-4	125340	93240	140390	109350	151030	619350
SMCL-5	123250	93810	130760	119350	138720	605890
Minimum of total cell layout cost (α)($)	(b) total rearrangement cost is zero α = (a) + (b)					598360

Below, the *steady-DMCL is obtained from the *SMCLs (see Figure 5.10-5.17). These *SMCLs are determined by the first two stages of MAIN algorithm, as mentioned before. The third stage (Step 12b) of the MAIN algorithm is that there is no need to orient the locations of machines because the rearrangement cost is taken away in this experiment. The results of total cell layout costs are provided in Table 5.37-5.43.

(a) Part handling factors equal to 1

Table 5.37 Minimum cost of *steady-DMCL - Yaman's & Tang's cases (λ=1)

Yaman's and Tang's cases						
Planning period / Total traveling cost (ζ x ω)($)	p=1	p=2	p=3	p=4	p=5	Total (a)
SMCL-1	28500	27900	35100	36100	25300	152900
SMCL-2	28500	27900	35100	36100	25300	152900
SMCL-3	31400	29700	31600	35150	24650	152500
SMCL-4	32600	30200	35900	31650	24550	154900
SMCL-5	29400	28200	31700	33650	22750	145700
Minimum of total cell layout cost (α)($)	(b) total rearrangement cost is zero α = (a) + (b)					145700

Table 5.38 Minimum cost of *steady-DMCL - Conway's case (λ=1)

Conway's case						
Planning period / Total traveling cost (ζ x ω)($)	p=1	p=2	p=3	p=4	p=5	Total (a)
SMCL-1	117043	135773	132860	139620	142014	667310
SMCL-2	144782	116053	147521	135624	135318	679298
SMCL-3	134737	142321	121757	136051	132871	667737
SMCL-4	129398	138793	153546	119792	141589	683118
SMCL-5	139466	138817	129955	154012	121403	683653
Minimum of total cell layout cost (α)($)	(b) total rearrangement cost is zero α = (a) + (b)					667310

Table 5.39 Minimum cost of *steady-DMCL - Self-developed case five (λ=1)

Self-developed case five						
Planning period / Total traveling cost (ζ x ω)($)	p=1	p=2	p=3	p=4	p=5	Total (a)
SMCL-1	70740	52860	55020	71420	74320	324360
SMCL-2	71280	52760	56220	71400	73420	325080
SMCL-3	72440	55680	55120	73840	75520	332600
SMCL-4	74840	56360	59860	75040	75620	341720
SMCL-5	69880	55340	58640	77720	69080	330660
Minimum of total cell layout cost (α)($)	(b) total rearrangement cost is zero α = (a) + (b)					324360

Table 5.40 Minimum cost of *steady-DMCL - Self-developed case six (λ=1)

Self-developed case six						
Planning period / Total traveling cost (ζ x ω)($)	p=1	p=2	p=3	p=4	p=5	Total (a)
SMCL-1	56190	45790	66950	58690	74630	302250
SMCL-2	59030	44930	65150	60970	73030	303110
SMCL-3	57010	47390	66950	60890	73870	306110
SMCL-4	56270	46030	67270	57730	73890	301190
SMCL-5	56320	44500	61920	58920	68240	289900
Minimum of total cell layout cost (α)($)	(b) total rearrangement cost is zero α = (a) + (b)					289900

(b) Part handling factors vary

Table 5.41 Minimum cost of *steady-DMCL - Yaman's & Tang's cases (λ vary)

Yaman's and Tang's cases						
Planning period / Total traveling cost (ζ x ω)($)	p=1	p=2	p=3	p=4	p=5	Total (a)
SMCL-1	95900	91500	114050	113050	77800	492300
SMCL-2	97900	89750	109050	103750	72850	473300
SMCL-3	95950	89550	98400	104900	67750	456550
SMCL-4	102050	97800	128500	98850	82350	509550
SMCL-5	95950	89550	98400	104900	67750	456550
Minimum of total cell layout cost (α)($)	(b) total rearrangement cost is zero α = (a) + (b)					456550

Table 5.42 Minimum cost of *steady-DMCL - Self-developed case five (λ vary)

Self-developed case five						
Planning period / Total traveling cost (ζ x ω)($)	p=1	p=2	p=3	p=4	p=5	Total (a)
SMCL-1	147990	121040	116680	174240	148710	708660
SMCL-2	150830	121530	118030	161560	154090	706040
SMCL-3	151500	122820	114560	168040	152670	709590
SMCL-4	150830	121530	118030	161560	154090	706040
SMCL-5	148840	123330	117790	172420	149970	712350
Minimum of total cell layout cost (α)($)	(b) total rearrangement cost is zero α = (a) + (b)					706040

Table 5.43 Minimum cost of *steady-DMCL - Self-developed case six (λ vary)

Self-developed case six						
Planning period / Total traveling cost (ζ x ω)($)	p=1	p=2	p=3	p=4	p=5	Total (a)
SMCL-1	118950	94070	139130	117350	148840	618340
SMCL-2	121680	90970	136610	114270	154800	618330
SMCL-3	129920	97000	141350	122850	160710	651830
SMCL-4	123980	94430	132960	112010	141820	605200
SMCL-5	121090	96400	135550	115830	139920	608790
Minimum of total cell layout cost (α)($)	(b) total rearrangement cost is zero α = (a) + (b)					605200

5.7 Results

Performance evaluation in the proposed MAIN algorithm can be classified according to four aspects. A more extensive comparison will be shown on following sections. First, SMCLs are obtained in experiment 1, and the total traveling scores are used as the indicators of the effectiveness of the static layouts. The absolute and relative solution qualities will be employed to study the performance of the MAIN algorithm. Second, multi-DMCLs determined in experiment 2 will be examined. The total cell layout costs are used as measuring indicators. The absolute and relative solution qualities are also used to generate comparative indices. Third, the modified multi-DMCLs produced in experiment 3 will be looked at. The evaluation method is similar to the second one. Finally, the outcomes of the steady-DMCL in experiment 4 will be investigated.

5.7.1 SMCLs Performance

The effectiveness of SMCLs on corresponding planning periods is examined in experiment 1. Optimal layouts (obtained by exhaustive search by using computer program), current approaches and the proposed MAIN algorithm are compared. In section 5.7.1-a, the averages QA_c and QA_m from existing approaches and the proposed MAIN algorithm are 0.887 and 0.968 respectively; self-developed cases are not included. The average QR shows 10.83% improvement throughout all cases (see Table 5.44-5.51). Obviously, the average performance of the first two stages of MAIN algorithm is better than the existing approaches by about 10%. In section 5.7.1-b, the part handling factors are considered in the MAIN algorithm, and only the averages of absolute solution qualities are calculated for comparison purpose. One can find that the average absolute solution quality is 0.974 (see Table 5.52-5.54). This means that the first two stages of the MAIN algorithm can generate near optimal solutions, the accuracy is about 97%. That is very good for heuristic approaches.

(a) Part handling factors equal to 1

Table 5.44 Performance of SMCLs - spiral type one of Yaman's approach (λ=1)

By spiral type one of Yaman's approach						
Planning periods	ζ_a	ζ_c	ζ_m	**QA_c**	**QA_m**	**QR (%)**
p=1	2780	3630	2850	0.766	0.976	21.49
p=2	2640	3180	2790	0.830	0.946	12.26
p=3	2950	3690	3160	0.800	0.933	14.36
p=4	3020	3975	3165	0.760	0.954	20.38
p=5	2200	3045	2275	0.723	0.967	25.29
			Average:	0.776	0.955	18.76

Table 5.45 Performance of SMCLs - spiral type two of Yaman's approach (λ=1)

By spiral type two of Yaman's approach						
Planning periods	ζ_a	ζ_c	ζ_m	QA_c	QA_m	QR (%)
p=1	2780	3470	2850	0.801	0.976	17.87
p=2	2640	3350	2790	0.788	0.946	16.72
p=3	2950	3570	3160	0.826	0.933	11.48
p=4	3020	4065	3165	0.743	0.954	22.14
p=5	2200	2975	2275	0.740	0.967	23.53
			Average:	0.780	0.955	18.35

Table 5.46 Performance of SMCLs - minimum score of Tang's approach (λ=1)

By minimum of total traveling score at Tang's approach						
Planning periods	ζ_a	ζ_c	ζ_m	QA_c	QA_m	QR (%)
p=1	2780	2820	2850	0.986	0.976	-1.06
p=2	2640	2980	2790	0.886	0.946	6.38
p=3	2950	3200	3160	0.922	0.933	1.25
p=4	3020	3100	3165	0.975	0.954	-2.10
p=5	2200	2355	2275	0.935	0.967	3.40
			Average:	0.941	0.955	7.87

Table 5.47 Performance of SMCLs - maximum score of Tang's approach (λ=1)

By maximum of total traveling score at Tang's approach						
Planning periods	ζ_a	ζ_c	ζ_m	QA_c	QA_m	QR (%)
p=1	2780	3310	2850	0.840	0.976	13.90
p=2	2640	3150	2790	0.838	0.946	11.43
p=3	2950	3315	3160	0.890	0.933	4.68
p=4	3020	3450	3165	0.876	0.954	8.26
p=5	2200	2575	2275	0.855	0.967	11.65
			Average:	0.860	0.955	9.98

Table 5.48 Performance of SMCLs - Conway's approach (λ=1)

By Conway's approach						
Planning periods	ζ_a	ζ_c	ζ_m	QA_c	QA_m	**QR (%)**
p=1	116288	118875	117043	0.978	0.994	1.54
p=2	115795	115795	116053	1.000	0.998	-0.22
p=3	120172	122353	121757	0.982	0.987	0.49
p=4	119004	119004	119792	1.000	0.993	-0.66
p=5	120770	120770	121403	1.000	0.995	-0.52
			Average:	0.992	0.993	0.63

Table 5.49 Performance of SMCLs - Rosenblatt's approach (λ=1)

By Rosenblatt's approach						
Planning periods	ζ_a	ζ_c	ζ_m	QA_c	QA_m	**QR (%)**
p=1	12822	12894	12896	0.994	0.994	-0.02
p=2	14853	15356	14883	0.967	0.998	3.08
p=3	13172	13172	13488	1.000	0.977	-2.40
p=4	13032	13188	13032	0.988	1.000	1.18
p=5	12819	13867	12819	0.924	1.000	7.56
			Average:	0.975	0.994	9.40

Table 5.50 Performance of SMCLs - Self-developed case five (λ=1)

Self-developed case five						
Planning periods	ζ_a	ζ_c	ζ_m	QA_c	QA_m	**QR (%)**
p=1	6988	-	7074	-	0.988	-
p=2	5276	-	5276	-	1.000	-
p=3	5502	-	5512	-	0.998	-
p=4	7140	-	7504	-	0.951	-
p=5	6908	-	6908	-	1.000	-
			Average:	-	0.987	-

Table 5.51 Performance of SMCLs - self-developed case six (λ=1)

Self-developed case six						
Planning periods	ζ_a	ζ_c	ζ_m	QA_c	QA_m	QR (%)
p=1	5530	-	5619	-	0.984	-
p=2	4450	-	4493	-	0.990	-
p=3	6192	-	6695	-	0.925	-
p=4	5773	-	5773	-	1.000	-
p=5	6719	-	6824	-	0.985	-
			Average:	-	0.977	-

(b) Part handling factors vary

Table 5.52 Performance of SMCLs - Yaman's and Tang's cases (λ vary)

From modified Yaman's and Tang's cases						
Planning periods	ζ_a	ζ_c	ζ_m	QA_c	QA_m	QR (%)
p=1	9085	-	9590	-	0.947	-
p=2	8360	-	8975	-	0.931	-
p=3	9780	-	9840	-	0.994	-
p=4	9375	-	9885	-	0.948	-
p=5	6545	-	6775	-	0.966	-
			Average:	-	0.957	-

Table 5.53 Performance of SMCLs - Self-developed case five (λ vary)

From self-developed case five						
Planning periods	ζ_a	ζ_c	ζ_m	QA_c	QA_m	QR (%)
p=1	14799	-	14799	-	1.000	-
p=2	11938	-	12153	-	0.982	-
p=3	11312	-	11456	-	0.987	-
p=4	16145	-	16156	-	0.999	-
p=5	14871	-	14997	-	0.992	-
			Average:	-	0.992	-

Table 5.54 Performance of SMCLs - Self-developed case six (λ vary)

From self-developed case six						
Planning periods	ζ_a	ζ_c	ζ_m	**QA_c**	**QA_m**	**QR (%)**
p=1	11775	-	11895	-	0.990	-
p=2	8952	-	9097	-	0.984	-
p=3	12989	-	14135	-	0.919	-
p=4	10935	-	11201	-	0.976	-
p=5	13872	-	13992	-	0.991	-
			Average:	-	0.972	-

5.7.2 Multi-DMCLs Performance

The multi-DMCLs determined by the MAIN algorithm provided very good results. However, Conway's approach has generated an odd solution in Table 5.55. The value of α_a is greater than α_c. This means that α_a is not the optimum layout. The reason for this is simply that the #SMCL determined by computer program is only suitable for a specific quantitative demand. The #multi-DMCLs obtained from these #SMCLs may not be optimal results, and the rearrangement costs may not be minimum in these cases. The results of the multi-DMCLs show in Table 5.55 and 5.56 are determined by SMCLs (#SMCLs and *SMCLs) in experiment 2. In section 5.7.2-a, the part handling factors are assigned to be 1. The average values of QA_c and QA_m are 0.865 and 0.961 respectively. Furthermore, the average QR is 10.0%. In section 5.7.2-b, part handling factors vary, and the average QA_m is 0.970. This indicates that the general performance of the MAIN algorithm is good and stable in this part.

(a) Part handling factors equal to 1

Table 5.55 Performance of multi-DMCLs (λ =1)

cases	α_a	α_c	α_m	QA_c	QA_m	QR (%)
Yaman (type 1)	139242	181395	146351	0.768	0.951	19.32
Yaman (type 2)	139242	180231	146351	0.773	0.951	18.80
Tang (min)	139242	150140	146351	0.927	0.951	2.52
Tang (max)	139242	163687	146351	0.851	0.951	10.59
Conway	620689	617914	625558	1.004	0.992	-1.23
Case five	346972	-	354826	-	0.978	-
Case six	303784	-	318096	-	0.955	-
			Average:	0.865	0.961	10.0

(b) Part handling factors vary

Table 5.56 Performance of multi-DMCLs (λ vary)

cases	α_a	α_c	α_m	QA_c	QA_m	QR (%)
Yaman & Tang	434151	-	457326	-	0.949	-
Case five	719355	-	723024	-	0.995	-
Case six	608329	-	629074	-	0.967	-
			Average:	-	0.970	-

5.7.3 Modified Multi-DMCLs Performance

The performance measure method is similar to that indicated in the previous section. The data are obtained in experiment 3. The difference between experiments 2 and 3 is that the modified multi-DMCLs have undergone Step 12c and Step 13 of the MAIN algorithm. As a result, the total rearrangement cost will be minimized, whilst the total traveling cost is still unchanged. In section 5.7.3-a, the average QA_c and QA_m are 0.860 and 0.967 respectively. Furthermore, the average QR is 10.63%. In section 5.7.3-b, the average QA_m is 0.969.

All values of α_a, α_c and α_m are improved, in comparison with the results in experiment 2 (multi-DMCLs). This is because the performances of the modified multi-DMCLs have been enhanced by the layout replication techniques developed and the proposed modified SC. Therefore, the total rearrangement costs are reduced. This proves that the function of third stage of the MAIN algorithm is important.

(a) Part handling factors equal to 1

Table 5.57 Performance of modified multi-DMCLs (λ =1)

cases	α_a	α_c	α_m	QA_c	QA_m	QR (%)
Yaman (type 1)	138514	179631	144787	0.771	0.957	19.40
Yaman (type 2)	138514	179463	144787	0.772	0.957	19.32
Tang (min)	138514	149390	144787	0.927	0.957	3.08
Tang (max)	138514	163003	144787	0.850	0.957	11.18
Conway	612386	617914	616866	0.991	0.993	0.17
Case five	342012	-	344818	-	0.992	-
Case six	300204	-	314086	-	0.956	-
			Average:	0.860	0.967	10.63

(b) Part handling factors vary

Table 5.58 Performance of modified multi-DMCLs (λ vary)

cases	α_a	α_c	α_m	QA_c	QA_m	QR (%)
Yaman & Tang	434151	-	456366	-	0.951	-
Case five	709168	-	716098	-	0.990	-
Case six	603499	-	624664	-	0.966	-
			Average:	-	0.969	-

5.7.4 Steady-DMCL Performance

The steady-DMCL is a layout designed to fit the fluctuating quantitative demands in multi-planning periods. The one with minimum total cell layout cost will be selected. As the total rearrangement cost is zero, it only involved the total traveling cost that is affected by the part handling factors and parts flow frequencies. The results are shown in Table 5.59-5.60. In section 5.7.4-a, the average value QA_c and QA_m are 0.895 and 0.961 respectively. Furthermore, the average QR is 5.35% and in section 5.7.4-b, the average QA_m is 0.976.

Although the average QR obtained is about 5.35%, less than the experiment 1,2 & 3, the QA_m is good (0.976), the proposed MAIN algorithm has a good performance in different environments.

(a) Part handling factors equal to 1

Table 5.59 Performance of modified multi-DMCLs (λ =1)

cases	α_a	α_c	α_m	QA_c	QA_m	QR (%)
Yaman (type 1)	137000	165800	145700	0.826	0.940	12.12
Yaman (type 2)	137000	161700	145700	0.847	0.940	9.89
Tang (min)	137000	146200	145700	0.937	0.940	0.34
Tang (max)	137000	158550	145700	0.864	0.940	8.10
Conway	643502	643502	667310	1.000	0.964	-3.70
Case five	324360	-	324360	-	1.000	-
Case six	289900	-	289900	-	1.000	-
			Average:	0.895	0.961	5.35

(b) Part handling factors vary

Table 5.60 Performance of modified multi-DMCLs (λ vary)

cases	α_a	α_c	α_m	QA_c	QA_m	QR (%)
Yaman & Tang	436450	-	456550	-	0.956	-
Case five	693790	-	706040	-	0.983	-
Case six	598360	-	605200	-	0.989	-
			Average:	-	0.976	-

5.8 Summary

In this chapter, four experiments were conducted to verify the performance of proposed MAIN algorithm. All the results of these experiments were provided. In general, the MAIN algorithm shows good performance and is also very stable. The detail analysis will be presented in section 6.1.

6. DISCUSSIONS

The discussions contain six sections and the advantages of using the proposed MAIN algorithm are described. In all cases, optimal solutions, solutions from existing approaches and proposed MAIN algorithm are given and discussed. In section 6.1, the solutions of multi-DMCLs are compared with the modified multi-DMCLs. And in next section, the solutions of multi-DMCLs and steady-DMCL are studied. Section 6.3 further examines the modified multi-DMCLs and the Steady-DMCL. Following this, some problems related to this research project and the drawbacks of the proposed MAIN algorithm will be described. Lastly, the important findings through this project and some observations are highlighted.

6.1 Multi-DMCLs vs Modified Multi-DMCLs

The multi-DMCLs and the modified multi-DMCLs with various cases were tested in experiments 2 and 3 respectively. Tables 5.55-5.58 show the results of these experiments. For instance, the α_a of Yaman (Type1) is 139242 in multi-DMCLs in Table 5.55 and the modified multi-DMCLs gives 138514 in Table 5.57. As a result, the relative improvement is 0.52% {(139242-138514)/139242*100%}. Others are verified by the same method. The purpose is to confirm the significance of the layout replication and SC techniques developed in the proposed MAIN algorithm; the higher the value represents the better the improvement.

In unique part handling factors, the average improvement by using the modified #multi-DMCLs is 0.86% in using the #SMCLs plus stage three of MAIN. Also, from the multi-DMCLs and the modified multi-DMCLs obtained from existing static layout approaches and the proposed MAIN algorithm, the averages of solutions are improved by 0.46% and 1.38% respectively. In vary part handling factors, the average solution is enhanced by 0.74% for multi-DMCLs manipulated by optimal SMCLs plus stage three of MAIN and 0.62% by purely using the MAIN algorithm. As a result, the application of stage three of the MAIN algorithm always shows improvements. Table 6.1 shows the results of each case.

Table 6.1 Improvement from using multi-DMCLs to modified multi-DMCLs

Improvement of quality solutions between experiment 2 & 3 (λ =1)			
Cases	**#SMCLs plus MAIN (Stage 3) (%)**	**Existing approaches plus MAIN (Stage 3) (%)**	**MAIN (Stage 1, 2, 3) (%)**
Yaman (type 1)	0.52	0.97	1.07
Yaman (type 2)	0.52	0.43	1.07
Tang (min)	0.52	0.50	1.07
Tang (max)	0.52	0.42	1.07
Conway	1.34	0.00	1.33
Case five	1.43	-	2.82
Case six	1.18	-	1.26
Average:	0.86	0.46	1.38
Improvement of quality solutions between experiment 2 & 3 (λ vary)			
Yaman's & Tang's case	0.00	-	0.21
Case five	1.42	-	0.95
Case six	0.79	-	0.70
Average:	0.74	-	0.62

6.2 Multi-DMCLs vs Steady-DMCL

The investigation of the multi-DMCLs and the steady-DMCL was conducted in experiments 2 and 4 respectively and the results were presented in Tables 5.55, 5.56, 5.59 & 5.60. The purpose is simply to find an appropriate layout to be used in all periods. If the deviation of solutions (multi-DMCLs minus steady-DMCL) is positive, then the performance of steady-DMCL is better than the multi-DMCL and so on. In unique part handling factors, the average deviation in using #SMCLs plus MAIN is 1.98%. And the average deviations obtained from existing approaches plus MAIN and the pure MAIN algorithm are 4.1% and 1.78% respectively. In varying part handling factors, the average deviations in #SMCL plus MAIN and purely MAIN were 1.55% and 2.11% respectively. In fact, all the average deviations are positives except for Conway's, and Yaman's & Tang's cases (#SMCL plus stage three of MAIN) in Table 6.2. Therefore, in Conway's, and Yaman's & Tang's cases, it is better to use the multi-DMCLs rather than the Steady-DMCL.

