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A Heuristic Procedure for Designing a Cellular Manufacturing System While Minimizing Makespan

Panduranga Badam

A HEURISTIC PROCEDURE FOR DESIGNING A CELLULAR MANUFACTURING SYSTEM WHILE MINIMIZING MAKESPAN

by

Panduranga Badam

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A HEURISTIC PROCEDURE FOR DESIGNING A CELLULAR MANUFACTURING SYSTEM WHILE MINIMIZING MAKESPAN

Panduranga Badam, M.S.

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This study is the first of its kind in Group Technology (GT) literature and successfully demonstrates the application of the simulation technique to analyze different alternatives for machine and part grouping problem.

This study considers several aspects such as processing time, sequence of operations, alternative routing, setup time and dynamic shop condition for machine-part grouping. The heuristic developed aims to reduce intercellular moves, setup time and makespan time of parts. It also enables the decision makers to evaluate performance measures and to choose the best alternative at every step of the machine grouping process. Two examples have been used to illustrate and test the effectiveness of the approach. From the results, the heuristic is found to be effective in offering a satisfactory result.

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CHAPTER I

INTRODUCTION

Background of the Study

Cellular Manufacturing (CM) is an application of Group Technology (GT) principles to create manufacturing cells and part groups. The main objective is to achieve productivity by exploiting similarities inherent in the production of parts. Creation of manufacturing cells involves three aspects: (1) the identification of cell equipment, (2) the identification of part family and (3) the allocation of part family to the appropriate manufacturing cell. Besides identifying cell equipment and part family, several other objectives and manufacturing constraints are important when designing a manufacturing cell system. Other objectives are: (a) minimization of material handling, (b) minimization of setup time, (c) improved material flow and control, (d) reduced makespan of parts, and (e) minimization of work-in-process inventory. The makespan of a part is the time elapsed to produce the part.

In the past decade, several heuristic methods have been developed using different approaches. Much of this effort has focused on minimizing the total moves of parts between the cells (Logendran, 1990). Some of the heuristic methods focused on optimizing both intercellular and intracellular made by the parts. In the last few years, several heuristic methods have been developed based on similarity coefficients. The shortcomings of these heuristic methods include the inability to consider (a) the dynamic shop condition, (b) makespan time as a direct objective, and (c) evaluation of performance indicators such as set-up time, lead time, work-in-process, machine utilization while designing the cellular manufacturing system.

Statement of the Problem

From the literature review, it is apparent that the existing heuristics may ensure reduced material handling, but they do not ensure other objectives such as reduced set-up time, minimization of makespan and reduction in work-in-process inventory. In addition, most of the existing heuristics in literature are of static variety in the sense that all machines and parts are assumed to be available at time zero and do not change availability with time. With recent advancement in material handling and automatic transporters, material handling costs might even be less significant over time.

Thus, when designing cellular manufacturing systems there is a need for a comprehensive approach using a heuristic procedure which aims to reduce material handling, to consider alternative routings, operation sequence, makespan and dynamic shop condition in real time. The dynamic shop condition is, in a sense, the change with time in the availability of machines and other resources. Therefore, this study addresses the problem of designing the cellular manufacturing system by developing a heuristic method which aims to minimize (a) material handling costs, (b) makespan, and (c) consider dynamic shop condition.

Objective of the Study

The objective of this study is to develop a comprehensive approach for designing a cellular manufacturing system using a heuristic procedure. This procedure aims to reduce material handling costs and total makespan time, and to consider alternative routings, operation sequence and dynamic shop condition.

The main focus of this research is as follows:

1. To develop a heuristic procedure which determines machine cells and part family while aiming to minimize total makespan of parts by considering the dynamic shop condition.

2. To evaluate performance indicators while designing a cellular manufacturing system.

3. To test the effectiveness of the heuristic procedure using frequently referenced design problem data in the literature.

CHAPTER II

REVIEW OF RELATED LITERATURE

Cellular Manufacturing Systems

Cellular manufacturing systems have helped to achieve productivity by reducing machine set-up time, throughput time, work-in-process inventories, and complex flow of parts and materials in a manufacturing system.