Table 6.2 Deviation between multi-DMCLs & steady-DMCL

Deviation of solutions between experiment 2 & 4 (λ =1)			
Cases	#SMCLs plus MAIN (Stage 3) (%)	Existing approaches plus MAIN (Stage 3) (%)	MAIN (Stage 1, 2, 3) (%)
Yaman (type 1)	1.61	8.60	0.44
Yaman (type 2)	1.61	10.28	0.44
Tang (min)	1.61	2.62	0.44
Tang (max)	1.61	3.14	0.44
Conway	-3.68	-4.14	-6.74
Case five	6.52	-	8.59
Case six	4.57	-	8.86
Average:	1.98	4.10	1.78
Deviation of solutions between experiment 2 & 4 (λ vary)			
Yaman's & Tang's case	-0.53	-	0.17
Case five	3.55	-	2.35
Case six	1.64	-	3.80
Average:	1.55	-	2.11

6.3 Modified Multi-DMCLs vs Steady-DMCL

The modified multi-DMCLs and steady-DMCL with various cases were investigated in experiments 3 and 4 respectively. Results are in Table 5.57-5.60. The purpose of this section is to study the effectiveness of using the modified multi-DMCLs and steady-DMCL on the design of layout. Referring to Table 6.3, if the deviation of solutions is negative (modified multi-DMCLs minus steady-DMCL), then the performance of modified multi-DMCLs is better than steady-DMCL. In the situations of unique part handling factors, the average deviation in using #SMCLs plus MAIN is 1.12%. And the average deviations in using existing approaches plus MAIN and solely MAIN are 3.67% and 0.42% respectively. In Yaman's & Tang's cases, steady-DMCL gave better solution layouts. In Conway's case, it is good to use the modified multi-DMCLs. However, in self-developed case five and case six, the steady-DMCL is better. In vary part handling factors, the average of deviation in #SMCL plus MAIN and purely MAIN cases is 0.83% and 1.49% respectively. However, in Yaman's and Tang's cases, it is good to have the modified multi-DMCLs because negative values were obtained. In self-developed case five and six, it is appropriate to use steady-DMCL. As a result, no definite techniques are suitable for all cases, it depends on the conditions of the cell.

Table 6.3 Deviation between modified multi-DMCLs & steady-DMCL

Deviation of solutions between experiment 3 & 4 (λ =1)			
Cases	**#SMCLs plus MAIN (Stage 3) (%)**	**Existing approaches plus MAIN (Stage 3) (%)**	**MAIN (Stage 1, 2, 3) (%)**
Yaman (type 1)	1.09	7.70	-0.63
Yaman (type 2)	1.09	9.90	-0.63
Tang (min)	1.09	2.14	-0.63
Tang (max)	1.09	2.73	-0.63
Conway	-5.08	-4.14	-8.18
Case five	5.16	-	5.93
Case six	3.43	-	7.70
Average:	1.12	3.67	0.42
Deviation of solutions between experiment 3 & 4 (λ vary)			
Yaman's & Tang's case	-0.53	-	-0.04
Case five	2.17	-	1.40
Case six	0.85	-	3.12
Average:	0.83	-	1.49

6.4 Problems

The history of the development of the machine cellular layout studies is only around 15 years old. Therefore, there are not many papers that have been published in this area in comparison to other types of layout research such as plant layout, functional layout and flow line layout, etc. There are few established cases that can be used for comparison purpose. Thus, similar layout techniques have been used to verify the proposed MAIN algorithm in this project. Typically, the dominants of part flows in cellular layouts are more significant than other types of layout due to the using of the group technology technique for the rationalization of part families. Subsequently, the results may be biased in some situations.

During the research, a problem occurred in the first version of the software program for obtaining the #SMCLs. Calculating the combinations of n! and recording them took a large amount of memory and computational time, and this caused the computer to be stopped the operation. In the second version, the software program was modified such that we only kept the best solution amount each 1000 combinations search, and this takes more than 12 hours to locate an optimal layout for nine machines. Nevertheless, it took a considerable time to work out all the optimal solutions for various planning periods.

The new conceptual model contains constraints such as the part handling factors for the calculations of the part traveling cost, the basic cost and the cost per unit machine movement for calculating machine rearrangement layout cost. Therefore, it may not be easy to assign appropriate values practically. If these factors could be collected from industry, then the results of the experiments would be more accurate and reliable.

The experiments only tackled the layout problem in up to nine machines in a cell. Although the computer programs could be modified, a large machine group would spend a very long computation time in generating the optimal results. Moreover, a maximum of nine machines in a manufacturing cell is usually adequate according to the literature review.

6.5 Drawbacks

Not all the steps of the proposed MAIN algorithm were coded into the software programming in this research project. Sometimes, human intervention is needed. For example, in step 6 to 11, pair-wise machines would be pulled together manually, but the time spent in manipulating these steps is worth of spending as it usually takes only a few minutes.

The first two stages of the proposed MAIN algorithm do not give an optimal solution every time, but the average results in the testing cases showed that the error was around 3% in comparison to the optimal solutions. If the merged part flow weights have significant variations, the results of solution layouts could be better.

CHAPTER SIX: DISCUSSIONS

Although the results of the multi-DMLCs and the modified multi-DMCLs are determined by the third stage of MAIN, these layouts very much depend upon the solutions of SMCLs that are obtained in the first two stages MAIN. This is simply because the deviations of SMCLs will be carried into the following stages. The current MAIN algorithm can hardly recover these errors.

In the third stage of the MAIN algorithm, the similarity coefficient is used in the determination of modified multi-DMCLs. However, if the same SC value is obtained, then the rearrangement cost can be used as a piece of information to identify the best layout among the successive layouts. But, more calculations will be needed.

For comparison purposes, the absolute and relative solution qualities are formulated in a simple way, so that the result will not represent the deviation linearly. However, it is good for providing a quick check for the closeness to the optimal solution.

6.6 Findings & Observations

The research was evaluated by four experiments with six cases, each was divided into two portions, which were used to show the influence of the part handling factors with the same quantitative demands in a planning period. In Yaman's and Tang's cases, the results obtained by MAIN showed that it was more suitable to use the modified multi-DMCLs no matter the part handling factors is varying or not. In Conway's case, the performance of modified multi-DMCLs was also better than the steady-DMCLs. In the self-developed case five and six, as high basic costs and cost per unit machine movement were used, the performance of steady-DMCL is more superior to the modified multi-DMCLs. And also, the total cell layout costs of steady-DMCL generated may be less than the modified #multi-DMCLs both as the part handling factors vary or not.

In the static stage, the SMCL is determined by the first two stages MAIN. If the proportion of the quantitative demands is relatively consistent with two planning periods, then the layout will be similar. Therefore, one may simply consider using the steady-DMCL.

Generally, in the dynamic stage, the results obtained by the modified multi-DMCLs were usually better than the steady-DMCL. Indeed, the rearrangement cost would be a crucial factor in determining the use of modified multi-DMCLs or steady-DMCL. If some relationship between the total rearrangement cost and the total cell layout cost could be established, it may become an indicator for choosing a suitable approach. Typically, a small total rearrangement cost in the total cell layout cost may lead to the use of modified multi-DMCLs. Otherwise, one should consider choosing the steady-DMCL.

Based on the concept of the solution procedures in the proposed MAIN algorithm, there is no limitation on the number of machines. This algorithm can also be used for studying other types of machine layout such as the functional layout and flow line, etc. However, some modifications will be needed and this requires further studies.

6.7 Summary

In this chapter, extensive comparisons were performed. The problems, drawbacks, findings and observations of this research project were discussed thoroughly. The conclusions and further development will be presented in the next chapter.

7. CONCLUSIONS

7.1 Overall Conclusions

Machine layout problems in manufacturing have received considerable attention, and large numbers of research studies have been published on this subject. However, cellular layout is gaining popularity, so research attention should also focus on the resolution of associated problems. The proposed MAIN algorithm addresses the problems in both the SMCL and the DMCL by incorporating practical factors such as the part handling factors, the basic cost for machine relocation and the cost per unit machine movement, etc. The MAIN algorithm works for a maximum of 9 machines, which are put into a 3x3 matrix-like layout by the pushing technique developed for MAIN in the static stage. According to the experiment results, this algorithm would be able to give solution layout up to 97% accuracy in comparison to the optimal solutions in the cases of static machine layouts (SMCL). In fact, the number of machines and location styles are not the definite constrains to the proposed model such as in the conditions of more than 9 machines or irregular machine disposition sites, but further investigations will be needed to verify the effectiveness of using this model.

The MAIN algorithm contributes to the construction of the machine layout, which is able to maximize the closeness of machines relationship and minimizing the total cell layout cost (include the total traveling cost and total rearrangement cost), in cellular manufacturing. In the first stage of MAIN, the ranked merged part flow weight matrix shows the relative efforts required for transferring parts in a planning period. In the second stage, this matrix is used to determine the machine pairs subject to the constraint of 9 equal zones (a 3x3 grid). After machines have been assigned into corresponding zones, the total traveling is derived by the objective functions. If there is more than one planning period, the operations can be repeated for each planning period. In the last stage of the MAIN algorithm, all SMCLs will be examined by looking into their relationships with successive periods. Modified Similarity Coefficient (SC) is used to find the best machine layout since there are eight possible replications with identical total traveling cost to a layout. By choosing the layout with the highest SC value, the cell layout cost would be minimized.

The average absolute solution quality (QA) was developed to measure the performance of MAIN and other developed approaches in the literature. Although the calculated values are not in a linear respect, it serves as a quick way to score the results.

In all experiments, the QA generated by the MAIN algorithm was very satisfactory. In terms of average relative solution quality, it was better than the current approaches by around 10%. This is a significant improvement in tackling the machine layout problem in cellular manufacturing. In the tested cases, machine layouts produced by MAIN were very close to the optimal solutions. The average QA_m is 0.972 in the static cases and 0.967 in the dynamic cases. It also showed that the MAIN algorithm was very stable in terms of generating solutions in both the static and the dynamic stages.

To summarize, we have extensively addressed the machine layout problems in cellular manufacturing in this project. Both the SMCL and the DMCLs of MAIN are useful to machine layout, and this was proved by extensive comparisons between the existing methods and the MAIN algorithm. According to the experiment results, the MAIN algorithm gave better machine layout solutions than other heuristic approaches. Furthermore, in terms of multi-planning periods, the choosing of either steady-DMCL or modified multi-DMCLs is highly depended on the proportion of the machine rearrangement cost. And, therefore, there is not definite answer to it.

7.2 Future Development

The ultimate purpose of this research study is to help industry to solve the machine layout problems in cellular manufacturing. The author hopes to obtain a practical set of data from a company to verify the developed algorithm. Therefore, the investigations can reflect realistic and subsequently, corresponding fine turnings can be made to improve the algorithm. For example, the selection of either steady-

DMCL or modified multi-DMCL will relate to the rearrangement cost. If there is any reference figure, perhaps, the decision process can be simplified.

The overall results of the MAIN algorithm shows good solution quality in various test cases, but further studies on using the algorithm to validate problems with larger number of machines will be needed. Indeed, this also makes it more suitable for choosing heuristic approach. For instance, using computer can hardly solve problems with more than fifteen machines with limited constrains according to the information in literature review.

Most researchers have concentrated on reducing the total traveling cost within a cell, but there was little work on the rearrangement cost incurred by different layouts due to periodical variations. Sometimes, this cost will influence the choice of successive machine layouts. In fact, if the rearrangement costs are ignored, the cellular machine layout is only the summation of the total traveling cost of parts within a cell. This may lead to the selection of the wrong successive machine layouts for the coming periods. That may also affect the accuracy of estimating the actual production cost.

The basic cost for machine relocation and cost per unit machine movement is needed for machine relocations. We assumed that the cost per unit machine movement contains 10% of basic cost for machine relocation in this project. Indeed, practical values should be used to replace the assumption values. And, perhaps, some more observations will be obtained by applying practical data.

According to the analysis, it may be seen that the ratio of total traveling cost to total cell layout cost and the ratio of total rearrangement cost to total cell layout cost may be very important factors to decide the layout tactics. Therefore, there is a potential to look into these ratios, which could be used as indicators for determining the layout strategy. However, further investigations will be needed.

Lastly, some improvements can be made by automating the processes of operating the MAIN algorithm. For example, step 6 to 11 could be manipulated by computer program but this will require further work.

7.3 Application of the model

In general, the layout strategies are divided into two perspectives such as static and dynamic. The static layout is a traditional type of layout for production. It also may be adopted in every industry especially the machine rearrangement costs are prohibitive such as movement of heavy machinery or expensive on installation. For example, if the press works of production line has been developed in a car manufacturing industry, it does not frequently change the location of machinery [8]. Meanwhile, the dynamic layout may advocated to use in frequently change of product mix pattern due to change of the flow dominance. As the semiconductor manufacturing industry are required to improve the production efficiency for throughput and setting time, the improvement of production line is a method to be reduced by parts handling time [4][18]. Therefore, this model can be helped to evaluate which layout strategy is more suitable for the different industries. In addition, this model has been considered in the static and dynamic situations with the practical constraints. The decision maker only put the data in the model without movement of production line before the reconfiguration processes. It can be reduced to the cost of unnecessary change.

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Appendices

Appendix I: The Program of MAIN Algorithm Source Code

(program 1:overall 7x)

```
clear;
[filename,path]=uigetfile('*.mat','get file')
eval(['load ' [path filename]]);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%% Transfer operation sequence and Quantity to matrix
%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
qq=2;
while qq==2
[plan,pa]=uigetfile('*.mat','get file')
eval(['load ' [pa plan]]);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%% measuring distance between m/c at donimated flow %%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
sep=input('Select the option: \n "1" not separate
evaluation \n "2" Separate evaluation \n Input no.:')
clear time;
t0=clock;
if sep==1
     e=1;
     d=0;
     dd=0;
     ff=0;
      for g=1:nn
        for r=1:v
          for j=1:mm
            for i=1:mm
              if z(r,1)==y(g,i) & z(r,2)==y(g,j);
                 w(e,1+d)=i;
                 w(e,2+d)=j;
                 e=e+1;
              end
            end
          end
        end
         d=d+2;
         e=1;
     end
```

```
     for i=1:nn
       for ee=1:v
          f(ee,1+ff)=loc(w(ee,1+dd),w(ee,2+dd))*z(ee,3);
       end
        ff=ff+1;
        dd=dd+2;
     end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%% caculate the min. total traveling distance %%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
sumf=sum(f,1);
mttd=min(sumf)
j=1
for i=1:nn
   if sumf(1,i)==mttd
      u(j,:)=y(i,:)
      uu(j,1)=i
      j=j+1;
   end
end
time=etime(clock,t0)
end
rep=1;
rr=1;
fin=1;
C=0;
F=0;
E=0;
while rep==1 ~ fin<nn
   if sep==2
    loop=input('no. of loop for trying generation:')
    st=input('Input the start number:')
    fin=input('Input the finish number:')
    interval=input('Input interval between each loop:')
    for i=1:loop
     rep=1;
     e=1;
     d=0;
     dd=0;
     ff=0;
     w=[];
     f=[];
      for g=st:fin
        for r=1:v
          for j=1:mm
            for i=1:mm
              if z(r,1)==y(g,i) & z(r,2)==y(g,j);
```

```
                  w(e,1+d)=i;
                  w(e,2+d)=j;
                  e=e+1;
               end
             end
           end
         end
          d=d+2;
          e=1;
      end
      for i=1:fin-st+1
        for ee=1:v
           f(ee,1+ff)=loc(w(ee,1+dd),w(ee,2+dd))*z(ee,3);
        end
         ff=ff+1;
         dd=dd+2;
      end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%% caculate the min. total traveling distance %%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
sumf=sum(f,1);
mttd(rr,:)=min(sumf)
j=1
for i=1:fin-st+1
   if sumf(1,i)==mttd(rr,:)
      u(j+C,:)=y(i+F,:)
      uu(j+C,1)=i+F
      j=j+1;
   end
   F=st-1;
end
cc=size(u);
C=cc(1,1);
rr=rr+1;
time=etime(clock,t0)
st=fin
fin=fin+interval
end
end
rep=rep+1;
rep=input('Select the option: \n "1" repeat the
separating generation \n "2" is quit \n Input no:')
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
% minimize total traveling distance from n!combination %
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
mttduu=min(mttd)
j=1
for i=1:length(mttd)
   if mttd(i,1)==mttduu
      G(j,1)=i
      j=j+1;
   end
end
qq=input('Select the repeating steps at stages \n "1" is
change generation \n "2" is changing quantities demand
\n "3" is Stop \n Input:')
end
```

Data Collection of the MAIN Algorithm

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%% Transfer operation sequence and Quantity to matrix
%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
```

(program 2: overall 8x)

```
clear;
qq=2;
while qq==2
n=input('Select the data collection method \n "1" is
input the operational sequence and quantities of each
part \n "2" is input the fr-to matrix \n Input: ')
if n==1
   seq=[];
   handling=[];
   x=[];
   seq=[];
   freq=[];
   sumqty=[];
   qty=[];
   k=0;
   total=[];
   uftm=[];
   a=input('Input number of m/cs within cell: ')
   sumqty=zeros(a);
   total=zeros(a);
   n=input('Input number of parts within cell: ')
   for i=1:n
```

```
     fprintf('Input number of parts per each
transportation, part %g : ',i)
     qty(i,:)=input('')
   end
   for i=1:n
      j=i
      fprintf('input no. of machines are employed by
part %g : ',i)
      m=input('')
      for i=1:m
         fprintf('input the operation %g of part %g :
',i,j)
         seq(j,i)=input('')
      end
      for i=1:m-1
         fprintf('input part handling factors m/c from
%g to %g, part %g : ',seq(j,i),seq(j,i+1),j)
         handling(j,i)=input('')
      end
      for i=1:m-1
          x(j,1)=seq(j,i);
          x(j,2)=seq(j,i+1);
          x(j,3)=qty(j,:);
          x(j,4)=handling(j,i);
          x(j,5)=x(j,3)*x(j,4);
          if x(j,1)~x(j,2)
             freq(i+k,:)=x(j,:);

sumqty(freq(i+k,1),freq(i+k,2))=freq(i+k,5);
          end
       end
       total=sumqty+total;
       sumqty=zeros(a);
       k=m-1+k;
    end
end
if n==2
   m=input('Number of m/c within cell:')
   a=m;
    for j=1:m
      for i=1:m
       fprintf('input quantities demand from m/c %g to
m/c %g : ',j,i)
       total(j,i)=input('')
      end
    end
end
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%Transfer sysmetric matrix to unsysmetric%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

b=input('Select the fr-to matrix: \n "1" is
Unsymmetrical matrix \n "2" is symmetrical matrix \n
Input number: ')
if b==1
    for i=1:a
       for j=1:a
           uftm(i,j)=total(i,j)+total(j,i);
       end
    end
      for c=0:a
        for i=1:a-c
           uftm(i+c,i)=0;
        end
      end
 end
if b==2
    uftm=total;
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%% identify the flow between m/c %%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
v=1;
z=[];
for t=1:a
   for s=1:a
      if uftm(t,s)>0
         z(v,1)=t;
         z(v,2)=s;
         z(v,3)=uftm(t,s);
         v=v+1;
      end
   end
end
v=v-1;
qq=qq+2;
end
```

The First Two Stages of the MAIN Algorithm

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%% distance between the location %%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

(program 3: overall 2x)

```
clear
k=0;
h=0;
n=input('Input number of machines within cell:')
if n<=9
  for i=1:3
     for j=1:3
        coord(j+k,1)=i;
        coord(j+k,2)=j;
     end
     k=3+k;
  end
end
if n>=10 & n<=16
  for i=1:4
     for j=1:4
        coord(j+k,1)=i;
        coord(j+k,2)=j;
     end
     k=4+k;
  end
end
if n>=17 & n<=25
  for i=1:5
     for j=1:5
        coord(j+k,1)=i;
        coord(j+k,2)=j;
     end
     k=5+k;
  end
end
m=input('Select measuring method for distance between
machines \n "1" is Rectangular \n "2" is Euclidean \n
"3" is Square Euclidean\n "4" is by self-measuring
method\n Input number: ')
if m==1
   for j=1:9
     for i=1:9
        loc(i,j)=abs(coord(j,1)-
coord(i,1))+abs(coord(j,2)-coord(i,2));
     end
   end
end
if m==2
   for j=1:9
     for i=1:9
```