Research is being pursued to attain maximum productivity through various approaches and techniques. Many decisions have to be made during the design of a cellular manufacturing system. Some of the more important ones include (Alfa, Ahmed, and Nandkeolyar,1991): (a) Type and number of machines required to process a given set of parts, (b) Type and number of material handling equipment required to transport parts and other material between machines, (c) Grouping of machines into their respective cells, (d) Layout of machines within cells, and (e) Layout of cells with respect to one another.

The cell formation problem has multiple objectives and constraints. The computational difficulty of design process grows exponentially with the size of the problem. In the past decade, numerous techniques have been developed to solve cell design problems. Some of the prominent techniques are discussed in the following paragraphs.

Heuristic Developed in Past Decades

An analytical approach based on production flow data was developed by Burbidge (1971) for the formation of part family and machine cells. The approach is manual in nature, but it becomes more complex as the size of the grouping problem increases. Thus, the algorithm is suitable only for a small-sized problem.

McAuley (1972) developed a similarity coefficient approach. Similarity coefficient is a measure of the association between two machines based on production data. Similarity coefficients for all possible pairs of machines are calculated and clustered based on the calculated similarity coefficient. This approach has the advantage of simplicity for large-sized problems.

King and Nakornchai (1982) developed an iterative algorithm, Rank Order Clustering (ROC). This technique needs a machine component matrix to be developed on the basis of production data. The algorithm takes a finite number of iterations and rearranges both rows and columns of the machine components in order of decreasing value read as binary words. The algorithm is simple and effective.

Chan and Milner (1982) developed the Direct Clustering algorithm

(DCA). This algorithm forms part family and machine cells by changing the sequence of components listed in the matrix. Instead of using binary word representation, the algorithm uses the 0-1 incidence matrix.

Some of the algorithms discussed above use only parts routing information and do not take into consideration the cost factors of manufacturing components, viz. parts volume, intra and intercell material handling. Most of the above mentioned algorithms use or depend on the machine-part matrix, which is developed on parts-routing data.

Algorithms which use or depend on machine-part matrix have some limitations which are as follows (Currie, 1992):

1. No consideration is given for differing capacities and demands of equipment selected for particular cell.

2. Implicitly assumes design similarities coincide with manufacturing similarities.

3. In many cases the cell design is "all or nothing" in that all parts are grouped into one and only one cell. In some instances a part may have characteristics in common with one or more cells.

4. Economics has played a very minor role and has only been used in minimizing the inter-cellular movement of parts.

Heuristic Developed in the Past Few Years

In the last few years, some of the heuristics cited in the literature were based on similarity coefficient methods and mathematical programming models. Significant among these are:

1. Taboun and Sharma (1991) proposed algorithm of weighted similarities of the required objectives, based on experience and/or approximation. The proposed model takes into consideration the desired minimum weight of each proximity index and the total available resources, such as the available machining capacity.

2. Another study conducted by Min and Shin (1992) explores the formation of machine-part manufacturing cell in essence of GT and its full benefits can be gained by forming human cells. The cells are formed on the basis of similar expertise and skills to produce similar parts. A multiple objective approach for the simultaneous formation of machine and human cells is proposed. The proposed approach intends to match the similarities among machine and human cells.

3. An attempt has been made by Ahmed, Ahmed and Nandkeolyar (1981) to take into consideration the material handling cost factor. The heuristic developed considers the components' volume, the costs related to movement of parts between and within cells, and also a penalty for not using all the machines in a cell visited by a part. The methodology uses integer programming which leads to a computational difficult problem even for a small sized cell design. Some of the shortcomings of this algorithm are that it does not take into consideration (a) the alternative routing

possibilities, (b) the set-up time, and (c) the lot size.

4. A machine-part based algorithm by Logendran and Thomas (1990), uses a binary machine-part matrix aims to reduce intercellular and intracellular movements.

5. A material-flow approach by Vakharia and Wemmerlov (1990) evolves a coefficient based on operations sequence of parts and groups the machines based on coefficient. Furthermore, with-in-cell operation sequence and machine loads are considered during the design process.

6. A process-flow based machine grouping algorithm by GU (1991) forms machine cells and part family. The parts grouping is based on process similarities and the cells formed based on the grouped part family.