```
        loc(i,j)=((coord(j,1)-coord(i,1))^2+(coord(j,2)-
coord(i,2))^2)^0.5;
     end
   end
end
if m==3
   for j=1:9
      for i=1:9
        loc(i,j)=(coord(j,1)-coord(i,1))^2+(coord(j,2)-
coord(i,2))^2;
     end
   end
end
if m==4
  n=input('Number of m/c within cell:')
    for j=1:n
      for i=1:n
       fprintf('input the generation %g location %g :
',j,i)
       loc(j,i)=input('')
      end
    end
 end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%% generate the random number %%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
qq=1;
while qq==1
y=[];
q=input('Select the generating method for allocating m/c
locations: \n "1" input location  \n "2" random
generation  \n "3" optimal solution \n Input:')
if q==1
   nn=input('no. of generations:')
   mm=input('input no. of m/c for each generation:')
    for j=1:nn
      for i=1:mm
       fprintf('input the generation %g location %g :
',j,i)
       y(j,i)=input('')
      end
    end
end
if q==2
   nn=input('input no. of generation:')
   mm=input('input no. of m/c for each generation:')
     for i=1:nn
```

```
      y(i,:)=randperm(mm);
     end
end
if q==3
     mm=input('input number of m/c for generating
optimal solution: ')
     y=perms(1:mm);
     nn=prod(1:mm);

end
```

The Rank of Unsymmetrical Part Flow Weight Matrix

```
%%%%%%%%%%%%%%
%% rank uftm %%
%%%%%%%%%%%%%%
```

(program 4: ranuftm_1x)

```
clear;
[filename,path]=uigetfile('*.mat','get file')
eval(['load ' [path filename]]);
k=1;
rank=[];
for i=1:9^2
     pp=max(uftm);
     ppp=max(pp);
        for i=1:9
          for j=1:9
            if uftm(i,j)==ppp & ppp(1,:)>0
                  rank(k,1)=i;
                  rank(k,2)=j;
                  rank(k,3)=uftm(i,j);
                  k=k+1;
                  uftm(i,j)=0;
             end
           end
         end
end
k=1;
r=rank(:,3);
for i=1:length(rank);
rr=max(r);
for i=1:length(rank);
  if r(i,1)==rr & rr(1,:)>0
      r(i,1)=0;
      rank(i,4)=k;
  end
end
```

```
k=k+1;
end
ranuftm=zeros(n);
for i=1:length(rank)
   ranuftm(rank(i,1),rank(i,2))=rank(i,4);
end
rank
ranuftm
```

The Third Stage of the MAIN Algorithm

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%% distance between the location%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

(program 5: stage3_sc_reco)

```
clear;
k=0;
for i=1:3
   for j=1:3
      coord(j+k,1)=i;
      coord(j+k,2)=j;
   end
      k=3+k;
end
m=input('Select measuring method for distance between
machines \n "1" is Rectangular \n "2" is Euclidean \n
"3" is Square Euclidean\n "4" is by self-measuring
method\n Input number: ')
if m==1
   for j=1:9
     for i=1:9
        loc(i,j)=abs(coord(j,1)-
coord(i,1))+abs(coord(j,2)-coord(i,2));
     end
   end
end
if m==2
   for j=1:9
     for i=1:9
        loc(i,j)=((coord(j,1)-coord(i,1))^2+(coord(j,2)
coord(i,2))^2)^0.5;
     end
   end
end
if m==3
   for j=1:9
      for i=1:9
```

```
        loc(i,j)=(coord(j,1)-coord(i,1))^2+(coord(j,2)-
coord(i,2))^2;
     end
   end
end
if m==4
  n=input('Number of m/c within cell:')
    for j=1:n
      for i=1:n
       fprintf('input the generation %g location %g :
',j,i)
       loc(j,i)=input('')
      end
    end
 end


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%% Calculate the SC          %%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
nn=input('no. of planning periods:')
mm=input('input no. of m/c for each planning period:')
k=0;
for i=1:mm
   fprintf('input basic cost for machine arrangement %g:
',i)
   cost(i,1)=input('');
end
for i=1:mm
   fprintf('input cost per unit machine movement for
machine %g: ',i)
   movement(i,1)=input('');
end
for j=1:nn
   for i=1:mm
     fprintf('input the generation %g location %g :
',j,i)
     pa(1,i)=input('');
   end
        p1=reshape(pa,3,3);
        p2=rot90(rot90(flipud(p1),1),2);
        p3=flipdim(p1,2);
        p4=rot90(p1,1);
        p5=rot90(p1,3);
        p6=flipdim(p1,1);
        p7=rot90(flipud(p1),1);
        p8=rot90(p1,2);
```

```
        pa=reshape(p1,1,9);
        pb=reshape(p2,1,9);
        pc=reshape(p3,1,9);
        pd=reshape(p4,1,9);
        pe=reshape(p5,1,9);
        pf=reshape(p6,1,9);
        pg=reshape(p7,1,9);
        ph=reshape(p8,1,9);
        p(1+k,:)=pa;
        p(2+k,:)=pb;
        p(3+k,:)=pc;
        p(4+k,:)=pd;
        p(5+k,:)=pe;
        p(6+k,:)=pf;
        p(7+k,:)=pg;
        p(8+k,:)=ph;
        k=k+8;
        pa=[];
end
sc=zeros(8);
num=0;
q=0;
w=0;
remcno=zeros(9,64);
for i=1:8
   for j=9:16
      for r=1:9
         if p(i,r)==p(j,r);
            num=num+1;
         end
         if p(i,r)~=p(j,r);
            q=q+1;
            remcno(q,1+w)=p(i,r);
         end
      end
      sc(i,j)=num/9;
      number(i,j)=9-num;
      num=0;
      q=0;
      w=w+1;
   end
end
sc
sc(:,9)
sc(:,10)
sc(:,11)
sc(:,12)
```

```
sc(:,13)
sc(:,14)
sc(:,15)
sc(:,16)
number
remcno

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%% Calculate the total rearrangement cost %%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
i=1;
u=0;
loca=zeros(9,128);
locb=zeros(9,128);
for a=1:8
   for b=9:16
      rpa=reshape(p(a,:),3,3);
      rpb=reshape(p(b,:),3,3);
        for p=1:9
           for j=1:3
              for k=1:3
                if remcno(p,i)==rpa(j,k);
                   loca(p,1+u)=j;
                   loca(p,2+u)=k;
                end
                if remcno(p,i)==rpb(j,k);
                   locb(p,1+u)=j;
                   locb(p,2+u)=k;
                end
              end
           end
        end
       u=u+2;
       i=i+1;
   end
end
v=0;
for j=1:64
   for i=1:9
      location(i,j)=abs(loca(i,v+1)-
locb(i,v+1))+abs(loca(i,v+2)-locb(i,v+2));
   end
   v=v+2;
end
reacost=zeros(9,64);
movecost=zeros(9,64);
movementcost=zeros(9,64);
```