7. Simultaneous grouping of parts and machines presented by Gunasingh and Lashkhari (1991), uses non-liner 0-1 integer programming formulation and forms machine-part groups on the basis of compatibility of the parts with the machines. It also performs a trade-off between the cost of duplicating the machines and the cost of intercell movement.

8. Shafer and Rogers (1991) presented a mathematical programming approach which addressed minimizing set-up time, intercellular movements, and investment in new equipment, while maintaining an acceptable machine utilization level.

Recent Areas of Research

Recent areas of research in the subject of cellular manufacturing are focused toward comparison of clustering techniques and performance analysis. It is mentioned by Lin and Chiu (1992) that identifying the significant factors influencing the cell performance is vital to the design, operation and control of the manufacturing cell system.

In recent research by Yang and Dean (1992), an attempt was made to investigate the relationship between the set-up time reduction and the cell flow performance measures (average flow time, variance of flow time, product lot size). Part of the study concludes with the analytical qualification that, in a closed manufacturing cell, the flow time performance in terms of average flow time, variance of average flow time, and optimal lot size will improve at a lesser rate as product set-up time is reduced. The closed manufacturing cell is one that produces a predetermined and limited set of products in batches.

To study the performance behavior of some manufacturing cells and to combine the advantages of analytical and simulation methods, a hybrid approach was done by Lin and Chiu (1993). The study was conducted by building a metamodel of a manufacturing cell and performing extensive simulation runs. The variables used in the study of operating characteristics of manufacturing systems were: (a) average flow time, (b) work-in-process, and (c) throughput rate. Research was also performed on cell transient behavior in response to dynamic events that are often encountered during production, such as a sudden machine breakdown or job change.

Summary

From the preceding discussion, it is evident that most of the heuristic methods have focused on optimizing the material handling cost. These heuristic methods may ensure reduced material handling, but do not evaluate other objectives such as set-up time, lead time, work-in-process inventory and machine utilization of the system. Most of the heuristics focused on reducing material handling cost, but the material handling cost might be even less expensive over time because of the advancement in material handling technology. Thus, the objective of reducing material handling may now be less important and more emphasis should be given to other objectives of cellular manufacturing systems. Another aspect which has not been considered while designing the cellular manufacturing system is evaluation of performance indicators. Lin and Chiu (1993), in their study, explained that identifying the factors influencing the cell performance is vital to design, operation and control of a manufacturing cell system. Also, recent research by Yang (1993), Lin and Chiu (1992) and Yang and Dean (1992) has underlined the importance of the performance indicators while designing cellular manufacturing systems.

Overall, the cellular manufacturing system may yield sub-optimal benefits if machine cells and parts groups are based only on one set of objectives.

Thus, there is a need for a comprehensive approach while designing a cellular manufacturing system which aims at reducing both material handling and makespan. In order to achieve these objectives, it is essential to consider alternative routings, operation sequence, and dynamic shop condition.

CHAPTER III

PERFORMANCE INDICATORS

Identification of Performance Indicators

Determining the cell performance is important, as the success of a manufacturing system depends on cell performance . The success of cells can be determined by defining what results are desired and comparing them with the actual results obtained. It is important that performance of a manufacturing system meets the objective of the business strategy. Therefore, indicators for system performance evaluation should be derived from the business strategy. It is apparent from the above discussion that manufacturing engineers who design cellular manufacturing systems should identify performance indicators based on the business strategy.

Importance of Measuring Performance Indicators

In an ongoing cellular manufacturing system design, measuring performance is important as undesirable results can be detected and corrective action can be initiated in the early stages of design. Measuring performance and taking corrective action during the design stage ensure operational and profit objectives of the business at reduced cost.

CHAPTER IV

ALGORITHM

Overview

As previously mentioned, the design of a manufacturing system has multiple objectives and constraints, and as the size increases, the cellular manufacturing problem complexity increases. The following set of steps are helpful in reducing the efforts to achieve an efficient cell design:

1. Identification of key machines, in this step key machines for each cell are identified from general machine pool (GMP).

2. Simulation model development, in this step a simulation model of key machines selected in the previous step is developed. The main objective while formulating the model is to evaluate the required performance indicators.

3. Clustering phase, in this step machines and parts are assigned to appropriate cells and part family.

Model Assumptions and Notations

It is assumed that data pertaining to the assumptions listed below are available:

Assumptions

1. C_{max} and M_{limit} are known.

2. The demand for each part is known and batch size of each part is determined.

3. The routing of each part is known.

4. The processing time for each part at each machine is known.

5. The set-up time for a machine depends on previous operations performed on the part.

6. It is assumed arbitrarily that set-up time on any machine for a part moved from the same cell is null and a part moved from a different cell is sixty minutes. This assumption is due to lack of data available on sequence based set-up time and move time delays.

7. The processing is done in lots and movement of parts between machines is also done in lots.

8. A part coming in first in the system has the highest priority to get processed.

9. It is assumed that parts are transferred directly from one machine to the other without delay.

10. Teardown time is assumed to be zero for all parts.

11. Resources, tools and fixtures necessary for processing parts are assumed to be available without any delay.

Notations

n : total number of parts to manufacture

c : total number of cells

m : total number of machines

i= 1,......m

j= 1,......n

l= 1,......c

K_i machine number

C_{max} maximum number of cells

M_{limit} maximum number of machines in a cell

Identification of Key Machines

In any manufacturing system, work force, space and budgetary limitations are important factors, and these are under the control of the management. These factors are important for deciding C_{max} and M_{limit} values. Therefore, it is assumed, that management decides the maximum number of cells and the cell size (Logendran, 1991). Hence, the assumption that factors C_{max} and M_{limit} are known prior to cell design process. The following steps are performed to identify the key machines for a cellular manufacturing system. A flow diagram depicting the important steps of the procedure is shown in Figure 1.