```
for j=1:64
   for i=1:9
      if remcno(i,j)>0
         reacost(i,j)=cost(remcno(i,j),1);
         movecost(i,j)=movement(remcno(i,j),1);
         movementcost(i,j)=location(i,j)*movecost(i,j);
      end
   end
end
mov=sum(movementcost,1);
non=sum(reacost,1);
tot=mov+non;
f=0;
for i=1:8
   for j=1:8
      tot_rea_loc(i,j)=tot(1,j+f);
      basic_cost(i,j)=non(1,j+f);
      move_cost(i,j)=mov(1,j+f);
   end
   f=f+8;
end
```

APPENDICES

Appendix II: Existing Approaches Results

Case 1: Various SMCLs determined by existing approaches (refer to experiment 1)

9	4	7
2	6	5
8	1	3
ζ_1=3630		

3	8	1
5	2	4
7	6	9
ζ_2=3180		

9	2	8
1	7	5
6	4	3
ζ_3=3690		

4	3	8
6	2	1
9	5	7
ζ_4=3975		

4	3	8
7	2	1
5	6	9
ζ_5=3045		

Figure Appendix II-1 Existing SMCLs - spiral type one of Yaman's approach

1	7	8
4	6	5
3	9	2
ζ_1=3470		

6	1	7
8	2	4
9	3	5
ζ_2=3350		

4	8	6
2	7	5
3	9	1
ζ_3=3570		

5	8	9
3	2	1
7	4	6
ζ_4=4065		

6	8	5
3	2	1
9	4	7
ζ_5=2975		

Figure Appendix II-2 Existing SMCLs - spiral type two of Yaman's approach

1	2	4
7	5	6
8	3	9
ζ_1=2820		

1	4	2
5	6	3
7	8	9
ζ_2=2980		

1	2	4
3	5	6
8	7	9
ζ_3=3200		

1	4	5
3	2	6
9	8	7
ζ_4=3100		

8	7	6
1	2	4
9	3	5
ζ_5=2355		

Figure Appendix II-3 Existing SMCLs - minimum score of Tang's approach

1	7	8
4	6	3
2	9	5
ζ_1=3310		

1	4	2
5	7	3
6	8	9
ζ_2=3150		

1	3	8
6	5	7
4	2	9
ζ_3=3315		

1	5	6
4	8	7
2	3	9
ζ_4=3450		

1	2	4
5	3	6
8	9	7
ζ_5=2575		

Figure Appendix II-4 Existing SMCLs - maximum score of Tang's approach

7	3	8
1	2	9
4	5	6
ζ_1=118875		

7	1	8
2	3	9
4	5	6
ζ_2=115795		

8	1	3
2	4	9
7	5	6
ζ_3=122353		

8	1	9
4	3	2
7	5	6
ζ_4=119004		

7	2	9
8	3	6
1	5	4
ζ_5=120770		

Figure Appendix II-5 Existing SMCLs - Conway's approach

2	4	6
1	3	5
ζ_1=12894		

2	4	6
1	3	5
ζ_2=15356		

2	4	6
1	5	3
ζ_3=13172		

2	6	4
1	5	3
ζ_4=13188		

2	1	4
6	5	3
ζ_5=13867		

Figure Appendix II-6 Existing SMCLs - Rosemblatt's approach

APPENDICES

Case 2: Multi-DMCLs are determined by existing SMCLs (refer to experiment 2)

Table Appendix II-1 Cost of existing multi-DMCLs - spiral type one of Yaman's approach

By spiral type one of Yaman's approach						
Planning period	p=1	p=2	p=3	p=4	p=5	Total (a)
Total traveling cost (ζ x ω) ($)	36300	31800	36900	39750	30450	175200
Successive periods	$R_{1\rightarrow2}$	$R_{2\rightarrow3}$	$R_{3\rightarrow4}$		$R_{4\rightarrow5}$	Total (b)
Rearrangement cost ($R_{p\rightarrow p+1}$) ($)	1915	1841	1677		762	6195
Total cell layout cost (α) ($)	α = (a) + (b)					181395

Table Appendix II-2 Cost of existing multi-DMCLs - spiral type two of Yaman's approach

By spiral type two of Yaman's approach						
Planning period	p=1	p=2	p=3	p=4	p=5	Total (a)
Total traveling cost (ζ x ω) ($)	34700	33500	35700	40650	29750	174300
Successive periods	$R_{1\rightarrow2}$	$R_{2\rightarrow3}$	$R_{3\rightarrow4}$		$R_{4\rightarrow5}$	Total (b)
Rearrangement cost ($R_{p\rightarrow p+1}$) ($)	1727	1790	1658		756	5931
Total cell layout cost (α) ($)	α = (a) + (b)					180231

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Table Appendix II-3 Cost of existing multi-DMCLs - minimum score of Tang's approach

By minimum traveling score of Tang's approach						
Planning period	p=1	p=2	p=3	p=4	p=5	Total (a)
Total traveling cost (ζ x ω) ($)	28200	29800	32000	31000	23550	144550
Successive periods	$R_{1\to2}$	$R_{2\to3}$	$R_{3\to4}$	$R_{4\to5}$		Total (b)
Rearrangement cost ($R_{p\to p+1}$) ($)	1406	1406	1193	1585		5590
Total cell layout cost (α) ($)	α = (a) + (b)					150140

Table Appendix II-4 Cost of existing multi-DMCLs - maximum score of Tang's approach

By maximum traveling score of Tang's approach						
Planning period	p=1	p=2	p=3	p=4	p=5	Total (a)
Total traveling cost (ζ x ω) ($)	33100	31500	33150	34500	25750	158000
Successive periods	$R_{1\to2}$	$R_{2\to3}$	$R_{3\to4}$	$R_{4\to5}$		Total (b)
Rearrangement cost ($R_{p\to p+1}$) ($)	1398	1516	1173	1600		5687
Total cell layout cost (α) ($)	α = (a) + (b)					163687

Table Appendix II-5 Cost of existing multi-DMCLs - Conway's approach

By Conway's approach						
Planning period	p=1	p=2	p=3	p=4	p=5	Total (a)
Total traveling cost (ζ x ω) ($)	118875	115795	122353	119004	120770	596797
Successive periods	$R_{1\to2}$	$R_{2\to3}$	$R_{3\to4}$	$R_{4\to5}$		Total (b)
Rearrangement cost ($R_{p\to p+1}$) ($)	3106	4698	4427	8886		21117
Total cell layout cost (α) ($)	α = (a) + (b)					617914

Case 3: Modified multi-DMCLs determined by SMCLs (refer to experiment 3)

Table Appendix II-6 Cost of modified existing multi-DMCLs - spiral type one of Yaman's approach

By spiral type one of Yaman's approach						
Planning period	p=1	p=2	p=3	p=4	p=5	Total (a)
Total traveling cost (ζ x ω) ($)	36300	31800	36900	39750	30450	175200
Successive periods	$R_{1\rightarrow2}$	$R_{2\rightarrow3}$	$R_{3\rightarrow4}$	$R_{4\rightarrow5}$		Total (b)
Rearrangement cost ($R_{p\rightarrow p+1}$) ($)	901	1233	1571	726		4431
Total cell layout cost (α) ($)	α = (a) + (b)					179631

9	4	7
2	6	5
8	1	3
ζ_1=3630		

9	6	7
4	2	5
1	8	3
ζ_2=3180		

9	2	8
1	7	5
6	4	3
ζ_3=3690		

8	1	7
3	2	5
4	6	9
ζ_4=3975		

8	1	9
3	2	6
4	7	5
ζ_5=3045		

Figure Appendix II-7 Modified existing multi-DMCLs - spiral type one of Yaman's approach

Table Appendix II-7 Cost of modified existing multi-DMCLs - spiral type two of Yaman's approach

By spiral type two of Yaman's approach						
Planning period	p=1	p=2	p=3	p=4	p=5	Total (a)
Total traveling cost (ζ x ω) ($)	34700	33500	35700	40650	29750	174300
Successive periods	$R_{1\rightarrow2}$	$R_{2\rightarrow3}$	$R_{3\rightarrow4}$	$R_{4\rightarrow5}$		Total (b)
Rearrangement cost ($R_{p\rightarrow p+1}$) ($)	1353	1550	1624	636		5163
Total cell layout cost (α) ($)	α = (a) + (b)					179463

1	7	8
4	6	5
3	9	2
ζ_1=3470		

7	1	6
4	2	8
5	3	9
ζ_2=3350		

1	5	6
9	7	8
3	2	4
ζ_3=3570		

9	1	6
8	2	4
5	3	7
ζ_4=4065		

6	3	9
8	2	4
5	1	7
ζ_5=2975		

Figure Appendix II-8 Modified existing multi-DMCLs - spiral type two of Yaman's approach

Table Appendix II-8 Cost of modified existing DMCLs - minimum score of Tang's approach

By minimum traveling score of Tang's approach						
Planning period	p=1	p=2	p=3	p=4	p=5	Total (a)
Total traveling cost (ζ x ω) ($)	28200	29800	32000	31000	23550	144550
Successive periods	$R_{1\rightarrow2}$	$R_{2\rightarrow3}$	$R_{3\rightarrow4}$	$R_{4\rightarrow5}$		Total (b)
Rearrangement cost ($R_{p\rightarrow p+1}$) ($)	1324	1406	1193	917		4840
Total cell layout cost (α) ($)	α = (a) + (b)					149390

1	2	4
7	5	6
8	3	9
ζ_1=2820		

1	5	7
4	6	8
2	3	9
ζ_2=2980		

1	3	8
2	5	7
4	6	9
ζ_3=3200		

1	3	9
4	2	8
5	6	7
ζ_4=3100		

5	4	6
3	2	7
9	1	8
ζ_5=2355		

Figure Appendix II-9 Modified existing multi-DMCLs - minimum score of Tang's approach

Table Appendix II-9 Cost of modified existing multi-DMCLs - maximum score of Tang's approach

By maximum traveling score of Tang's approach						
Planning period	p=1	p=2	p=3	p=4	p=5	Total (a)
Total traveling cost (ζ x ω) ($)	33100	31500	33150	34500	25750	158000
Successive periods	$R_{1\to2}$	$R_{2\to3}$	$R_{3\to4}$	$R_{4\to5}$		Total (b)
Rearrangement cost ($R_{p\to p+1}$) ($)	1088	1424	1173	1318		5003
Total cell layout cost (α) ($)	α = (a) + (b)					163003

1	7	8	1	5	6	1	3	8	1	5	6	1	5	8
4	6	3	4	7	8	6	5	7	4	8	7	2	3	9
2	9	5	2	3	9	4	2	9	2	3	9	4	6	7
ζ_1=3310			ζ_2=3150			ζ_3=3315			ζ_4=3450			ζ_5=2575		

Figure Appendix II-10 Modified existing multi-DMCLs - maximum score of Tang's approach

Table Appendix II-10 Cost of modified existing multi-DMCLs - Conway's approach

By Conway's approach						
Planning period	p=1	p=2	p=3	p=4	p=5	Total (a)
Total traveling cost (ζ x ω) ($)	118875	115795	122353	119004	120770	596797
Successive periods	$R_{1\to2}$	$R_{2\to3}$	$R_{3\to4}$	$R_{4\to5}$		Total (b)
Rearrangement cost ($R_{p\to p+1}$) ($)	3106	4698	4427	8886		21117
Total cell layout cost (α) ($)	α = (a) + (b)					617914

6	1	4	4	5	6	6	5	3	4	3	1	5	1	8
5	2	9	2	3	9	2	4	9	6	5	2	4	3	2
7	3	8	7	1	8	8	7	1	8	7	9	9	6	7
ζ_1=116295			ζ_2=115795			ζ_3=120172			ζ_4=119792			ζ_5=121802		

Figure Appendix II-11 Modified existing multi-DMCLs - Conway's approach

Case 4: Steady-DMCL determined by SMCLs (refer to experiment 4)

Table Appendix II-11 Minimum cost of Steady-DMCL - spiral type one of Yaman's case

By spiral type one of Yaman's case						
Planning period / Total traveling cost (ζ x ω)($)	p=1	p=2	p=3	p=4	p=5	Total (a)
SMCL-1	36360	35500	38800	40750	30850	182260
SMCL-2	33400	31800	35700	37500	27400	165800
SMCL-3	35900	35200	36900	40750	28850	177600
SMCL-4	34700	34300	37600	39750	28250	174600
SMCL-5	38100	36400	40400	42050	30450	187400
Minimum of total cell layout cost (α)($)	(b) total rearrangement cost is zero α = (a) + (b)					165800

Table Appendix II-12 Minimum cost of Steady-DMCL - spiral type two of Yaman's case

By spiral type two of Yaman's case						
Planning period / Total traveling cost (ζ x ω)($)	p=1	p=2	p=3	p=4	p=5	Total (a)
SMCL-1	34700	34600	40800	37750	29950	177800
SMCL-2	36700	33500	41100	40750	28350	180400
SMCL-3	34400	32100	35700	33950	25550	161700
SMCL-4	36400	34200	40800	40650	28450	180500
SMCL-5	37100	35400	41200	38750	29750	182200
Minimum of total cell layout cost (α)($)	(b) total rearrangement cost is zero α = (a) + (b)					161700

Table Appendix II-13 Minimum cost of Steady-DMCL - minimum of total score of Tang's case

By minimum of total traveling score of Tang's case						
Planning period / Total traveling cost (ζ x ω)($)	p=1	p=2	p=3	p=4	p=5	Total (a)
SMCL-1	28200	27800	33100	32900	24200	146200
SMCL-2	30500	29800	38200	32600	26900	158000
SMCL-3	30900	29200	32000	33500	24300	149900
SMCL-4	31300	28800	35700	31000	23900	150700
SMCL-5	32800	29300	36300	34950	23550	156900
Minimum of total cell layout cost (α)($)	(b) total rearrangement cost is zero α = (a) + (b)					146200

Table Appendix II-14 Minimum cost of Steady-DMCL - maximum of score of Tang's case

By maximum of total traveling score of Tang's case						
Planning period / Total traveling cost (ζ x ω)($)	p=1	p=2	p=3	p=4	p=5	Total (a)
SMCL-1	33100	32800	39600	39750	29350	174600
SMCL-2	34100	31500	37900	34600	27300	165400
SMCL-3	33100	31700	33150	34300	26300	158550
SMCL-4	31800	30900	37700	34500	26500	161400
SMCL-5	32600	31000	37600	34750	25750	161700
Minimum of total cell layout cost (α)($)	(b) total rearrangement cost is zero α = (a) + (b)					158550

Table Appendix II-15 Minimum cost of Steady-DMCL - Conway's case

By Conway's case						
Planning period / Total traveling cost (ζ x ω)($)	p=1	p=2	p=3	p=4	p=5	Total (a)
SMCL-1	118875	132539	134393	142276	139402	667485
SMCL-2	132999	115795	134935	138849	135311	657889
SMCL-3	142339	136339	122353	133519	133387	667937
SMCL-4	128143	122200	135306	119004	138849	643502
SMCL-5	136117	123872	141774	143023	120770	665556
Minimum of total cell layout cost (α)($)	(b) total rearrangement cost is zero α = (a) + (b)					643502

APPENDICES

Appendix III: Similarity Coefficient of Different Cases

Case 1: Use #SMCLs (it is manipulated by optimal n! solutions) with the third stage of MAIN to establish the Similarity Coefficients matrix and to determine modified #multi-DMCLs.

(a) Part handling factors equal to 1

Table Appendix III-1 Eight #SMCLs in a planning period - Yaman's and Tang's cases (λ=1)

	P-1									P-2								
1	9	6	4	8	7	2	3	5	1	9	6	4	8	7	2	3	5	1
2	9	8	3	6	7	5	4	2	1	9	8	3	6	7	5	4	2	1
3	3	5	1	8	7	2	9	6	4	3	5	1	8	7	2	9	6	4
4	3	8	9	5	7	6	1	2	4	3	8	9	5	7	6	1	2	4
5	4	2	1	6	7	5	9	8	3	4	2	1	6	7	5	9	8	3
6	4	6	9	2	7	8	1	5	3	4	6	9	2	7	8	1	5	3
7	1	2	4	5	7	6	3	8	9	1	2	4	5	7	6	3	8	9
8	1	5	3	2	7	8	4	6	9	1	5	3	2	7	8	4	6	9
	P-3									P-4								
1	9	6	4	8	7	2	3	5	1	7	8	9	5	2	3	6	4	1
2	9	8	3	6	7	5	4	2	1	7	5	6	8	2	4	9	3	1
3	3	5	1	8	7	2	9	6	4	6	4	1	5	2	3	7	8	9
4	3	8	9	5	7	6	1	2	4	6	5	7	4	2	8	1	3	9
5	4	2	1	6	7	5	9	8	3	9	3	1	8	2	4	7	5	6
6	4	6	9	2	7	8	1	5	3	9	8	7	3	2	5	1	4	6
7	1	2	4	5	7	6	3	8	9	1	3	9	4	2	8	6	5	7
8	1	5	3	2	7	8	4	6	9	1	4	6	3	2	5	9	8	7
	P-5																	
1	9	6	4	8	7	2	3	5	1	e.g. 9	6	4	8	7	2	3	5	1
2	9	8	3	6	7	5	4	2	1									
3	3	5	1	8	7	2	9	6	4									
4	3	8	9	5	7	6	1	2	4									
5	4	2	1	6	7	5	9	8	3									
6	4	6	9	2	7	8	1	5	3									
7	1	2	4	5	7	6	3	8	9									
8	1	5	3	2	7	8	4	6	9									

9	8	3
6	7	5
4	2	1

APPENDICES

Table Appendix III-2 Similarity Coefficient of eight SMCLs - Yaman's and Tang's cases (λ=1)

	P-2,1	P-2,2	P-2,3	P-2,4	P-2,5	P-2,6	P-2,7	P-2,8
P-1,1	1.0000	0.3333	0.3333	0.1111	0.1111	0.3333	0.3333	0.1111
P-1,2	0.3333	1.0000	0.1111	0.3333	0.3333	0.1111	0.1111	0.3333
P-1,3	0.3333	0.1111	1.0000	0.3333	0.3333	0.1111	0.1111	0.3333
P-1,4	0.1111	0.3333	0.3333	1.0000	0.1111	0.3333	0.3333	0.1111
P-1,5	0.1111	0.3333	0.3333	0.1111	1.0000	0.3333	0.3333	0.1111
P-1,6	0.3333	0.1111	0.1111	0.3333	0.3333	1.0000	0.1111	0.3333
P-1,7	0.3333	0.1111	0.1111	0.3333	0.3333	0.1111	1.0000	0.3333
P-1,8	0.1111	0.3333	0.3333	0.1111	0.1111	0.3333	0.3333	1.0000

	P-3,1	P-3,2	P-3,3	P-3,4	P-3,5	P-3,6	P-3,7	P-3,8
P-2,1	1.0000	0.3333	0.3333	0.1111	0.1111	0.3333	0.3333	0.1111
P-2,2	0.3333	1.0000	0.1111	0.3333	0.3333	0.1111	0.1111	0.3333
P-2,3	0.3333	0.1111	1.0000	0.3333	0.3333	0.1111	0.1111	0.3333
P-2,4	0.1111	0.3333	0.3333	1.0000	0.1111	0.3333	0.3333	0.1111
P-2,5	0.1111	0.3333	0.3333	0.1111	1.0000	0.3333	0.3333	0.1111
P-2,6	0.3333	0.1111	0.1111	0.3333	0.3333	1.0000	0.1111	0.3333
P-2,7	0.3333	0.1111	0.1111	0.3333	0.3333	0.1111	1.0000	0.3333
P-2,8	0.1111	0.3333	0.3333	0.1111	0.1111	0.3333	0.3333	1.0000

	P-4,1	P-4,2	P-4,3	P-4,4	P-4,5	P-4,6	P-4,7	P-4,8
P-3,1	0.1111	0.2222	0	0	0.3333	0.1111	0.1111	0
P-3,2	0.2222	0.1111	0	0	0.1111	0.3333	0	0.1111
P-3,3	0	0.3333	0.1111	0.1111	0.2222	0	0	0.1111
P-3,4	0.3333	0	0.1111	0.1111	0	0.2222	0.1111	0
P-3,5	0	0.1111	0.2222	0	0.1111	0.1111	0	0.3333
P-3,6	0.1111	0	0	0.2222	0.1111	0.1111	0.3333	0
P-3,7	0.1111	0	0.3333	0.1111	0	0	0.1111	0.2222
P-3,8	0	0.1111	0.1111	0.3333	0	0	0.2222	0.1111

	P-5,1	P-5,2	P-5,3	P-5,4	P-5,5	P-5,6	P-5,7	P-5,8
P-4,1	0.1111	0.2222	0	0.3333	0	0.1111	0.1111	0
P-4,2	0.2222	0.1111	0.3333	0	0.1111	0	0	0.1111
P-4,3	0	0	0.1111	0.1111	0.2222	0	0.3333	0.1111
P-4,4	0	0	0.1111	0.1111	0	0.2222	0.1111	0.3333
P-4,5	0.3333	0.1111	0.2222	0	0.1111	0.1111	0	0
P-4,6	0.1111	0.3333	0	0.2222	0.1111	0.1111	0	0
P-4,7	0.1111	0	0	0.1111	0	0.3333	0.1111	0.2222
P-4,8	0	0.1111	0.1111	0	0.3333	0	0.2222	0.1111

Table Appendix III-3 eight #SMCLs in a planning period - Conway's case (λ=1)

	P-1									P-2								
1	8	9	4	7	2	3	6	5	1	8	1	7	9	3	2	6	5	4
2	8	7	6	9	2	5	4	3	1	8	9	6	1	3	5	7	2	4
3	6	5	1	7	2	3	8	9	4	6	5	4	9	3	2	8	1	7
4	6	7	8	5	2	9	1	3	4	6	9	8	5	3	1	4	2	7
5	4	3	1	9	2	5	8	7	6	7	2	4	1	3	5	8	9	6
6	4	9	8	3	2	7	1	5	6	7	1	8	2	3	9	4	5	6
7	1	3	4	5	2	9	6	7	8	4	2	7	5	3	1	6	9	8
8	1	5	6	3	2	7	4	9	8	4	5	6	2	3	9	7	1	8
	P-3									P-4								
1	6	2	8	5	4	7	3	9	1	8	1	9	4	3	2	7	5	6
2	6	5	3	2	4	9	8	7	1	8	4	7	1	3	5	9	2	6
3	3	9	1	5	4	7	6	2	8	7	5	6	4	3	2	8	1	9
4	3	5	6	9	4	2	1	7	8	7	4	8	5	3	1	6	2	9
5	8	7	1	2	4	9	6	5	3	9	2	6	1	3	5	8	4	7
6	8	2	6	7	4	5	1	9	3	9	1	8	2	3	4	6	5	7
7	1	7	8	9	4	2	3	5	6	6	2	9	5	3	1	7	4	8
8	1	9	3	7	4	5	8	2	6	6	5	7	2	3	4	9	1	8
	P-5																	
1	9	6	4	2	3	5	7	8	1									
2	9	2	7	6	3	8	4	5	1									
3	7	8	1	2	3	5	9	6	4									
4	7	2	9	8	3	6	1	5	4									
5	4	5	1	6	3	8	9	2	7									
6	4	6	9	5	3	2	1	8	7									
7	1	5	4	8	3	6	7	2	9									
8	1	8	7	5	3	2	4	6	9									

Table Appendix III-4 Similarity Coefficient of eight #SMCLs - Conway's case (λ=1)

	P-2,1	P-2,2	P-2,3	P-2,4	P-2,5	P-2,6	P-2,7	P-2,8
P-1,1	0.3333	0.2222	0.1111	0.1111	0.1111	0.1111	0.1111	0
P-1,2	0.2222	0.3333	0.1111	0.1111	0.1111	0.1111	0	0.1111
P-1,3	0.1111	0.1111	0.3333	0.1111	0.2222	0	0.1111	0.1111
P-1,4	0.1111	0.1111	0.1111	0.3333	0	0.2222	0.1111	0.1111
P-1,5	0.1111	0.1111	0.2222	0	0.3333	0.1111	0.1111	0.1111
P-1,6	0.1111	0.1111	0	0.2222	0.1111	0.3333	0.1111	0.1111
P-1,7	0.1111	0	0.1111	0.1111	0.1111	0.1111	0.3333	0.2222
P-1,8	0	0.1111	0.1111	0.1111	0.1111	0.1111	0.2222	0.3333

	P-3,1	P-3,2	P-3,3	P-3,4	P-3,5	P-3,6	P-3,7	P-3,8
P-2,1	0	0	0.1111	0.2222	0.3333	0.1111	0.3333	0
P-2,2	0	0	0.2222	0.1111	0.1111	0.3333	0	0.3333
P-2,3	0.1111	0.3333	0	0.3333	0	0	0.2222	0.1111
P-2,4	0.3333	0.1111	0.3333	0	0	0	0.1111	0.2222
P-2,5	0.2222	0.1111	0	0	0	0.3333	0.1111	0.3333
P-2,6	0.1111	0.2222	0	0	0.3333	0	0.3333	0.1111
P-2,7	0.3333	0	0.3333	0.1111	0.1111	0.2222	0	0
P-2,8	0	0.3333	0.1111	0.3333	0.2222	0.1111	0	0

	P-4,1	P-4,2	P-4,3	P-4,4	P-4,5	P-4,6	P-4,7	P-4,8
P-3,1	0	0	0	0.2222	0.1111	0.1111	0.3333	0.1111
P-3,2	0	0	0.2222	0	0.1111	0.1111	0.1111	0.3333
P-3,3	0	0.1111	0	0.3333	0	0.1111	0.2222	0.1111
P-3,4	0.1111	0	0.3333	0	0.1111	0	0.1111	0.2222
P-3,5	0.2222	0.1111	0	0.1111	0	0.3333	0	0.1111
P-3,6	0.1111	0.2222	0.1111	0	0.3333	0	0.1111	0
P-3,7	0.3333	0.1111	0.1111	0.1111	0	0.2222	0	0
P-3,8	0.1111	0.3333	0.1111	0.1111	0.2222	0	0	0

	P-5,1	P-5,2	P-5,3	P-5,4	P-5,5	P-5,6	P-5,7	P-5,8
P-4,1	0.2222	0.2222	0.1111	0.3333	0.1111	0.3333	0.2222	0.2222
P-4,2	0.2222	0.2222	0.3333	0.1111	0.3333	0.1111	0.2222	0.2222
P-4,3	0.1111	0.1111	0.2222	0.2222	0.2222	0.2222	0.3333	0.3333
P-4,4	0.1111	0.1111	0.2222	0.2222	0.2222	0.2222	0.3333	0.3333
P-4,5	0.3333	0.3333	0.2222	0.2222	0.2222	0.2222	0.1111	0.1111
P-4,6	0.3333	0.3333	0.2222	0.2222	0.2222	0.2222	0.1111	0.1111
P-4,7	0.2222	0.2222	0.1111	0.3333	0.1111	0.3333	0.2222	0.2222
P-4,8	0.2222	0.2222	0.3333	0.1111	0.3333	0.1111	0.2222	0.2222

Table Appendix III-5 Eight #SMCLs in a planning period - Self-developed case five (λ=1)

	P-1									P-2								
1	8	3	7	9	5	2	6	4	1	9	8	7	3	2	1	5	6	4
2	8	9	6	3	5	4	7	2	1	9	3	5	8	2	6	7	1	4
3	6	4	1	9	5	2	8	3	7	5	6	4	3	2	1	9	8	7
4	6	9	8	4	5	3	1	2	7	5	3	9	6	2	8	4	1	7
5	7	2	1	3	5	4	8	9	6	7	1	4	8	2	6	9	3	5
6	7	3	8	2	5	9	1	4	6	7	8	9	1	2	3	4	6	5
7	1	2	7	4	5	3	6	9	8	4	1	7	6	2	8	5	3	9
8	1	4	6	2	5	9	7	3	8	4	6	5	1	2	3	7	8	9
	P-3									P-4								
1	9	5	3	8	6	2	7	4	1	9	8	7	3	2	1	5	6	4
2	9	8	7	5	6	4	3	2	1	9	3	5	8	2	6	7	1	4
3	7	4	1	8	6	2	9	5	3	5	6	4	3	2	1	9	8	7
4	7	8	9	4	6	5	1	2	3	5	3	9	6	2	8	4	1	7
5	3	2	1	5	6	4	9	8	7	7	1	4	8	2	6	9	3	5
6	3	5	9	2	6	8	1	4	7	7	8	9	1	2	3	4	6	5
7	1	2	3	4	6	5	7	8	9	4	1	7	6	2	8	5	3	9
8	1	4	7	2	6	8	3	5	9	4	6	5	1	2	3	7	8	9
	P-5																	
1	8	3	7	9	5	2	6	4	1									
2	8	9	6	3	5	4	7	2	1									
3	6	4	1	9	5	2	8	3	7									
4	6	9	8	4	5	3	1	2	7									
5	7	2	1	3	5	4	8	9	6									
6	7	3	8	2	5	9	1	4	6									
7	1	2	7	4	5	3	6	9	8									
8	1	4	6	2	5	9	7	3	8									

Table Appendix III-6 Similarity Coefficient of eight #SMCLs - Self-developed case five (λ=1)

	P-2,1	P-2,2	P-2,3	P-2,4	P-2,5	P-2,6	P-2,7	P-2,8
P-1,1	0.1111	0.1111	0	0.1111	0	0	0.1111	0
P-1,2	0.1111	0.1111	0.1111	0	0	0	0	0.1111
P-1,3	0	0	0.1111	0.1111	0.1111	0	0.1111	0
P-1,4	0	0	0.1111	0.1111	0	0.1111	0	0.1111
P-1,5	0.1111	0	0.1111	0	0.1111	0.1111	0	0
P-1,6	0	0.1111	0	0.1111	0.1111	0.1111	0	0
P-1,7	0.1111	0	0	0	0	0.1111	0.1111	0.1111
P-1,8	0	0.1111	0	0	0.1111	0	0.1111	0.1111

	P-3,1	P-3,2	P-3,3	P-3,4	P-3,5	P-3,6	P-3,7	P-3,8
P-2,1	0.1111	0.3333	0	0.1111	0	0	0	0.1111
P-2,2	0.3333	0.1111	0.1111	0	0	0	0.1111	0
P-2,3	0	0	0.1111	0	0.3333	0.1111	0.1111	0
P-2,4	0	0	0	0.1111	0.1111	0.3333	0	0.1111
P-2,5	0.1111	0	0.3333	0.1111	0.1111	0	0	0
P-2,6	0	0.1111	0.1111	0.3333	0	0.1111	0	0
P-2,7	0	0.1111	0	0	0	0.1111	0.1111	0.3333
P-2,8	0.1111	0	0	0	0.1111	0	0.3333	0.1111

	P-4,1	P-4,2	P-4,3	P-4,4	P-4,5	P-4,6	P-4,7	P-4,8
P-3,1	0.1111	0.3333	0	0	0.1111	0	0	0.1111
P-3,2	0.3333	0.1111	0	0	0	0.1111	0.1111	0
P-3,3	0	0.1111	0.1111	0	0.3333	0.1111	0	0
P-3,4	0.1111	0	0	0.1111	0.1111	0.3333	0	0
P-3,5	0	0	0.3333	0.1111	0.1111	0	0	0.1111
P-3,6	0	0	0.1111	0.3333	0	0.1111	0.1111	0
P-3,7	0	0.1111	0.1111	0	0	0	0.1111	0.3333
P-3,8	0.1111	0	0	0.1111	0	0	0.3333	0.1111

	P-5,1	P-5,2	P-5,3	P-5,4	P-5,5	P-5,6	P-5,7	P-5,8
P-4,1	0.1111	0.1111	0	0	0.1111	0	0.1111	0
P-4,2	0.1111	0.1111	0	0	0	0.1111	0	0.1111
P-4,3	0	0.1111	0.1111	0.1111	0.1111	0	0	0
P-4,4	0.1111	0	0.1111	0.1111	0	0.1111	0	0
P-4,5	0	0	0.1111	0	0.1111	0.1111	0	0.1111
P-4,6	0	0	0	0.1111	0.1111	0.1111	0.1111	0
P-4,7	0.1111	0	0.1111	0	0	0	0.1111	0.1111
P-4,8	0	0.1111	0	0.1111	0	0	0.1111	0.1111

Table Appendix III-7 Eight #SMCLs in a planning period - Self-developed case six (λ=1)

	P-1									P-2								
1	9	8	7	5	3	2	6	4	1	9	5	3	8	6	2	7	4	1
2	9	5	6	8	3	4	7	2	1	9	8	7	5	6	4	3	2	1
3	6	4	1	5	3	2	9	8	7	7	4	1	8	6	2	9	5	3
4	6	5	9	4	3	8	1	2	7	7	8	9	4	6	5	1	2	3
5	7	2	1	8	3	4	9	5	6	3	2	1	5	6	4	9	8	7
6	7	8	9	2	3	5	1	4	6	3	5	9	2	6	8	1	4	7
7	1	2	7	4	3	8	6	5	9	1	2	3	4	6	5	7	8	9
8	1	4	6	2	3	5	7	8	9	1	4	7	2	6	8	3	5	9
	P-3									P-4								
1	9	5	3	8	6	2	7	4	1	7	6	4	3	5	2	8	9	1
2	9	8	7	5	6	4	3	2	1	7	3	8	6	5	9	4	2	1
3	7	4	1	8	6	2	9	5	3	8	9	1	3	5	2	7	6	4
4	7	8	9	4	6	5	1	2	3	8	3	7	9	5	6	1	2	4
5	3	2	1	5	6	4	9	8	7	4	2	1	6	5	9	7	3	8
6	3	5	9	2	6	8	1	4	7	4	6	7	2	5	3	1	9	8
7	1	2	3	4	6	5	7	8	9	1	2	4	9	5	6	8	3	7
8	1	4	7	2	6	8	3	5	9	1	9	8	2	5	3	4	6	7
	P-5																	
1	9	8	7	3	2	1	5	6	4									
2	9	3	5	8	2	6	7	1	4									
3	5	6	4	3	2	1	9	8	7									
4	5	3	9	6	2	8	4	1	7									
5	7	1	4	8	2	6	9	3	5									
6	7	8	9	1	2	3	4	6	5									
7	4	1	7	6	2	8	5	3	9									
8	4	6	5	1	2	3	7	8	9									

Table Appendix III-8 Similarity Coefficient of eight #SMCLs - Self-developed case six (λ=1)

	P-2,1	P-2,2	P-2,3	P-2,4	P-2,5	P-2,6	P-2,7	P-2,8
P-1,1	0.4444	0.5556	0.1111	0.1111	0.1111	0.1111	0	0.1111
P-1,2	0.5556	0.4444	0.1111	0.1111	0.1111	0.1111	0.1111	0
P-1,3	0.1111	0.1111	0.4444	0	0.5556	0.1111	0.1111	0.1111
P-1,4	0.1111	0.1111	0	0.4444	0.1111	0.5556	0.1111	0.1111
P-1,5	0.1111	0.1111	0.5556	0.1111	0.4444	0	0.1111	0.1111
P-1,6	0.1111	0.1111	0.1111	0.5556	0	0.4444	0.1111	0.1111
P-1,7	0	0.1111	0.1111	0.1111	0.1111	0.1111	0.4444	0.5556
P-1,8	0.1111	0	0.1111	0.1111	0.1111	0.1111	0.5556	0.4444

	P-3,1	P-3,2	P-3,3	P-3,4	P-3,5	P-3,6	P-3,7	P-3,8
P-2,1	1.0000	0.3333	0.3333	0.1111	0.1111	0.3333	0.3333	0.1111
P-2,2	0.3333	1.0000	0.1111	0.3333	0.3333	0.1111	0.1111	0.3333
P-2,3	0.3333	0.1111	1.0000	0.3333	0.3333	0.1111	0.1111	0.3333
P-2,4	0.1111	0.3333	0.3333	1.0000	0.1111	0.3333	0.3333	0.1111
P-2,5	0.1111	0.3333	0.3333	0.1111	1.0000	0.3333	0.3333	0.1111
P-2,6	0.3333	0.1111	0.1111	0.3333	0.3333	1.0000	0.1111	0.3333
P-2,7	0.3333	0.1111	0.1111	0.3333	0.3333	0.1111	1.0000	0.3333
P-2,8	0.1111	0.3333	0.3333	0.1111	0.1111	0.3333	0.3333	1.0000

	P-4,1	P-4,2	P-4,3	P-4,4	P-4,5	P-4,6	P-4,7	P-4,8
P-3,1	0.2222	0.1111	0.2222	0	0.1111	0	0	0
P-3,2	0.1111	0.2222	0	0.2222	0	0.1111	0	0
P-3,3	0.2222	0.1111	0.2222	0	0.1111	0	0	0
P-3,4	0.1111	0.2222	0	0.2222	0	0.1111	0	0
P-3,5	0	0	0.1111	0	0.2222	0	0.2222	0.1111
P-3,6	0	0	0	0.1111	0	0.2222	0.1111	0.2222
P-3,7	0	0	0.1111	0	0.2222	0	0.2222	0.1111
P-3,8	0	0	0	0.1111	0	0.2222	0.1111	0.2222

	P-5,1	P-5,2	P-5,3	P-5,4	P-5,5	P-5,6	P-5,7	P-5,8
P-4,1	0.1111	0	0.3333	0	0.2222	0.1111	0	0.1111
P-4,2	0	0.1111	0	0.3333	0.1111	0.2222	0.1111	0
P-4,3	0.3333	0.2222	0.1111	0	0	0.1111	0	0.1111
P-4,4	0.2222	0.3333	0	0.1111	0.1111	0	0.1111	0
P-4,5	0	0.1111	0	0.1111	0.1111	0	0.3333	0.2222
P-4,6	0.1111	0	0.1111	0	0	0.1111	0.2222	0.3333
P-4,7	0	0.1111	0.2222	0.1111	0.3333	0	0.1111	0
P-4,8	0.1111	0	0.1111	0.2222	0	0.3333	0	0.1111

(b) Part handling factors vary

Table Appendix III-9 Eight #SMCLs in a planning period - Yaman's and Tang's cases (λ vary)

	P-1									P-2								
1	9	6	4	8	7	2	3	5	1	6	9	4	7	8	2	5	3	1
2	9	8	3	6	7	5	4	2	1	6	7	5	9	8	3	4	2	1
3	3	5	1	8	7	2	9	6	4	5	3	1	7	8	2	6	9	4
4	3	8	9	5	7	6	1	2	4	5	7	6	3	8	9	1	2	4
5	4	2	1	6	7	5	9	8	3	4	2	1	9	8	3	6	7	5
6	4	6	9	2	7	8	1	5	3	4	9	6	2	8	7	1	3	5
7	1	2	4	5	7	6	3	8	9	1	2	4	3	8	9	5	7	6
8	1	5	3	2	7	8	4	6	9	1	3	5	2	8	7	4	9	6
	P-3									P-4								
1	6	9	4	7	8	2	5	3	1	7	6	4	8	5	2	9	3	1
2	6	7	5	9	8	3	4	2	1	7	8	9	6	5	3	4	2	1
3	5	3	1	7	8	2	6	9	4	9	3	1	8	5	2	7	6	4
4	5	7	6	3	8	9	1	2	4	9	8	7	3	5	6	1	2	4
5	4	2	1	9	8	3	6	7	5	4	2	1	6	5	3	7	8	9
6	4	9	6	2	8	7	1	3	5	4	6	7	2	5	8	1	3	9
7	1	2	4	3	8	9	5	7	6	1	2	4	3	5	6	9	8	7
8	1	3	5	2	8	7	4	9	6	1	3	9	2	5	8	4	6	7
	P-5																	
1	6	9	4	7	8	2	5	3	1									
2	6	7	5	9	8	3	4	2	1									
3	5	3	1	7	8	2	6	9	4									
4	5	7	6	3	8	9	1	2	4									
5	4	2	1	9	8	3	6	7	5									
6	4	9	6	2	8	7	1	3	5									
7	1	2	4	3	8	9	5	7	6									
8	1	3	5	2	8	7	4	9	6									

APPENDICES

Table Appendix III-10 Similarity Coefficient of eight #SMCLs - Yaman's and Tang's cases (λ vary)

	P-2,1	P-2,2	P-2,3	P-2,4	P-2,5	P-2,6	P-2,7	P-2,8
P-1,1	0.3333	0.1111	0.1111	0	0	0	0.1111	0
P-1,2	0.1111	0.3333	0	0.1111	0	0	0	0.1111
P-1,3	0.1111	0	0.3333	0.1111	0.1111	0	0	0
P-1,4	0	0.1111	0.1111	0.3333	0	0.1111	0	0
P-1,5	0	0	0.1111	0	0.3333	0.1111	0.1111	0
P-1,6	0	0	0	0.1111	0.1111	0.3333	0	0.1111
P-1,7	0.1111	0	0	0	0.1111	0	0.3333	0.1111
P-1,8	0	0.1111	0	0	0	0.1111	0.1111	0.3333

	P-3,1	P-3,2	P-3,3	P-3,4	P-3,5	P-3,6	P-3,7	P-3,8
P-2,1	1.0000	0.3333	0.3333	0.1111	0.1111	0.3333	0.3333	0.1111
P-2,2	0.3333	1.0000	0.1111	0.3333	0.3333	0.1111	0.1111	0.3333
P-2,3	0.3333	0.1111	1.0000	0.3333	0.3333	0.1111	0.1111	0.3333
P-2,4	0.1111	0.3333	0.3333	1.0000	0.1111	0.3333	0.3333	0.1111
P-2,5	0.1111	0.3333	0.3333	0.1111	1.0000	0.3333	0.3333	0.1111
P-2,6	0.3333	0.1111	0.1111	0.3333	0.3333	1.0000	0.1111	0.3333
P-2,7	0.3333	0.1111	0.1111	0.3333	0.3333	0.1111	1.0000	0.3333
P-2,8	0.1111	0.3333	0.3333	0.1111	0.1111	0.3333	0.3333	1.0000

	P-4,1	P-4,2	P-4,3	P-4,4	P-4,5	P-4,6	P-4,7	P-4,8
P-3,1	0.4444	0.1111	0.1111	0	0	0.1111	0.1111	0
P-3,2	0.1111	0.4444	0	0.1111	0.1111	0	0	0.1111
P-3,3	0.1111	0	0.4444	0.1111	0.1111	0	0	0.1111
P-3,4	0	0.1111	0.1111	0.4444	0	0.1111	0.1111	0
P-3,5	0	0.1111	0.1111	0	0.4444	0.1111	0.1111	0
P-3,6	0.1111	0	0	0.1111	0.1111	0.4444	0	0.1111
P-3,7	0.1111	0	0	0.1111	0.1111	0	0.4444	0.1111
P-3,8	0	0.1111	0.1111	0	0	0.1111	0.1111	0.4444

	P-5,1	P-5,2	P-5,3	P-5,4	P-5,5	P-5,6	P-5,7	P-5,8
P-4,1	0.4444	0.1111	0.1111	0	0	0.1111	0.1111	0
P-4,2	0.1111	0.4444	0	0.1111	0.1111	0	0	0.1111
P-4,3	0.1111	0	0.4444	0.1111	0.1111	0	0	0.1111
P-4,4	0	0.1111	0.1111	0.4444	0	0.1111	0.1111	0
P-4,5	0	0.1111	0.1111	0	0.4444	0.1111	0.1111	0
P-4,6	0.1111	0	0	0.1111	0.1111	0.4444	0	0.1111
P-4,7	0.1111	0	0	0.1111	0.1111	0	0.4444	0.1111
P-4,8	0	0.1111	0.1111	0	0	0.1111	0.1111	0.4444

Table Appendix III-11 Eight #SMCLs in a planning period - Self-developed case five (λ vary)

	P-1									P-2								
1	8	3	7	9	5	2	6	4	1	7	1	8	6	4	2	9	5	3
2	8	9	6	3	5	4	7	2	1	7	6	9	1	4	5	8	2	3
3	6	4	1	9	5	2	8	3	7	9	5	3	6	4	2	7	1	8
4	6	9	8	4	5	3	1	2	7	9	6	7	5	4	1	3	2	8
5	7	2	1	3	5	4	8	9	6	8	2	3	1	4	5	7	6	9
6	7	3	8	2	5	9	1	4	6	8	1	7	2	4	6	3	5	9
7	1	2	7	4	5	3	6	9	8	3	2	8	5	4	1	9	6	7
8	1	4	6	2	5	9	7	3	8	3	5	9	2	4	6	8	1	7
	P-3									P-4								
1	7	1	8	6	4	2	9	5	3	8	7	9	2	1	3	6	4	5
2	7	6	9	1	4	5	8	2	3	8	2	6	7	1	4	9	3	5
3	9	5	3	6	4	2	7	1	8	6	4	5	2	1	3	8	7	9
4	9	6	7	5	4	1	3	2	8	6	2	8	4	1	7	5	3	9
5	8	2	3	1	4	5	7	6	9	9	3	5	7	1	4	8	2	6
6	8	1	7	2	4	6	3	5	9	9	7	8	3	1	2	5	4	6
7	3	2	8	5	4	1	9	6	7	5	3	9	4	1	7	6	2	8
8	3	5	9	2	4	6	8	1	7	5	4	6	3	1	2	9	7	8
	P-5																	
1	8	3	7	9	5	2	6	4	1									