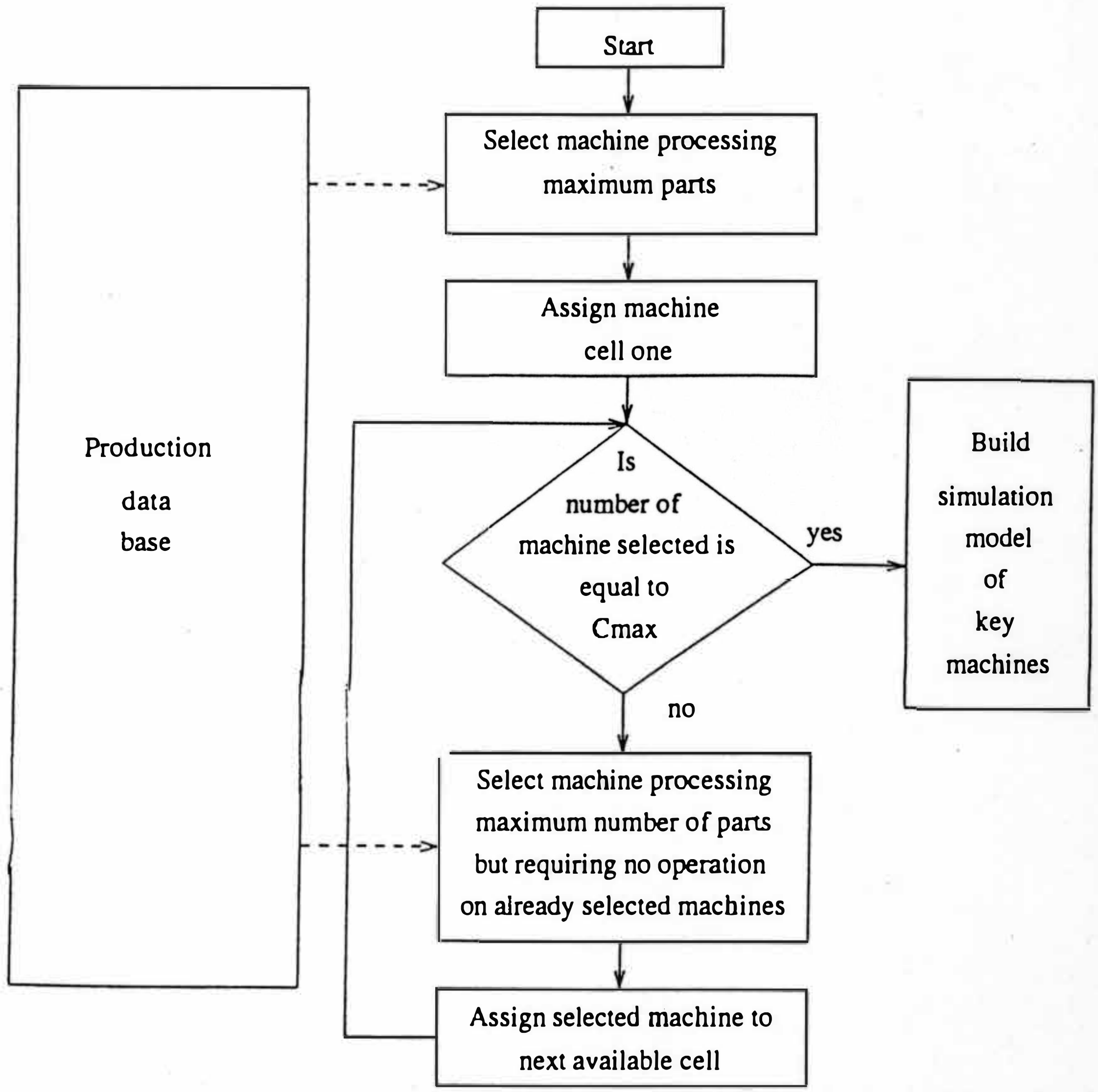

Figure 1. Flow Diagram for Key Machine Identification.

1. Step 1, select first key machine K_i from General Machine Pool (GMP) and assign to cell C_1, such that M_i processes the maximum number of parts.

2. Step 2, this step is performed to select the key machine, for the next cell. The key machine K_i for the cell 2 is the one that processes the maximum number of parts with no operations to be performed on other key machines identified so far.

3. Step 3, if the key machines selected are equal to C_{max}, then stop at this stage; otherwise, repeat Steps 2 and 3.

Simulation Model Development Stage

In the proposed algorithm, a simulation model is developed and required performance indicators are assessed for the grouping of machines at each clustering stage. The main objective while developing the model is to minimizing makespan at each grouping stage. This step facilitates the consideration of the dynamic shop condition while grouping machines and parts. The details of grouping are discussed in the clustering stage.

The process for the successful development of a simulation model consist of beginning with simple model which is embellished in an evolutionary fashion to meet problem-solving requirements. With in this process, the following stages of developments can be identified (Pritsker): (a) Problem formulation, (b) Model building, (c) Data Acquisition, (d) Model translation, (e) Model verification, (f) Model validation, (g) Experimentation, (h) Analysis of results, and (I) Implementation and documentation.

Initially a simulation model is developed with key machines. Each key machine forms a single machine cell.

Clustering Stage

Having developed the simulation model for key machines in the previous stage, the next step is to allocate unassigned machines to existing one machine cells.

Allocation of Unassigned Machines

Figure 2 depicts the flow diagram for the process of allocation of unassigned machines. This step consists of (a) identifying the machine and parts to be allocated to existing cells during each iteration, (b) identifying different cell alternatives for the selected machine, (c) collecting simulation run outputs for different alternatives, (d) evaluating the performance indicators, and (e) assigning machine to cell and parts to part family. The simulation model is enhanced due to the addition of machine and parts added in each iteration. Brief explanation of each step of flow diagram in Figure 2 is given below:

1. Step 1, select all the parts from the general part pool (GPP) that can be processed completely on key machines.

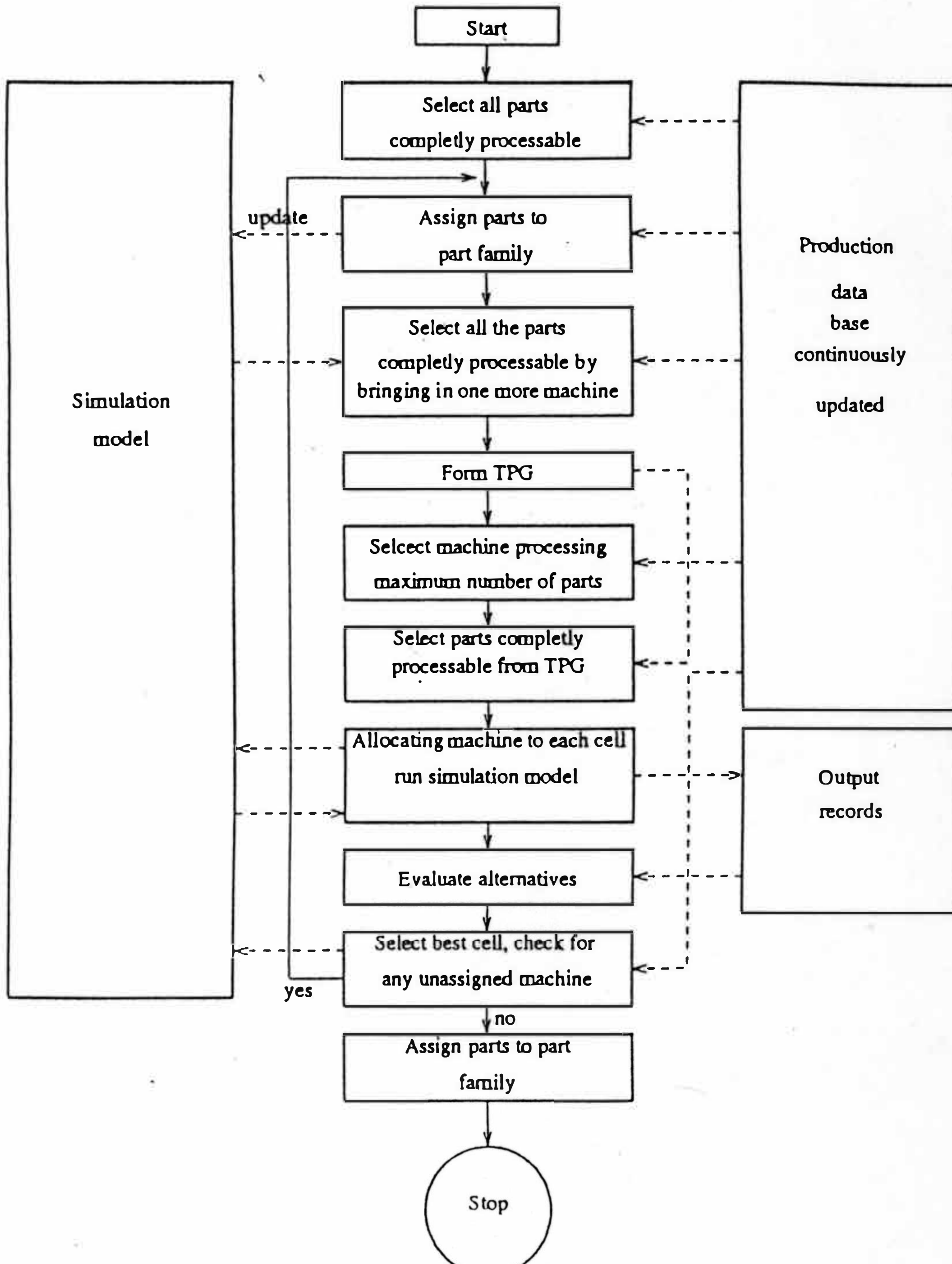

Figure 2. Flow Diagram for the Proposed Clustering Procedure.

2. Step 2, assign parts selected in Step 1 to the part family of the key machine on the basis of maximum intracell operations.

3. Step 3, update the simulation model by adding parts selected in Step 1; update the general part pool (GPP) by removing parts selected in Step 1.

4. Step 4, select all the parts from the updated GPP that can be processed completely by using the machines in the current cells and by bringing in one more unassigned machine.

5. Step 5, group all the parts selected in Step 4 into a tentative part group (TPG) and remove them from current GPP.

6. Step 6, repeat step 4 and 5 for all unassigned machines and update TPG each time.

7. Step 7, select one of the unassigned machine processing maximum number of parts currently in TPG. Select all the parts completely processable, using the selected machine and the machines in current cells. Update the simulation model by including the newly selected machine and parts.

8. Step 8, assign the machine selected in Step 6 tentatively to any one cell. Update the simulation model accordingly and run it for a predetermined number of replications.