2	8	9	6	3	5	4	7	2	1									
3	6	4	1	9	5	2	8	3	7									
4	6	9	8	4	5	3	1	2	7									
5	7	2	1	3	5	4	8	9	6									
6	7	3	8	2	5	9	1	4	6									
7	1	2	7	4	5	3	6	9	8									
8	1	4	6	2	5	9	7	3	8									

Table Appendix III-12 Similarity Coefficient of eight #SMCLs - Self-developed case five (λ vary)

	P-2,1	P-2,2	P-2,3	P-2,4	P-2,5	P-2,6	P-2,7	P-2,8
P-1,1	0.1111	0	0.1111	0.1111	0.1111	0.2222	0	0
P-1,2	0	0.1111	0.1111	0.1111	0.2222	0.1111	0	0
P-1,3	0.1111	0.1111	0.1111	0	0	0	0.1111	0.2222
P-1,4	0.1111	0.1111	0	0.1111	0	0	0.2222	0.1111
P-1,5	0.1111	0.2222	0	0	0.1111	0	0.1111	0.1111
P-1,6	0.2222	0.1111	0	0	0	0.1111	0.1111	0.1111
P-1,7	0	0	0.1111	0.2222	0.1111	0.1111	0.1111	0
P-1,8	0	0	0.2222	0.1111	0.1111	0.1111	0	0.1111

	P-3,1	P-3,2	P-3,3	P-3,4	P-3,5	P-3,6	P-3,7	P-3,8
P-2,1	1.0000	0.3333	0.3333	0.1111	0.1111	0.3333	0.3333	0.1111
P-2,2	0.3333	1.0000	0.1111	0.3333	0.3333	0.1111	0.1111	0.3333
P-2,3	0.3333	0.1111	1.0000	0.3333	0.3333	0.1111	0.1111	0.3333
P-2,4	0.1111	0.3333	0.3333	1.0000	0.1111	0.3333	0.3333	0.1111
P-2,5	0.1111	0.3333	0.3333	0.1111	1.0000	0.3333	0.3333	0.1111
P-2,6	0.3333	0.1111	0.1111	0.3333	0.3333	1.0000	0.1111	0.3333
P-2,7	0.3333	0.1111	0.1111	0.3333	0.3333	0.1111	1.0000	0.3333
P-2,8	0.1111	0.3333	0.3333	0.1111	0.1111	0.3333	0.3333	1.0000

	P-4,1	P-4,2	P-4,3	P-4,4	P-4,5	P-4,6	P-4,7	P-4,8
P-3,1	0	0.1111	0	0.1111	0	0.2222	0	0.2222
P-3,2	0.1111	0	0.1111	0	0.2222	0	0.2222	0
P-3,3	0	0	0	0	0.1111	0.2222	0.1111	0.2222
P-3,4	0	0	0	0	0.2222	0.1111	0.2222	0.1111
P-3,5	0.1111	0.2222	0.1111	0.2222	0	0	0	0
P-3,6	0.2222	0.1111	0.2222	0.1111	0	0	0	0
P-3,7	0	0.2222	0	0.2222	0	0.1111	0	0.1111
P-3,8	0.2222	0	0.2222	0	0.1111	0	0.1111	0

	P-5,1	P-5,2	P-5,3	P-5,4	P-5,5	P-5,6	P-5,7	P-5,8
P-4,1	0.3333	0.1111	0	0	0.1111	0.2222	0.2222	0.1111
P-4,2	0.1111	0.3333	0	0	0.2222	0.1111	0.1111	0.2222
P-4,3	0	0.1111	0.3333	0.2222	0.1111	0.1111	0	0.2222
P-4,4	0.1111	0	0.2222	0.3333	0.1111	0.1111	0.2222	0
P-4,5	0	0.2222	0.1111	0.1111	0.3333	0.2222	0	0.1111
P-4,6	0.2222	0	0.1111	0.1111	0.2222	0.3333	0.1111	0
P-4,7	0.2222	0.1111	0.1111	0.2222	0	0	0.3333	0.1111
P-4,8	0.1111	0.2222	0.2222	0.1111	0	0	0.1111	0.3333

Table Appendix III-13 Eight #SMCLs in a planning period - Self-developed case six (λ vary)

	P-1									P-2								
1	8	6	2	9	5	3	7	4	1	9	5	3	8	6	2	7	4	1
2	8	9	7	6	5	4	2	3	1	9	8	7	5	6	4	3	2	1
3	7	4	1	9	5	3	8	6	2	7	4	1	8	6	2	9	5	3
4	7	9	8	4	5	6	1	3	2	7	8	9	4	6	5	1	2	3
5	2	3	1	6	5	4	8	9	7	3	2	1	5	6	4	9	8	7
6	2	6	8	3	5	9	1	4	7	3	5	9	2	6	8	1	4	7
7	1	3	2	4	5	6	7	9	8	1	2	3	4	6	5	7	8	9
8	1	4	7	3	5	9	2	6	8	1	4	7	2	6	8	3	5	9
	P-3									P-4								
1	7	1	8	4	6	2	9	5	3	8	3	7	9	5	2	6	4	1
2	7	4	9	1	6	5	8	2	3	8	9	6	3	5	4	7	2	1
3	9	5	3	4	6	2	7	1	8	6	4	1	9	5	2	8	3	7
4	9	4	7	5	6	1	3	2	8	6	9	8	4	5	3	1	2	7
5	8	2	3	1	6	5	7	4	9	7	2	1	3	5	4	8	9	6
6	8	1	7	2	6	4	3	5	9	7	3	8	2	5	9	1	4	6
7	3	2	8	5	6	1	9	4	7	1	2	7	4	5	3	6	9	8
8	3	5	9	2	6	4	8	1	7	1	4	6	2	5	9	7	3	8
	P-5																	
1	9	3	5	8	2	6	7	1	4									
2	9	8	7	3	2	1	5	6	4									
3	7	1	4	8	2	6	9	3	5									
4	7	8	9	1	2	3	4	6	5									
5	5	6	4	3	2	1	9	8	7									
6	5	3	9	6	2	8	4	1	7									
7	4	6	5	1	2	3	7	8	9									
8	4	1	7	6	2	8	5	3	9									

Table Appendix III-14 Similarity Coefficient of eight #SMCLs - Self-developed case six (λ vary)

	P-2,1	P-2,2	P-2,3	P-2,4	P-2,5	P-2,6	P-2,7	P-2,8
P-1,1	0.3333	0.1111	0	0	0	0.1111	0.1111	0
P-1,2	0.1111	0.3333	0	0	0.1111	0	0	0.1111
P-1,3	0	0	0.3333	0.1111	0.1111	0	0	0.1111
P-1,4	0	0	0.1111	0.3333	0	0.1111	0.1111	0
P-1,5	0	0.1111	0.1111	0	0.3333	0.1111	0	0
P-1,6	0.1111	0	0	0.1111	0.1111	0.3333	0	0
P-1,7	0.1111	0	0	0.1111	0	0	0.3333	0.1111
P-1,8	0	0.1111	0.1111	0	0	0	0.1111	0.3333

	P-3,1	P-3,2	P-3,3	P-3,4	P-3,5	P-3,6	P-3,7	P-3,8
P-2,1	0.2222	0.1111	0.6667	0.2222	0.4444	0.1111	0.2222	0.2222
P-2,2	0.1111	0.2222	0.2222	0.6667	0.1111	0.4444	0.2222	0.2222
P-2,3	0.6667	0.4444	0.2222	0.2222	0.1111	0.2222	0.2222	0.1111
P-2,4	0.4444	0.6667	0.2222	0.2222	0.2222	0.1111	0.1111	0.2222
P-2,5	0.2222	0.1111	0.1111	0.2222	0.2222	0.2222	0.6667	0.4444
P-2,6	0.1111	0.2222	0.2222	0.1111	0.2222	0.2222	0.4444	0.6667
P-2,7	0.2222	0.2222	0.4444	0.1111	0.6667	0.2222	0.2222	0.1111
P-2,8	0.2222	0.2222	0.1111	0.4444	0.2222	0.6667	0.1111	0.2222

	P-4,1	P-4,2	P-4,3	P-4,4	P-4,5	P-4,6	P-4,7	P-4,8
P-3,1	0.1111	0	0.1111	0.2222	0.1111	0.2222	0.1111	0
P-3,2	0	0.1111	0.2222	0.1111	0.2222	0.1111	0	0.1111
P-3,3	0.1111	0.1111	0.1111	0.1111	0	0	0.2222	0.2222
P-3,4	0.1111	0.1111	0.1111	0.1111	0	0	0.2222	0.2222
P-3,5	0.2222	0.2222	0	0	0.1111	0.1111	0.1111	0.1111
P-3,6	0.2222	0.2222	0	0	0.1111	0.1111	0.1111	0.1111
P-3,7	0.1111	0	0.1111	0.2222	0.1111	0.2222	0.1111	0
P-3,8	0	0.1111	0.2222	0.1111	0.2222	0.1111	0	0.1111

	P-5,1	P-5,2	P-5,3	P-5,4	P-5,5	P-5,6	P-5,7	P-5,8
P-4,1	0.1111	0.1111	0	0	0	0.1111	0	0.1111
P-4,2	0.1111	0.1111	0	0	0.1111	0	0.1111	0
P-4,3	0	0	0.1111	0	0.1111	0.1111	0	0.1111
P-4,4	0	0	0	0.1111	0.1111	0.1111	0.1111	0
P-4,5	0	0.1111	0.1111	0.1111	0.1111	0	0	0
P-4,6	0.1111	0	0.1111	0.1111	0	0.1111	0	0
P-4,7	0	0.1111	0	0.1111	0	0	0.1111	0.1111
P-4,8	0.1111	0	0.1111	0	0	0	0.1111	0.1111

APPENDICES

Case 2: Use *SMCLs (it is manipulated by first two stages of MAIN algorithm) with the third stage of MAIN to obtain the Similarity Coefficient matrix and to determine the modified *multi-DMCLs.

(a) Part handling factors is equal to 1

Table Appendix III-15 Eight *SMCLs in a planning period - Yaman's and Tang's cases (λ=1)

	P-1									P-2								
1	2	8	3	4	6	5	1	7	9	2	8	3	4	6	5	1	7	9
2	2	4	1	8	6	7	3	5	9	2	4	1	8	6	7	3	5	9
3	1	7	9	4	6	5	2	8	3	1	7	9	4	6	5	2	8	3
4	1	4	2	7	6	8	9	5	3	1	4	2	7	6	8	9	5	3
5	3	5	9	8	6	7	2	4	1	3	5	9	8	6	7	2	4	1
6	3	8	2	5	6	4	9	7	1	3	8	2	5	6	4	9	7	1
7	9	5	3	7	6	8	1	4	2	9	5	3	7	6	8	1	4	2
8	9	7	1	5	6	4	3	8	2	9	7	1	5	6	4	3	8	2
	P-3									P-4								
1	1	2	4	8	7	9	3	5	6	1	9	3	2	8	7	4	6	5
2	1	8	3	2	7	5	4	9	6	1	2	4	9	8	6	3	7	5
3	3	5	6	8	7	9	1	2	4	4	6	5	2	8	7	1	9	3
4	3	8	1	5	7	2	6	9	4	4	2	1	6	8	9	5	7	3
5	4	9	6	2	7	5	1	8	3	3	7	5	9	8	6	1	2	4
6	4	2	1	9	7	8	6	5	3	3	9	1	7	8	2	5	6	4
7	6	9	4	5	7	2	3	8	1	5	7	3	6	8	9	4	2	1
8	6	5	3	9	7	8	4	2	1	5	6	4	7	8	2	3	9	1
	P-5																	
1	1	9	3	2	8	5	4	6	7									
2	1	2	4	9	8	6	3	5	7									
3	4	6	7	2	8	5	1	9	3									
4	4	2	1	6	8	9	7	5	3									
5	3	5	7	9	8	6	1	2	4									
6	3	9	1	5	8	2	7	6	4									
7	7	5	3	6	8	9	4	2	1									
8	7	6	4	5	8	2	3	9	1									

Table Appendix III-16 Similarity Coefficient of eight *SMCLs - Yaman's and Tang's cases (λ=1)

	P-2,1	P-2,2	P-2,3	P-2,4	P-2,5	P-2,6	P-2,7	P-2,8
P-1,1	1.0000	0.3333	0.3333	0.1111	0.1111	0.3333	0.3333	0.1111
P-1,2	0.3333	1.0000	0.1111	0.3333	0.3333	0.1111	0.1111	0.3333
P-1,3	0.3333	0.1111	1.0000	0.3333	0.3333	0.1111	0.1111	0.3333
P-1,4	0.1111	0.3333	0.3333	1.0000	0.1111	0.3333	0.3333	0.1111
P-1,5	0.1111	0.3333	0.3333	0.1111	1.0000	0.3333	0.3333	0.1111
P-1,6	0.3333	0.1111	0.1111	0.3333	0.3333	1.0000	0.1111	0.3333
P-1,7	0.3333	0.1111	0.1111	0.3333	0.3333	0.1111	1.0000	0.3333
P-1,8	0.1111	0.3333	0.3333	0.1111	0.1111	0.3333	0.3333	1.0000

	P-3,1	P-3,2	P-3,3	P-3,4	P-3,5	P-3,6	P-3,7	P-3,8
P-2,1	0	0.3333	0.1111	0.1111	0.2222	0	0	0.1111
P-2,2	0.3333	0	0.1111	0.1111	0	0.2222	0.1111	0
P-2,3	0.1111	0.2222	0	0	0.3333	0.1111	0.1111	0
P-2,4	0.2222	0.1111	0	0	0.1111	0.3333	0	0.1111
P-2,5	0.1111	0	0.3333	0.1111	0	0	0.1111	0.2222
P-2,6	0	0.1111	0.1111	0.3333	0	0	0.2222	0.1111
P-2,7	0	0.1111	0.2222	0	0.1111	0.1111	0	0.3333
P-2,8	0.1111	0	0	0.2222	0.1111	0.1111	0.3333	0

	P-4,1	P-4,2	P-4,3	P-4,4	P-4,5	P-4,6	P-4,7	P-4,8
P-3,1	0.1111	0.4444	0	0.2222	0	0	0.1111	0.2222
P-3,2	0.4444	0.1111	0.2222	0	0	0	0.2222	0.1111
P-3,3	0	0	0.1111	0.1111	0.4444	0.2222	0.2222	0
P-3,4	0	0	0.1111	0.1111	0.2222	0.4444	0	0.2222
P-3,5	0.2222	0	0.4444	0.2222	0.1111	0.1111	0	0
P-3,6	0	0.2222	0.2222	0.4444	0.1111	0.1111	0	0
P-3,7	0.1111	0.2222	0	0	0	0.2222	0.1111	0.4444
P-3,8	0.2222	0.1111	0	0	0.2222	0	0.4444	0.1111

	P-5,1	P-5,2	P-5,3	P-5,4	P-5,5	P-5,6	P-5,7	P-5,8
P-4,1	0.7778	0.2222	0.2222	0.1111	0.1111	0.3333	0.3333	0.1111
P-4,2	0.2222	0.7778	0.1111	0.2222	0.3333	0.1111	0.1111	0.3333
P-4,3	0.2222	0.1111	0.7778	0.3333	0.2222	0.1111	0.1111	0.3333
P-4,4	0.1111	0.2222	0.3333	0.7778	0.1111	0.2222	0.3333	0.1111
P-4,5	0.1111	0.3333	0.2222	0.1111	0.7778	0.3333	0.2222	0.1111
P-4,6	0.3333	0.1111	0.1111	0.2222	0.3333	0.7778	0.1111	0.2222
P-4,7	0.3333	0.1111	0.1111	0.3333	0.2222	0.1111	0.7778	0.2222
P-4,8	0.1111	0.3333	0.3333	0.1111	0.1111	0.2222	0.2222	0.7778

Table Appendix III-17 Eight *SMCLs in a planning period - Conway's case (λ=1)

	P-1									P-2								
1	6	4	7	5	2	3	1	9	8	2	1	7	9	3	8	6	5	4
2	6	5	1	4	2	9	7	3	8	2	9	6	1	3	5	7	8	4
3	1	9	8	5	2	3	6	4	7	6	5	4	9	3	8	2	1	7
4	1	5	6	9	2	4	8	3	7	6	9	2	5	3	1	4	8	7
5	7	3	8	4	2	9	6	5	1	7	8	4	1	3	5	2	9	6
6	7	4	6	3	2	5	8	9	1	7	1	2	8	3	9	4	5	6
7	8	3	7	9	2	4	1	5	6	4	8	7	5	3	1	6	9	2
8	8	9	1	3	2	5	7	4	6	4	5	6	8	3	9	7	1	2
	P-3									P-4								
1	8	2	3	1	4	9	7	5	6	9	2	1	7	5	3	8	6	4
2	8	1	7	2	4	5	3	9	6	9	7	8	2	5	6	1	3	4
3	7	5	6	1	4	9	8	2	3	8	6	4	7	5	3	9	2	1
4	7	1	8	5	4	2	6	9	3	8	7	9	6	5	2	4	3	1
5	3	9	6	2	4	5	8	1	7	1	3	4	2	5	6	9	7	8
6	3	2	8	9	4	1	6	5	7	1	2	9	3	5	7	4	6	8
7	6	9	3	5	4	2	7	1	8	4	3	1	6	5	2	8	7	9
8	6	5	7	9	4	1	3	2	8	4	6	8	3	5	7	1	2	9
	P-5																	
1	5	3	8	4	6	2	1	9	7									
2	5	4	1	3	6	9	8	2	7									
3	1	9	7	4	6	2	5	3	8									
4	1	4	5	9	6	3	7	2	8									
5	8	2	7	3	6	9	5	4	1									
6	8	3	5	2	6	4	7	9	1									
7	7	2	8	9	6	3	1	4	5									
8	7	9	1	2	6	4	8	3	5									

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Table Appendix III-18 Similarity Coefficient of eight *SMCLs - Conway's case (λ=1)

	P-2,1	P-2,2	P-2,3	P-2,4	P-2,5	P-2,6	P-2,7	P-2,8
P-1,1	0.1111	0	0.1111	0.2222	0.1111	0	0.3333	0
P-1,2	0	0.1111	0.2222	0.1111	0	0.1111	0	0.3333
P-1,3	0.1111	0.1111	0.1111	0.3333	0	0	0.2222	0
P-1,4	0.1111	0.1111	0.3333	0.1111	0	0	0	0.2222
P-1,5	0.2222	0	0	0	0.1111	0.3333	0.1111	0.1111
P-1,6	0	0.2222	0	0	0.3333	0.1111	0.1111	0.1111
P-1,7	0.3333	0	0.1111	0	0.1111	0.2222	0.1111	0
P-1,8	0	0.3333	0	0.1111	0.2222	0.1111	0	0.1111

	P-3,1	P-3,2	P-3,3	P-3,4	P-3,5	P-3,6	P-3,7	P-3,8
P-2,1	0.1111	0.2222	0	0.2222	0	0.3333	0	0.2222
P-2,2	0.2222	0.1111	0.2222	0	0.3333	0	0.2222	0
P-2,3	0	0	0.1111	0	0.2222	0.2222	0.2222	0.3333
P-2,4	0	0	0	0.1111	0.2222	0.2222	0.3333	0.2222
P-2,5	0.2222	0.3333	0.2222	0.2222	0.1111	0	0	0
P-2,6	0.3333	0.2222	0.2222	0.2222	0	0.1111	0	0
P-2,7	0	0.2222	0	0.3333	0	0.2222	0.1111	0.2222
P-2,8	0.2222	0	0.3333	0	0.2222	0	0.2222	0.1111

	P-4,1	P-4,2	P-4,3	P-4,4	P-4,5	P-4,6	P-4,7	P-4,8
P-3,1	0.1111	0	0.1111	0.1111	0	0.1111	0	0
P-3,2	0	0.1111	0.1111	0.1111	0.1111	0	0	0
P-3,3	0.1111	0	0.1111	0	0	0	0.1111	0.1111
P-3,4	0	0.1111	0	0.1111	0	0	0.1111	0.1111
P-3,5	0.1111	0.1111	0	0	0.1111	0	0.1111	0
P-3,6	0.1111	0.1111	0	0	0	0.1111	0	0.1111
P-3,7	0	0	0	0.1111	0.1111	0.1111	0.1111	0
P-3,8	0	0	0.1111	0	0.1111	0.1111	0	0.1111

	P-5,1	P-5,2	P-5,3	P-5,4	P-5,5	P-5,6	P-5,7	P-5,8
P-4,1	0	0.2222	0	0.1111	0.1111	0	0.2222	0.2222
P-4,2	0.2222	0	0.1111	0	0	0.1111	0.2222	0.2222
P-4,3	0	0.1111	0	0.2222	0.2222	0.2222	0.1111	0
P-4,4	0.1111	0	0.2222	0	0.2222	0.2222	0	0.1111
P-4,5	0.1111	0	0.2222	0.2222	0	0.2222	0	0.1111
P-4,6	0	0.1111	0.2222	0.2222	0.2222	0	0.1111	0
P-4,7	0.2222	0.2222	0.1111	0	0	0.1111	0	0.2222
P-4,8	0.2222	0.2222	0	0.1111	0.1111	0	0.2222	0

Table Appendix III-19 Eight *SMCLs in a planning period - Self-developed case five (λ=1)

	P-1	P-2
1	1 2 3 4 6 5 7 8 9	7 1 4 8 2 6 9 3 5
2	1 4 7 2 6 8 3 5 9	7 8 9 1 2 3 4 6 5
3	7 8 9 4 6 5 1 2 3	9 3 5 8 2 6 7 1 4
4	7 4 1 8 6 2 9 5 3	9 8 7 3 2 1 5 6 4
5	3 5 9 2 6 8 1 4 7	4 6 5 1 2 3 7 8 9
6	3 2 1 5 6 4 9 8 7	4 1 7 6 2 8 5 3 9
7	9 5 3 8 6 2 7 4 1	5 6 4 3 2 1 9 8 7
8	9 8 7 5 6 4 3 2 1	5 3 9 6 2 8 4 1 7
	P-3	**P-4**
1	1 4 8 2 6 7 3 5 9	3 5 9 1 4 7 2 6 8
2	1 2 3 4 6 5 8 7 9	3 1 2 5 4 6 9 7 8
3	3 5 9 2 6 7 1 4 8	2 6 8 1 4 7 3 5 9
4	3 2 1 5 6 4 9 7 8	2 1 3 6 4 5 8 7 9
5	8 7 9 4 6 5 1 2 3	9 7 8 5 4 6 3 1 2
6	8 4 1 7 6 2 9 5 3	9 5 3 7 4 1 8 6 2
7	9 7 8 5 6 4 3 2 1	8 7 9 6 4 5 2 1 3
8	9 5 3 7 6 2 8 4 1	8 6 2 7 4 1 9 5 3
	P-5	
1	8 3 7 9 5 2 6 4 1	
2	8 9 6 3 5 4 7 2 1	
3	6 4 1 9 5 2 8 3 7	
4	6 9 8 4 5 3 1 2 7	
5	7 2 1 3 5 4 8 9 6	
6	7 3 8 2 5 9 1 4 6	
7	1 2 7 4 5 3 6 9 8	
8	1 4 6 2 5 9 7 3 8	

Table Appendix III-20 Similarity Coefficient of eight *SMCLs Self-developed case five (λ=1)

	P-2,1	P-2,2	P-2,3	P-2,4	P-2,5	P-2,6	P-2,7	P-2,8
P-1,1	0	0	0.1111	0	0.3333	0.1111	0.1111	0
P-1,2	0	0	0	0.1111	0.1111	0.3333	0	0.1111
P-1,3	0.1111	0.3333	0	0.1111	0	0	0	0.1111
P-1,4	0.3333	0.1111	0.1111	0	0	0	0.1111	0
P-1,5	0	0.1111	0	0	0	0.1111	0.1111	0.3333
P-1,6	0.1111	0	0	0	0.1111	0	0.3333	0.1111
P-1,7	0.1111	0	0.3333	0.1111	0.1111	0	0	0
P-1,8	0	0.1111	0.1111	0.3333	0	0.1111	0	0

	P-3,1	P-3,2	P-3,3	P-3,4	P-3,5	P-3,6	P-3,7	P-3,8
P-2,1	0	0	0	0.1111	0	0.1111	0	0
P-2,2	0	0	0.1111	0	0.1111	0	0	0
P-2,3	0	0	0	0	0	0	0.1111	0.1111
P-2,4	0	0	0	0	0	0	0.1111	0.1111
P-2,5	0.1111	0.1111	0	0	0	0	0	0
P-2,6	0.1111	0.1111	0	0	0	0	0	0
P-2,7	0	0	0	0.1111	0	0.1111	0	0
P-2,8	0	0	0.1111	0	0.1111	0	0	0

	P-4,1	P-4,2	P-4,3	P-4,4	P-4,5	P-4,6	P-4,7	P-4,8
P-3,1	0.1111	0	0.5556	0.1111	0.2222	0	0	0.1111
P-3,2	0	0.1111	0.1111	0.5556	0	0.2222	0.1111	0
P-3,3	0.5556	0.2222	0.1111	0	0	0.1111	0.1111	0
P-3,4	0.2222	0.5556	0	0.1111	0.1111	0	0	0.1111
P-3,5	0.1111	0	0	0.1111	0.1111	0	0.5556	0.2222
P-3,6	0	0.1111	0.1111	0	0	0.1111	0.2222	0.5556
P-3,7	0	0.1111	0.2222	0	0.5556	0.1111	0.1111	0
P-3,8	0.1111	0	0	0.2222	0.1111	0.5556	0	0.1111

	P-5,1	P-5,2	P-5,3	P-5,4	P-5,5	P-5,6	P-5,7	P-5,8
P-4,1	0	0	0	0	0	0	0.1111	0.1111
P-4,2	0	0	0	0	0	0	0.1111	0.1111
P-4,3	0	0	0	0.1111	0	0.1111	0	0
P-4,4	0	0	0.1111	0	0.1111	0	0	0
P-4,5	0	0	0	0.1111	0	0.1111	0	0
P-4,6	0	0	0.1111	0	0.1111	0	0	0
P-4,7	0.1111	0.1111	0	0	0	0	0	0
P-4,8	0.1111	0.1111	0	0	0	0	0	0

Table Appendix III-21 Eight *SMCLs in a planning period - Self-developed case six (λ=1)

	P-1									P-2								
1	8	3	1	9	5	2	7	6	4	3	1	2	5	6	4	9	8	7
2	8	9	7	3	5	6	1	2	4	3	5	9	1	6	8	2	4	7
3	7	6	4	9	5	2	8	3	1	9	8	7	5	6	4	3	1	2
4	7	9	8	6	5	3	4	2	1	9	5	3	8	6	1	7	4	2
5	1	2	4	3	5	6	8	9	7	2	4	7	1	6	8	3	5	9
6	1	3	8	2	5	9	4	6	7	2	1	3	4	6	5	7	8	9
7	4	2	1	6	5	3	7	9	8	7	4	2	8	6	1	9	5	3
8	4	6	7	2	5	9	1	3	8	7	8	9	4	6	5	2	1	3
	P-3									P-4								
1	4	3	8	6	5	9	1	2	7	7	3	8	6	5	9	4	2	1
2	4	6	1	3	5	2	8	9	7	7	6	4	3	5	2	8	9	1
3	1	2	7	6	5	9	4	3	8	4	2	1	6	5	9	7	3	8
4	1	6	4	2	5	3	7	9	8	4	6	7	2	5	3	1	9	8
5	8	9	7	3	5	2	4	6	1	8	9	1	3	5	2	7	6	4
6	8	3	4	9	5	6	7	2	1	8	3	7	9	5	6	1	2	4
7	7	9	8	2	5	3	1	6	4	1	9	8	2	5	3	4	6	7
8	7	2	1	9	5	6	8	3	4	1	2	4	9	5	6	8	3	7
	P-5																	
1	1	4	7	2	6	8	3	5	9									
2	1	2	3	4	6	5	7	8	9									
3	3	5	9	2	6	8	1	4	7									
4	3	2	1	5	6	4	9	8	7									
5	7	8	9	4	6	5	1	2	3									
6	7	4	1	8	6	2	9	5	3									
7	9	8	7	5	6	4	3	2	1									
8	9	5	3	8	6	2	7	4	1									

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Table Appendix III-22 Similarity Coefficient of eight *SMCLs - Self-developed case six (λ=1)

	P-2,1	P-2,2	P-2,3	P-2,4	P-2,5	P-2,6	P-2,7	P-2,8
P-1,1	0	0	0	0.1111	0	0.1111	0	0
P-1,2	0	0	0.1111	0	0.1111	0	0	0
P-1,3	0	0	0	0	0	0	0.1111	0.1111
P-1,4	0	0	0	0	0	0	0.1111	0.1111
P-1,5	0.1111	0.1111	0	0	0	0	0	0
P-1,6	0.1111	0.1111	0	0	0	0	0	0
P-1,7	0	0	0	0.1111	0	0.1111	0	0
P-1,8	0	0	0.1111	0	0.1111	0	0	0

	P-3,1	P-3,2	P-3,3	P-3,4	P-3,5	P-3,6	P-3,7	P-3,8
P-2,1	0.1111	0.1111	0	0	0	0	0	0
P-2,2	0.1111	0.1111	0	0	0	0	0	0
P-2,3	0	0	0.1111	0	0.1111	0	0	0
P-2,4	0	0	0	0.1111	0	0.1111	0	0
P-2,5	0	0	0.1111	0	0.1111	0	0	0
P-2,6	0	0	0	0.1111	0	0.1111	0	0
P-2,7	0	0	0	0	0	0	0.1111	0.1111
P-2,8	0	0	0	0	0	0	0.1111	0.1111

	P-4,1	P-4,2	P-4,3	P-4,4	P-4,5	P-4,6	P-4,7	P-4,8
P-3,1	0.6667	0.1111	0.4444	0.3333	0.1111	0.4444	0.3333	0.2222
P-3,2	0.1111	0.6667	0.3333	0.4444	0.4444	0.1111	0.2222	0.3333
P-3,3	0.4444	0.1111	0.6667	0.3333	0.1111	0.2222	0.3333	0.4444
P-3,4	0.1111	0.4444	0.3333	0.6667	0.2222	0.1111	0.4444	0.3333
P-3,5	0.3333	0.4444	0.1111	0.2222	0.6667	0.3333	0.4444	0.1111
P-3,6	0.4444	0.3333	0.2222	0.1111	0.3333	0.6667	0.1111	0.4444
P-3,7	0.3333	0.2222	0.1111	0.4444	0.4444	0.3333	0.6667	0.1111
P-3,8	0.2222	0.3333	0.4444	0.1111	0.3333	0.4444	0.1111	0.6667

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	P-5,1	P-5,2	P-5,3	P-5,4	P-5,5	P-5,6	P-5,7	P-5,8
P-4,1	0	0	0	0	0.2222	0.1111	0.2222	0.1111
P-4,2	0	0	0	0	0.1111	0.2222	0.1111	0.2222
P-4,3	0	0.2222	0	0.2222	0	0.1111	0	0.1111
P-4,4	0.2222	0	0.2222	0	0.1111	0	0.1111	0
P-4,5	0	0.1111	0	0.1111	0	0.2222	0	0.2222
P-4,6	0.1111	0	0.1111	0	0.2222	0	0.2222	0
P-4,7	0.2222	0.1111	0.2222	0.1111	0	0	0	0
P-4,8	0.1111	0.2222	0.1111	0.2222	0	0	0	0

(b) Part handling factors vary

Table Appendix III-23 Eight *SMCLs in a planning period - Yaman's and Tang's cases (λ vary)

	P-1									P-2								
1	4	2	8	1	5	3	7	6	9	7	5	3	8	6	9	2	4	1
2	4	1	7	2	5	6	8	3	9	7	8	2	5	6	4	3	9	1
3	7	6	9	1	5	3	4	2	8	2	4	1	8	6	9	7	5	3
4	7	1	4	6	5	2	9	3	8	2	8	7	4	6	5	1	9	3
5	8	3	9	2	5	6	4	1	7	3	9	1	5	6	4	7	8	2
6	8	2	4	3	5	1	9	6	7	3	5	7	9	6	8	1	4	2
7	9	3	8	6	5	2	7	1	4	1	9	3	4	6	5	2	8	7
8	9	6	7	3	5	1	8	2	4	1	4	2	9	6	8	3	5	7
	P-3									P-4								
1	1	3	9	7	5	6	2	8	4	1	5	7	4	6	8	2	3	9
2	1	7	2	3	5	8	9	6	4	1	4	2	5	6	3	7	8	9
3	2	8	4	7	5	6	1	3	9	2	3	9	4	6	8	1	5	7
4	2	7	1	8	5	3	4	6	9	2	4	1	3	6	5	9	8	7
5	9	6	4	3	5	8	1	7	2	7	8	9	5	6	3	1	4	2
6	9	3	1	6	5	7	4	8	2	7	5	1	8	6	4	9	3	2
7	4	6	9	8	5	3	2	7	1	9	8	7	3	6	5	2	4	1
8	4	8	2	6	5	7	9	3	1	9	3	2	8	6	4	7	5	1
	P-5																	
1	9	3	1	6	5	7	4	8	2									
2	9	6	4	3	5	8	1	7	2									
3	4	8	2	6	5	7	9	3	1									
4	4	6	9	8	5	3	2	7	1									
5	1	7	2	3	5	8	9	6	4									
6	1	3	9	7	5	6	2	8	4									
7	2	7	1	8	5	3	4	6	9									
8	2	8	4	7	5	6	1	3	9									

Table Appendix III-24 Similarity Coefficient of eight *SMCLs - Yaman's and Tang's cases (λ vary)

	P-2,1	P-2,2	P-2,3	P-2,4	P-2,5	P-2,6	P-2,7	P-2,8
P-1,1	0	0	0.1111	0	0.1111	0	0	0
P-1,2	0	0	0	0.1111	0	0.1111	0	0
P-1,3	0.1111	0.1111	0	0	0	0	0	0
P-1,4	0.1111	0.1111	0	0	0	0	0	0
P-1,5	0	0	0	0	0	0	0.1111	0.1111
P-1,6	0	0	0	0	0	0	0.1111	0.1111
P-1,7	0	0	0.1111	0	0.1111	0	0	0
P-1,8	0	0	0	0.1111	0	0.1111	0	0

	P-3,1	P-3,2	P-3,3	P-3,4	P-3,5	P-3,6	P-3,7	P-3,8
P-2,1	0.1111	0	0	0.1111	0	0	0.3333	0.1111
P-2,2	0	0.1111	0.1111	0	0	0	0.1111	0.3333
P-2,3	0	0	0.1111	0.3333	0	0.1111	0.1111	0
P-2,4	0	0	0.3333	0.1111	0.1111	0	0	0.1111
P-2,5	0.1111	0	0	0.1111	0.1111	0.3333	0	0
P-2,6	0	0.1111	0.1111	0	0.3333	0.1111	0	0
P-2,7	0.3333	0.1111	0	0	0	0.1111	0.1111	0
P-2,8	0.1111	0.3333	0	0	0.1111	0	0	0.1111

	P-4,1	P-4,2	P-4,3	P-4,4	P-4,5	P-4,6	P-4,7	P-4,8
P-3,1	0.2222	0.2222	0.2222	0.1111	0.1111	0	0.1111	0.1111
P-3,2	0.2222	0.2222	0.1111	0.2222	0	0.1111	0.1111	0.1111
P-3,3	0.2222	0.1111	0.2222	0.1111	0.2222	0.1111	0.1111	0
P-3,4	0.1111	0.2222	0.1111	0.2222	0.1111	0.2222	0	0.1111
P-3,5	0.1111	0	0.2222	0.1111	0.2222	0.1111	0.2222	0.1111
P-3,6	0	0.1111	0.1111	0.2222	0.1111	0.2222	0.1111	0.2222
P-3,7	0.1111	0.1111	0.1111	0	0.2222	0.1111	0.2222	0.2222
P-3,8	0.1111	0.1111	0	0.1111	0.1111	0.2222	0.2222	0.2222

	P-5,1	P-5,2	P-5,3	P-5,4	P-5,5	P-5,6	P-5,7	P-5,8
P-4,1	0	0.1111	0.1111	0.1111	0.2222	0.2222	0.1111	0.2222
P-4,2	0.1111	0	0.1111	0.1111	0.2222	0.2222	0.2222	0.1111
P-4,3	0.1111	0.2222	0	0.1111	0.1111	0.2222	0.1111	0.2222
P-4,4	0.2222	0.1111	0.1111	0	0.2222	0.1111	0.2222	0.1111
P-4,5	0.1111	0.2222	0.1111	0.2222	0	0.1111	0.1111	0.2222
P-4,6	0.2222	0.1111	0.2222	0.1111	0.1111	0	0.2222	0.1111
P-4,7	0.1111	0.2222	0.2222	0.2222	0.1111	0.1111	0	0.1111
P-4,8	0.2222	0.1111	0.2222	0.2222	0.1111	0.1111	0.1111	0

Table Appendix III-25 Eight *SMCLs in a planning - Self-developed case five (λ vary)

	P-1	P-2
1	1 2 7 4 5 3 6 9 8	9 5 3 7 4 1 8 6 2
2	1 4 6 2 5 9 7 3 8	9 7 8 5 4 6 3 1 2
3	6 9 8 4 5 3 1 2 7	8 6 2 7 4 1 9 5 3
4	6 4 1 9 5 2 8 3 7	8 7 9 6 4 5 2 1 3
5	7 3 8 2 5 9 1 4 6	3 1 2 5 4 6 9 7 8
6	7 2 1 3 5 4 8 9 6	3 5 9 1 4 7 2 6 8
7	8 3 7 9 5 2 6 4 1	2 1 3 6 4 5 8 7 9
8	8 9 6 3 5 4 7 2 1	2 6 8 1 4 7 3 5 9
	P-3	**P-4**
1	3 2 7 5 4 1 9 6 8	9 5 3 7 4 1 8 6 2
2	3 5 9 2 4 6 7 1 8	9 7 8 5 4 6 3 1 2
3	9 6 8 5 4 1 3 2 7	8 6 2 7 4 1 9 5 3
4	9 5 3 6 4 2 8 1 7	8 7 9 6 4 5 2 1 3
5	7 1 8 2 4 6 3 5 9	3 1 2 5 4 6 9 7 8
6	7 2 3 1 4 5 8 6 9	3 5 9 1 4 7 2 6 8
7	8 1 7 6 4 2 9 5 3	2 1 3 6 4 5 8 7 9
8	8 6 9 1 4 5 7 2 3	2 6 8 1 4 7 3 5 9
	P-5	
1	2 7 1 3 5 4 8 9 6	
2	2 3 8 7 5 9 1 4 6	
3	8 9 6 3 5 4 2 7 1	
4	8 3 2 9 5 7 6 4 1	
5	1 4 6 7 5 9 2 3 8	
6	1 7 2 4 5 3 6 9 8	
7	6 4 1 9 5 7 8 3 2	
8	6 9 8 4 5 3 1 7 2	

Table Appendix III-26 Similarity Coefficient of eight *SMCLs - Self-developed case five (λ vary)

	P-2,1	P-2,2	P-2,3	P-2,4	P-2,5	P-2,6	P-2,7	P-2,8
P-1,1	0	0	0	0	0.1111	0.1111	0	0
P-1,2	0	0	0	0	0.1111	0.1111	0	0
P-1,3	0	0.1111	0	0	0	0	0	0.1111
P-1,4	0.1111	0	0	0	0	0	0.1111	0
P-1,5	0	0.1111	0	0	0	0	0	0.1111
P-1,6	0.1111	0	0	0	0	0	0.1111	0
P-1,7	0	0	0.1111	0.1111	0	0	0	0
P-1,8	0	0	0.1111	0.1111	0	0	0	0

	P-3,1	P-3,2	P-3,3	P-3,4	P-3,5	P-3,6	P-3,7	P-3,8
P-2,1	0.3333	0.2222	0.3333	0.5556	0.1111	0.4444	0.1111	0.1111
P-2,2	0.2222	0.3333	0.5556	0.3333	0.4444	0.1111	0.1111	0.1111
P-2,3	0.3333	0.1111	0.3333	0.1111	0.2222	0.1111	0.5556	0.4444
P-2,4	0.1111	0.3333	0.1111	0.3333	0.1111	0.2222	0.4444	0.5556
P-2,5	0.5556	0.4444	0.2222	0.1111	0.3333	0.1111	0.3333	0.1111
P-2,6	0.4444	0.5556	0.1111	0.2222	0.1111	0.3333	0.1111	0.3333
P-2,7	0.1111	0.1111	0.1111	0.4444	0.3333	0.5556	0.3333	0.2222
P-2,8	0.1111	0.1111	0.4444	0.1111	0.5556	0.3333	0.2222	0.3333

	P-4,1	P-4,2	P-4,3	P-4,4	P-4,5	P-4,6	P-4,7	P-4,8
P-3,1	0.3333	0.2222	0.3333	0.1111	0.5556	0.4444	0.1111	0.1111
P-3,2	0.2222	0.3333	0.1111	0.3333	0.4444	0.5556	0.1111	0.1111
P-3,3	0.3333	0.5556	0.3333	0.1111	0.2222	0.1111	0.1111	0.4444
P-3,4	0.5556	0.3333	0.1111	0.3333	0.1111	0.2222	0.4444	0.1111
P-3,5	0.1111	0.4444	0.2222	0.1111	0.3333	0.1111	0.3333	0.5556
P-3,6	0.4444	0.1111	0.1111	0.2222	0.1111	0.3333	0.5556	0.3333
P-3,7	0.1111	0.1111	0.5556	0.4444	0.3333	0.1111	0.3333	0.2222
P-3,8	0.1111	0.1111	0.4444	0.5556	0.1111	0.3333	0.2222	0.3333

	P-5,1	P-5,2	P-5,3	P-5,4	P-5,5	P-5,6	P-5,7	P-5,8
P-4,1	0.1111	0.1111	0	0	0.1111	0	0.2222	0.1111
P-4,2	0.1111	0.1111	0	0	0	0.1111	0.1111	0.2222
P-4,3	0	0.1111	0.1111	0.2222	0.1111	0.1111	0	0
P-4,4	0.1111	0	0.2222	0.1111	0.1111	0.1111	0	0
P-4,5	0	0	0.1111	0.1111	0.1111	0.2222	0	0.1111
P-4,6	0	0	0.1111	0.1111	0.2222	0.1111	0.1111	0
P-4,7	0.2222	0.1111	0.1111	0	0	0	0.1111	0.1111
P-4,8	0.1111	0.2222	0	0.1111	0	0	0.1111	0.1111

Table Appendix III-27 Eight *SMCLs in a planning period - Self-developed case six (λ is varied)

	P-1									P-2								
1	3	1	2	5	4	6	9	7	8	2	3	8	1	5	9	6	4	7
2	3	5	9	1	4	7	2	6	8	2	1	6	3	5	4	8	9	7
3	9	7	8	5	4	6	3	1	2	6	4	7	1	5	9	2	3	8
4	9	5	3	7	4	1	8	6	2	6	1	2	4	5	3	7	9	8
5	2	6	8	1	4	7	3	5	9	8	9	7	3	5	4	2	1	6
6	2	1	3	6	4	5	8	7	9	8	3	2	9	5	1	7	4	6
7	8	6	2	7	4	1	9	5	3	7	9	8	4	5	3	6	1	2
8	8	7	9	6	4	5	2	1	3	7	4	6	9	5	1	8	3	2
	P-3									P-4								
1	8	3	7	4	5	9	6	2	1	3	2	8	5	4	1	9	6	7
2	8	4	6	3	5	2	7	9	1	3	5	9	2	4	6	8	1	7
3	6	2	1	4	5	9	8	3	7	9	6	7	5	4	1	3	2	8
4	6	4	8	2	5	3	1	9	7	9	5	3	6	4	2	7	1	8
5	7	9	1	3	5	2	8	4	6	8	1	7	2	4	6	3	5	9
6	7	3	8	9	5	4	1	2	6	8	2	3	1	4	5	7	6	9
7	1	9	7	2	5	3	6	4	8	7	1	8	6	4	2	9	5	3
8	1	2	6	9	5	4	7	3	8	7	6	9	1	4	5	8	2	3
	P-5																	
1	1	7	8	4	5	3	6	2	9									
2	1	4	6	7	5	2	8	3	9									
3	6	2	9	4	5	3	1	7	8									
4	6	4	1	2	5	7	9	3	8									
5	8	3	9	7	5	2	1	4	6									
6	8	7	1	3	5	4	9	2	6									
7	9	3	8	2	5	7	6	4	1									
8	9	2	6	3	5	4	8	7	1									

Table Appendix III-28 Similarity Coefficient of eight *SMCLs Self-developed case six (λ is varied)

	P-2,1	P-2,2	P-2,3	P-2,4	P-2,5	P-2,6	P-2,7	P-2,8
P-1,1	0	0.1111	0.1111	0.3333	0	0.1111	0	0
P-1,2	0.1111	0	0.3333	0.1111	0.1111	0	0	0
P-1,3	0.1111	0	0	0	0.1111	0	0.3333	0.1111
P-1,4	0	0.1111	0	0	0	0.1111	0.1111	0.3333
P-1,5	0.3333	0.1111	0.1111	0	0	0	0.1111	0
P-1,6	0.1111	0.3333	0	0.1111	0	0	0	0.1111
P-1,7	0	0	0	0.1111	0.1111	0.3333	0	0.1111
P-1,8	0	0	0.1111	0	0.3333	0.1111	0.1111	0

	P-3,1	P-3,2	P-3,3	P-3,4	P-3,5	P-3,6	P-3,7	P-3,8
P-2,1	0.4444	0.1111	0.3333	0.3333	0.2222	0.3333	0.3333	0.1111
P-2,2	0.1111	0.4444	0.3333	0.3333	0.3333	0.2222	0.1111	0.3333
P-2,3	0.3333	0.2222	0.4444	0.3333	0.1111	0.1111	0.3333	0.3333
P-2,4	0.2222	0.3333	0.3333	0.4444	0.1111	0.1111	0.3333	0.3333
P-2,5	0.3333	0.3333	0.1111	0.1111	0.4444	0.3333	0.3333	0.2222
P-2,6	0.3333	0.3333	0.1111	0.1111	0.3333	0.4444	0.2222	0.3333
P-2,7	0.3333	0.1111	0.2222	0.3333	0.3333	0.3333	0.4444	0.1111
P-2,8	0.1111	0.3333	0.3333	0.2222	0.3333	0.3333	0.1111	0.4444

	P-4,1	P-4,2	P-4,3	P-4,4	P-4,5	P-4,6	P-4,7	P-4,8
P-3,1	0	0	0.2222	0	0.2222	0.1111	0	0.1111
P-3,2	0	0	0	0.2222	0.1111	0.2222	0.1111	0
P-3,3	0.2222	0.2222	0	0	0	0.1111	0	0.1111
P-3,4	0.2222	0.2222	0	0	0.1111	0	0.1111	0
P-3,5	0	0.1111	0	0.1111	0	0	0.2222	0.2222
P-3,6	0.1111	0	0.1111	0	0	0	0.2222	0.2222
P-3,7	0	0.1111	0.2222	0.1111	0.2222	0	0	0
P-3,8	0.1111	0	0.1111	0.2222	0	0.2222	0	0

	P-5,1	P-5,2	P-5,3	P-5,4	P-5,5	P-5,6	P-5,7	P-5,8
P-4,1	0.1111	0	0.1111	0.1111	0	0.1111	0.1111	0.1111
P-4,2	0	0.1111	0.1111	0.1111	0.1111	0	0.1111	0.1111
P-4,3	0.1111	0	0.1111	0.1111	0	0.1111	0.1111	0.1111
P-4,4	0	0.1111	0.1111	0.1111	0.1111	0	0.1111	0.1111
P-4,5	0.1111	0.1111	0	0.1111	0.1111	0.1111	0.1111	0
P-4,6	0.1111	0.1111	0.1111	0	0.1111	0.1111	0	0.1111
P-4,7	0.1111	0.1111	0	0.1111	0.1111	0.1111	0.1111	0
P-4,8	0.1111	0.1111	0.1111	0	0.1111	0.1111	0	0.1111

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Case 3: Use SMCLs (it is manipulated by existing approaches) with the third stage of MAIN to workout the Similarity Coefficient matrix and determine the modified multi-DMCLs.

Table Appendix III-29 Eight existing SMCLs in a planning period - spiral type one of Yaman's approach (λ=1)

	P-1									P-2								
1	9	2	8	4	6	1	7	5	3	3	5	7	8	2	6	1	4	9
2	9	4	7	2	6	5	8	1	3	3	8	1	5	2	4	7	6	9
3	7	5	3	4	6	1	9	2	8	1	4	9	8	2	6	3	5	7
4	7	4	9	5	6	2	3	1	8	1	8	3	4	2	5	9	6	7
5	8	1	3	2	6	5	9	4	7	7	6	9	5	2	4	3	8	1
6	8	2	9	1	6	4	3	5	7	7	5	3	6	2	8	9	4	1
7	3	1	8	5	6	2	7	4	9	9	6	7	4	2	5	1	8	3
8	3	5	7	1	6	4	8	2	9	9	4	1	6	2	8	7	5	3
	P-3									P-4								
1	9	1	6	2	7	4	8	5	3	4	6	9	3	2	5	8	1	7
2	9	2	8	1	7	5	6	4	3	4	3	8	6	2	1	9	5	7
3	8	5	3	2	7	4	9	1	6	8	1	7	3	2	5	4	6	9
4	8	2	9	5	7	1	3	4	6	8	3	4	1	2	6	7	5	9
5	6	4	3	1	7	5	9	2	8	9	5	7	6	2	1	4	3	8
6	6	1	9	4	7	2	3	5	8	9	6	4	5	2	3	7	1	8
7	3	4	6	5	7	1	8	2	9	7	5	9	1	2	6	8	3	4
8	3	5	8	4	7	2	6	1	9	7	1	8	5	2	3	9	6	4
	P-5																	
1	4	7	5	3	2	6	8	1	9									
2	4	3	8	7	2	1	5	6	9									
3	8	1	9	3	2	6	4	7	5									
4	8	3	4	1	2	7	9	6	5									
5	5	6	9	7	2	1	4	3	8									
6	5	7	4	6	2	3	9	1	8									
7	9	6	5	1	2	7	8	3	4									
8	9	1	8	6	2	3	5	7	4									

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Table Appendix III-30 Similarity Coefficient of eight existing SMCLs - spiral type one of Yaman's approach (λ=1)

	P-2,1	P-2,2	P-2,3	P-2,4	P-2,5	P-2,6	P-2,7	P-2,8
P-1,1	0	0.1111	0.1111	0.1111	0	0	0.3333	0.4444
P-1,2	0.1111	0	0.1111	0.1111	0	0	0.4444	0.3333
P-1,3	0.1111	0	0	0.3333	0.1111	0.4444	0.1111	0
P-1,4	0	0.1111	0.3333	0	0.4444	0.1111	0	0.1111
P-1,5	0.1111	0	0.1111	0.4444	0	0.3333	0.1111	0
P-1,6	0	0.1111	0.4444	0.1111	0.3333	0	0	0.1111
P-1,7	0.3333	0.4444	0	0	0.1111	0.1111	0	0.1111
P-1,8	0.4444	0.3333	0	0	0.1111	0.1111	0.1111	0

	P-3,1	P-3,2	P-3,3	P-3,4	P-3,5	P-3,6	P-3,7	P-3,8
P-2,1	0	0.1111	0.1111	0.1111	0	0	0.2222	0.3333
P-2,2	0.1111	0	0.1111	0.1111	0	0	0.3333	0.2222
P-2,3	0.1111	0	0	0.2222	0.1111	0.3333	0.1111	0
P-2,4	0	0.1111	0.2222	0	0.3333	0.1111	0	0.1111
P-2,5	0.1111	0	0.1111	0.3333	0	0.2222	0.1111	0
P-2,6	0	0.1111	0.3333	0.1111	0.2222	0	0	0.1111
P-2,7	0.2222	0.3333	0	0	0.1111	0.1111	0	0.1111
P-2,8	0.3333	0.2222	0	0	0.1111	0.1111	0.1111	0

	P-4,1	P-4,2	P-4,3	P-4,4	P-4,5	P-4,6	P-4,7	P-4,8
P-3,1	0.1111	0.1111	0.1111	0.1111	0.1111	0.1111	0.1111	0.1111
P-3,2	0.1111	0.1111	0.1111	0.1111	0.1111	0.1111	0.1111	0.1111
P-3,3	0.1111	0.1111	0.1111	0.1111	0.1111	0.1111	0.1111	0.1111
P-3,4	0.1111	0.1111	0.1111	0.1111	0.1111	0.1111	0.1111	0.1111
P-3,5	0.1111	0.1111	0.1111	0.1111	0.1111	0.1111	0.1111	0.1111
P-3,6	0.1111	0.1111	0.1111	0.1111	0.1111	0.1111	0.1111	0.1111
P-3,7	0.1111	0.1111	0.1111	0.1111	0.1111	0.1111	0.1111	0.1111
P-3,8	0.1111	0.1111	0.1111	0.1111	0.1111	0.1111	0.1111	0.1111

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	P-5,1	P-5,2	P-5,3	P-5,4	P-5,5	P-5,6	P-5,7	P-5,8
P-4,1	0.5556	0.2222	0.3333	0.1111	0.3333	0.2222	0.3333	0.1111
P-4,2	0.2222	0.5556	0.1111	0.3333	0.2222	0.3333	0.1111	0.3333
P-4,3	0.3333	0.3333	0.5556	0.3333	0.2222	0.1111	0.1111	0.2222
P-4,4	0.3333	0.3333	0.3333	0.5556	0.1111	0.2222	0.2222	0.1111
P-4,5	0.1111	0.2222	0.2222	0.1111	0.5556	0.3333	0.3333	0.3333
P-4,6	0.2222	0.1111	0.1111	0.2222	0.3333	0.5556	0.3333	0.3333
P-4,7	0.3333	0.1111	0.3333	0.2222	0.3333	0.1111	0.5556	0.2222
P-4,8	0.1111	0.3333	0.2222	0.3333	0.1111	0.3333	0.2222	0.5556

Table Appendix III-31 Eight existing SMCLs in a planning period - spiral type two of Yaman's approach (λ=1)

	P-1									P-2								
1	1	4	3	7	6	9	8	5	2	6	8	9	1	2	3	7	4	5
2	1	7	8	4	6	5	3	9	2	6	1	7	8	2	4	9	3	5
3	8	5	2	7	6	9	1	4	3	7	4	5	1	2	3	6	8	9
4	8	7	1	5	6	4	2	9	3	7	1	6	4	2	8	5	3	9
5	3	9	2	4	6	5	1	7	8	9	3	5	8	2	4	6	1	7
6	3	4	1	9	6	7	2	5	8	9	8	6	3	2	1	5	4	7
7	2	9	3	5	6	4	8	7	1	5	3	9	4	2	8	7	1	6
8	2	5	8	9	6	7	3	4	1	5	4	7	3	2	1	9	8	6
	P-3									P-4								
1	4	2	3	8	7	9	6	5	1	5	3	7	8	2	4	9	1	6
2	4	8	6	2	7	5	3	9	1	5	8	9	3	2	1	7	4	6
3	6	5	1	8	7	9	4	2	3	9	1	6	8	2	4	5	3	7
4	6	8	4	5	7	2	1	9	3	9	8	5	1	2	3	6	4	7
5	3	9	1	2	7	5	4	8	6	7	4	6	3	2	1	5	8	9
6	3	2	4	9	7	8	1	5	6	7	3	5	4	2	8	6	1	9
7	1	9	3	5	7	2	6	8	4	6	4	7	1	2	3	9	8	5
8	1	5	6	9	7	8	3	2	4	6	1	9	4	2	8	7	3	5
	P-5																	
1	6	3	9	8	2	4	5	1	7									
2	6	8	5	3	2	1	9	4	7									
3	5	1	7	8	2	4	6	3	9									
4	5	8	6	1	2	3	7	4	9									
5	9	4	7	3	2	1	6	8	5									
6	9	3	6	4	2	8	7	1	5									
7	7	4	9	1	2	3	5	8	6									
8	7	1	5	4	2	8	9	3	6									

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Table Appendix III-32 Similarity Coefficient of eight existing SMCLs - spiral type two of Yaman's approach (λ=1)

	P-2,1	P-2,2	P-2,3	P-2,4	P-2,5	P-2,6	P-2,7	P-2,8
P-1,1	0	0	0.1111	0	0	0	0	0.1111
P-1,2	0	0	0	0.1111	0	0	0.1111	0
P-1,3	0.1111	0	0	0	0	0.1111	0	0
P-1,4	0	0.1111	0	0	0.1111	0	0	0
P-1,5	0	0	0	0.1111	0	0	0.1111	0
P-1,6	0	0	0.1111	0	0	0	0	0.1111
P-1,7	0	0.1111	0	0	0.1111	0	0	0
P-1,8	0.1111	0	0	0	0	0.1111	0	0

	P-3,1	P-3,2	P-3,3	P-3,4	P-3,5	P-3,6	P-3,7	P-3,8
P-2,1	0	0.1111	0.1111	0.2222	0	0	0	0
P-2,2	0.1111	0	0.2222	0.1111	0	0	0	0
P-2,3	0.1111	0	0	0	0.1111	0	0.2222	0
P-2,4	0	0.1111	0	0	0	0.1111	0	0.2222
P-2,5	0.2222	0	0.1111	0	0	0	0.1111	0
P-2,6	0	0.2222	0	0.1111	0	0	0	0.1111
P-2,7	0	0	0	0	0.1111	0.2222	0	0.1111
P-2,8	0	0	0	0	0.2222	0.1111	0.1111	0

	P-4,1	P-4,2	P-4,3	P-4,4	P-4,5	P-4,6	P-4,7	P-4,8
P-3,1	0.1111	0	0.1111	0.1111	0	0.1111	0	0
P-3,2	0	0.1111	0.1111	0.1111	0.1111	0	0	0
P-3,3	0.1111	0	0.1111	0	0	0	0.1111	0.1111
P-3,4	0	0.1111	0	0.1111	0	0	0.1111	0.1111
P-3,5	0.1111	0.1111	0	0	0.1111	0	0.1111	0
P-3,6	0.1111	0.1111	0	0	0	0.1111	0	0.1111
P-3,7	0	0	0	0.1111	0.1111	0.1111	0.1111	0
P-3,8	0	0	0.1111	0	0.1111	0.1111	0	0.1111

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	P-5,1	P-5,2	P-5,3	P-5,4	P-5,5	P-5,6	P-5,7	P-5,8
P-4,1	0.5556	0.2222	0.5556	0.2222	0.2222	0.3333	0.2222	0.3333
P-4,2	0.2222	0.5556	0.2222	0.5556	0.3333	0.2222	0.3333	0.2222
P-4,3	0.5556	0.2222	0.5556	0.2222	0.2222	0.3333	0.2222	0.3333
P-4,4	0.2222	0.5556	0.2222	0.5556	0.3333	0.2222	0.3333	0.2222
P-4,5	0.2222	0.3333	0.2222	0.3333	0.5556	0.2222	0.5556	0.2222
P-4,6	0.3333	0.2222	0.3333	0.2222	0.2222	0.5556	0.2222	0.5556
P-4,7	0.2222	0.3333	0.2222	0.3333	0.5556	0.2222	0.5556	0.2222
P-4,8	0.3333	0.2222	0.3333	0.2222	0.2222	0.5556	0.2222	0.5556

Table Appendix III-33 Eight existing SMCLs in a planning period - minimum score of Tang's approach (λ=1)

	P-1									P-2								
1	1	7	8	2	5	3	4	6	9	1	5	7	4	6	8	2	3	9
2	1	2	4	7	5	6	8	3	9	1	4	2	5	6	3	7	8	9
3	4	6	9	2	5	3	1	7	8	2	3	9	4	6	8	1	5	7
4	4	2	1	6	5	7	9	3	8	2	4	1	3	6	5	9	8	7
5	8	3	9	7	5	6	1	2	4	7	8	9	5	6	3	1	4	2
6	8	7	1	3	5	2	9	6	4	7	5	1	8	6	4	9	3	2
7	9	3	8	6	5	7	4	2	1	9	8	7	3	6	5	2	4	1
8	9	6	4	3	5	2	8	7	1	9	3	2	8	6	4	7	5	1
	P-3									P-4								
1	1	3	8	2	5	7	4	6	9	1	3	9	4	2	8	5	6	7
2	1	2	4	3	5	6	8	7	9	1	4	5	3	2	6	9	8	7
3	4	6	9	2	5	7	1	3	8	5	6	7	4	2	8	1	3	9
4	4	2	1	6	5	3	9	7	8	5	4	1	6	2	3	7	8	9
5	8	7	9	3	5	6	1	2	4	9	8	7	3	2	6	1	4	5
6	8	3	1	7	5	2	9	6	4	9	3	1	8	2	4	7	6	5
7	9	7	8	6	5	3	4	2	1	7	8	9	6	2	3	5	4	1
8	9	6	4	7	5	2	8	3	1	7	6	5	8	2	4	9	3	1
	P-5																	
1	8	1	9	7	2	3	6	4	5									
2	8	7	6	1	2	4	9	3	5									
3	6	4	5	7	2	3	8	1	9									
4	6	7	8	4	2	1	5	3	9									
5	9	3	5	1	2	4	8	7	6									
6	9	1	8	3	2	7	5	4	6									
7	5	3	9	4	2	1	6	7	8									
8	5	4	6	3	2	7	9	1	8									

Table Appendix III-34 Similarity Coefficient of eight existing SMCLs - minimum traveling score of Tang's approach (λ=1)

	P-2,1	P-2,2	P-2,3	P-2,4	P-2,5	P-2,6	P-2,7	P-2,8
P-1,1	0.2222	0.3333	0	0	0.1111	0	0	0
P-1,2	0.3333	0.2222	0	0	0	0.1111	0	0
P-1,3	0	0.1111	0.2222	0	0.3333	0	0	0
P-1,4	0.1111	0	0	0.2222	0	0.3333	0	0
P-1,5	0	0	0.3333	0	0.2222	0	0	0.1111
P-1,6	0	0	0	0.3333	0	0.2222	0.1111	0
P-1,7	0	0	0.1111	0	0	0	0.2222	0.3333
P-1,8	0	0	0	0.1111	0	0	0.3333	0.2222

	P-3,1	P-3,2	P-3,3	P-3,4	P-3,5	P-3,6	P-3,7	P-3,8
P-2,1	0.2222	0.2222	0.1111	0	0	0	0	0.1111
P-2,2	0.2222	0.2222	0	0.1111	0	0	0.1111	0
P-2,3	0.1111	0	0.2222	0	0.2222	0.1111	0	0
P-2,4	0	0.1111	0	0.2222	0.1111	0.2222	0	0
P-2,5	0	0	0.2222	0.1111	0.2222	0	0.1111	0
P-2,6	0	0	0.1111	0.2222	0	0.2222	0	0.1111
P-2,7	0	0.1111	0	0	0.1111	0	0.2222	0.2222
P-2,8	0.1111	0	0	0	0	0.1111	0.2222	0.2222

	P-4,1	P-4,2	P-4,3	P-4,4	P-4,5	P-4,6	P-4,7	P-4,8
P-3,1	0.3333	0.1111	0.1111	0.1111	0	0.2222	0	0
P-3,2	0.1111	0.3333	0.1111	0.1111	0.2222	0	0	0
P-3,3	0.1111	0	0.3333	0	0.1111	0	0.1111	0.2222
P-3,4	0	0.1111	0	0.3333	0	0.1111	0.2222	0.1111
P-3,5	0.1111	0.2222	0.1111	0	0.3333	0	0.1111	0
P-3,6	0.2222	0.1111	0	0.1111	0	0.3333	0	0.1111
P-3,7	0	0	0	0.2222	0.1111	0.1111	0.3333	0.1111
P-3,8	0	0	0.2222	0	0.1111	0.1111	0.1111	0.3333

	P-5,1	P-5,2	P-5,3	P-5,4	P-5,5	P-5,6	P-5,7	P-5,8
P-4,1	0.2222	0.1111	0.1111	0.3333	0.2222	0.2222	0.4444	0.1111
P-4,2	0.1111	0.2222	0.3333	0.1111	0.2222	0.2222	0.1111	0.4444
P-4,3	0.1111	0.2222	0.2222	0.4444	0.1111	0.1111	0.3333	0.2222
P-4,4	0.2222	0.1111	0.4444	0.2222	0.1111	0.1111	0.2222	0.3333
P-4,5	0.3333	0.2222	0.1111	0.1111	0.2222	0.4444	0.1111	0.2222
P-4,6	0.2222	0.3333	0.1111	0.1111	0.4444	0.2222	0.2222	0.1111
P-4,7	0.4444	0.1111	0.2222	0.2222	0.1111	0.3333	0.2222	0.1111
P-4,8	0.1111	0.4444	0.2222	0.2222	0.3333	0.1111	0.1111	0.2222

Table Appendix III-35 Eight existing SMCLs in a planning period - maximum score of Tang's approach (λ=1)

	P-1									P-2								
1	1	4	2	7	6	9	8	3	5	1	5	6	4	7	8	2	3	9
2	1	7	8	4	6	3	2	9	5	1	4	2	5	7	3	6	8	9
3	8	3	5	7	6	9	1	4	2	2	3	9	4	7	8	1	5	6
4	8	7	1	3	6	4	5	9	2	2	4	1	3	7	5	9	8	6
5	2	9	5	4	6	3	1	7	8	6	8	9	5	7	3	1	4	2
6	2	4	1	9	6	7	5	3	8	6	5	1	8	7	4	9	3	2
7	5	9	2	3	6	4	8	7	1	9	8	6	3	7	5	2	4	1
8	5	3	8	9	6	7	2	4	1	9	3	2	8	7	4	6	5	1
	P-3									P-4								
1	1	6	4	3	5	2	8	7	9	1	4	2	5	8	3	6	7	9
2	1	3	8	6	5	7	4	2	9	1	5	6	4	8	7	2	3	9
3	8	7	9	3	5	2	1	6	4	6	7	9	5	8	3	1	4	2
4	8	3	1	7	5	6	9	2	4	6	5	1	7	8	4	9	3	2
5	4	2	9	6	5	7	1	3	8	2	3	9	4	8	7	1	5	6
6	4	6	1	2	5	3	9	7	8	2	4	1	3	8	5	9	7	6
7	9	2	4	7	5	6	8	3	1	9	3	2	7	8	4	6	5	1
8	9	7	8	2	5	3	4	6	1	9	7	6	3	8	5	2	4	1
	P-5																	
1	1	5	8	2	3	9	4	6	7									
2	1	2	4	5	3	6	8	9	7									
3	4	6	7	2	3	9	1	5	8									
4	4	2	1	6	3	5	7	9	8									
5	8	9	7	5	3	6	1	2	4									
6	8	5	1	9	3	2	7	6	4									
7	7	9	8	6	3	5	4	2	1									
8	7	6	4	9	3	2	8	5	1									

Table Appendix III-36 Similarity Coefficient of eight existing SMCLs - maximum score of Tang's approach (λ=1)

	P-2,1	P-2,2	P-2,3	P-2,4	P-2,5	P-2,6	P-2,7	P-2,8
P-1,1	0.2222	0.3333	0	0.1111	0	0.1111	0	0.1111
P-1,2	0.3333	0.2222	0.1111	0	0.1111	0	0.1111	0
P-1,3	0	0	0.2222	0	0.3333	0.1111	0.1111	0.1111
P-1,4	0	0	0	0.2222	0.1111	0.3333	0.1111	0.1111
P-1,5	0.1111	0.1111	0.3333	0.1111	0.2222	0	0	0
P-1,6	0.1111	0.1111	0.1111	0.3333	0	0.2222	0	0
P-1,7	0	0.1111	0	0.1111	0	0.1111	0.2222	0.3333
P-1,8	0.1111	0	0.1111	0	0.1111	0	0.3333	0.2222

	P-3,1	P-3,2	P-3,3	P-3,4	P-3,5	P-3,6	P-3,7	P-3,8
P-2,1	0.2222	0.2222	0	0	0.1111	0	0.1111	0
P-2,2	0.2222	0.2222	0	0	0	0.1111	0	0.1111
P-2,3	0	0.1111	0.2222	0.1111	0.2222	0	0	0
P-2,4	0.1111	0	0.1111	0.2222	0	0.2222	0	0
P-2,5	0	0	0.2222	0	0.2222	0.1111	0	0.1111
P-2,6	0	0	0	0.2222	0.1111	0.2222	0.1111	0
P-2,7	0.1111	0	0.1111	0	0	0	0.2222	0.2222
P-2,8	0	0.1111	0	0.1111	0	0	0.2222	0.2222

	P-4,1	P-4,2	P-4,3	P-4,4	P-4,5	P-4,6	P-4,7	P-4,8
P-3,1	0.3333	0.2222	0	0	0	0.2222	0	0.1111
P-3,2	0.2222	0.3333	0	0	0.2222	0	0.1111	0
P-3,3	0	0	0.3333	0	0.2222	0.1111	0	0.2222
P-3,4	0	0	0	0.3333	0.1111	0.2222	0.2222	0
P-3,5	0	0.2222	0.2222	0.1111	0.3333	0	0	0
P-3,6	0.2222	0	0.1111	0.2222	0	0.3333	0	0
P-3,7	0	0.1111	0	0.2222	0	0	0.3333	0.2222
P-3,8	0.1111	0	0.2222	0	0	0	0.2222	0.3333

	P-5,1	P-5,2	P-5,3	P-5,4	P-5,5	P-5,6	P-5,7	P-5,8
P-4,1	0.1111	0.2222	0	0	0.1111	0	0	0
P-4,2	0.2222	0.1111	0	0	0	0.1111	0	0
P-4,3	0	0.1111	0.1111	0	0.2222	0	0	0
P-4,4	0.1111	0	0	0.1111	0	0.2222	0	0
P-4,5	0	0	0.2222	0	0.1111	0	0	0.1111
P-4,6	0	0	0	0.2222	0	0.1111	0.1111	0
P-4,7	0	0	0.1111	0	0	0	0.1111	0.2222
P-4,8	0	0	0	0.1111	0	0	0.2222	0.1111

Table Appendix III-37 Eight existing SMCLs in a planning period - Conway's approach (λ=1)

	P-1									P-2								
1	7	1	4	3	2	5	8	9	6	7	2	4	1	3	5	8	9	6
2	7	3	8	1	2	9	4	5	6	7	1	8	2	3	9	4	5	6
3	8	9	6	3	2	5	7	1	4	8	9	6	1	3	5	7	2	4
4	8	3	7	9	2	1	6	5	4	8	1	7	9	3	2	6	5	4
5	4	5	6	1	2	9	7	3	8	4	5	6	2	3	9	7	1	8
6	4	1	7	5	2	3	6	9	8	4	2	7	5	3	1	6	9	8
7	6	5	4	9	2	1	8	3	7	6	5	4	9	3	2	8	1	7
8	6	9	8	5	2	3	4	1	7	6	9	8	5	3	1	4	2	7
	P-3									P-4								
1	8	2	7	1	4	5	3	9	6	8	4	7	1	3	5	9	2	6
2	8	1	3	2	4	9	7	5	6	8	1	9	4	3	2	7	5	6
3	3	9	6	1	4	5	8	2	7	9	2	6	1	3	5	8	4	7
4	3	1	8	9	4	2	6	5	7	9	1	8	2	3	4	6	5	7
5	7	5	6	2	4	9	8	1	3	7	5	6	4	3	2	8	1	9
6	7	2	8	5	4	1	6	9	3	7	4	8	5	3	1	6	2	9
7	6	5	7	9	4	2	3	1	8	6	5	7	2	3	4	9	1	8
8	6	9	3	5	4	1	7	2	8	6	2	9	5	3	1	7	4	8
	P-5																	
1	7	8	1	2	3	5	9	6	4									
2	7	2	9	8	3	6	1	5	4									
3	9	6	4	2	3	5	7	8	1									
4	9	2	7	6	3	8	4	5	1									
5	1	5	4	8	3	6	7	2	9									
6	1	8	7	5	3	2	4	6	9									
7	4	5	1	6	3	8	9	2	7									
8	4	6	9	5	3	2	1	8	7									

Table appendix III-38 Similarity Coefficient of existing SMCLs - Conway's approach (λ=1)

	P-2,1	P-2,2	P-2,3	P-2,4	P-2,5	P-2,6	P-2,7	P-2,8
P-1,1	0.6667	0.3333	0.1111	0.1111	0	0.1111	0.2222	0
P-1,2	0.3333	0.6667	0.1111	0.1111	0.1111	0	0	0.2222
P-1,3	0.1111	0	0.6667	0.2222	0.3333	0	0.1111	0.1111
P-1,4	0	0.1111	0.2222	0.6667	0	0.3333	0.1111	0.1111
P-1,5	0.1111	0.1111	0.3333	0	0.6667	0.2222	0.1111	0
P-1,6	0.1111	0.1111	0	0.3333	0.2222	0.6667	0	0.1111
P-1,7	0.2222	0	0	0.1111	0.1111	0.1111	0.6667	0.3333
P-1,8	0	0.2222	0.1111	0	0.1111	0.1111	0.3333	0.6667

	P-3,1	P-3,2	P-3,3	P-3,4	P-3,5	P-3,6	P-3,7	P-3,8
P-2,1	0.5556	0.1111	0.3333	0	0.2222	0.3333	0	0
P-2,2	0.1111	0.5556	0	0.3333	0.3333	0.2222	0	0
P-2,3	0.3333	0.2222	0.5556	0	0.1111	0	0	0.3333
P-2,4	0.2222	0.3333	0	0.5556	0	0.1111	0.3333	0
P-2,5	0	0.3333	0.1111	0	0.5556	0	0.3333	0.2222
P-2,6	0.3333	0	0	0.1111	0	0.5556	0.2222	0.3333
P-2,7	0	0	0.2222	0.3333	0.3333	0	0.5556	0.1111
P-2,8	0	0	0.3333	0.2222	0	0.3333	0.1111	0.5556

	P-4,1	P-4,2	P-4,3	P-4,4	P-4,5	P-4,6	P-4,7	P-4,8
P-3,1	0.5556	0.2222	0.3333	0	0	0	0.1111	0.1111
P-3,2	0.2222	0.5556	0	0.3333	0	0	0.1111	0.1111
P-3,3	0.3333	0	0.5556	0.1111	0.2222	0.1111	0	0
P-3,4	0	0.3333	0.1111	0.5556	0.1111	0.2222	0	0
P-3,5	0	0	0.2222	0.1111	0.5556	0.1111	0.3333	0
P-3,6	0	0	0.1111	0.2222	0.1111	0.5556	0	0.3333
P-3,7	0.1111	0.1111	0	0	0.3333	0	0.5556	0.2222
P-3,8	0.1111	0.1111	0	0	0	0.3333	0.2222	0.5556

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	P-5,1	P-5,2	P-5,3	P-5,4	P-5,5	P-5,6	P-5,7	P-5,8
P-4,1	0.3333	0.1111	0.2222	0.2222	0.2222	0.2222	0.3333	0.1111
P-4,2	0.1111	0.3333	0.2222	0.2222	0.2222	0.2222	0.1111	0.3333
P-4,3	0.2222	0.2222	0.3333	0.3333	0.1111	0.1111	0.2222	0.2222
P-4,4	0.2222	0.2222	0.3333	0.3333	0.1111	0.1111	0.2222	0.2222
P-4,5	0.2222	0.2222	0.1111	0.1111	0.3333	0.3333	0.2222	0.2222
P-4,6	0.2222	0.2222	0.1111	0.1111	0.3333	0.3333	0.2222	0.2222
P-4,7	0.3333	0.1111	0.2222	0.2222	0.2222	0.2222	0.3333	0.1111
P-4,8	0.1111	0.3333	0.2222	0.2222	0.2222	0.2222	0.1111	0.3333