9. Step 9, change the assignment of the machine selected in Step 6 to the next available cell and update the model. Repeat Steps 8 and 9 until

all possible alternative assignments are simulated.

10. Step 10, assign the machine selected in Step 7 to the cell in such a way that it minimizes makespan.

11. Step 11, assign the parts selected in Step 6 to the part family on the basis of maximum number of operations within the cell. This leads to reduction in set-up time as well. Update the simulation model by assigning machine and parts to appropriate cells.

12. Step 12, repeat step 4 to 11 until all machines and parts are grouped.

Analysis of Simulation Results

This step consists of (a) evaluating the performance indicators of an intermediate design alternative, and (b) determining the best alternative based on the performance indicators. Some of the response variables that can be quantified by the simulation model are intercellular and intracellular movements made by each part, parts' makespan, work-in-process level, inventory cost, and total set-up time. The output of the simulation run results can be recorded in the chart, as shown in Figure 3. In this study, the total makespan time is considered as the prime performance indicator, as it leads to a reduction in work-in-process level, inventory cost, and material handling cost. Thus, the alternative with minimum makespan is selected as the best alternative. The makespan is the total time taken to completely process all parts in the system from start to finish. The additional machine is included in each cell one by one. The model is modified for each alternative scenario created by the assignment of additional machine. The performance indicators for each scenario are evaluated. After assigning the machine to a cell, part are assigned to a cell that minimizes intercellular moves. Table 3 in Appendix B shows makespan when each unassigned machine was included in different cells for illustrative problem 1.

Part	Machine	Cell Number			
		Total Inter-cellular Movements	Makespan Time	Total Inventory Cost	Total Work-in-process

Figure 3. Chart for Recording Simulation Run Results.

CHAPTER V

COMPARISON OF HEURISTICS AND RESULTS

In order to demonstrate the effectiveness of the proposed heuristic, two sample problems frequently cited in the GT literature were solved. These problems have been referred and solved by many researchers and have been used to compare the performance of the heuristics. Gupta and Seifoddini (1990) solved this problem by using the similarity coefficient method. The first problem is of 16 machines and 43 parts and the second problem is of 8 machines and 30 parts. The data were generated by a simulation program, the production data developed by simulation are given in Appendix A.

To test the effectiveness of the proposed heuristic, it is compared with one of the heuristics developed by Gupta and Seifoddini (1990). The above-mentioned sample problems were solved using both heuristics for the same number of cells. The grouping results are shown in Tables 3, 4, 5, and 6. By using these grouping results, simulation models were developed and the total makespan of the parts was determined. The planning horizon considered for the first problem was 12 months and for the second problem was 30 months. The lot size was determined on the basis of annual requirement and raw material replenished every three months. The detailed steps in solving the example are given in Appendix B. The maximum number of cells considered was five for Problem 1 and four for Problem 2. Simfactory software was used to build simulation models and evaluate performance indicators. Simfactory is a software which is designed for the simulation of factory activities. The model of the production system is developed interactively and data is entered through a set of menus describing the components and limitations of the system. The sample output results obtained by simulation models are given in Appendix C.

As seen from the summary tables (Table 1 and Table 2), the proposed heuristic is successful in reducing the makespan compared to the other heuristic. The makespan is reduced for both problem when solved with proposed heuristic. For the first problem set, among 43 parts, makespan of 19 parts was reduced using the proposed heuristic (compared to other heuristic solution). The makespan of all 43 parts using the proposed heuristic was 4605 hours and using the similarity coefficient method makespan was 4778 hours. For the second problem set, the makespan was 40,793 using the proposed heuristic and 41,350 hours using the similarity coefficient method. Therefore, based on the results of illustrative problems, it can be said that the solution obtained with proposed heuristic is superior to the other heuristic with respect to minimizing makespan.

Table 1

Results for Example Problem 1

Heuristic Method	Total Moves	Intercell Moves	Total Makespan
Proposed	97	53	4605 hours
Gupta and Seifoddini	97	51	4777 hours

Table 2

Results for Example Problem 2

Heuristic Method	Total Moves	Intercell Moves	Total Makespan
Proposed	89	70	40,793 hours
Gupta and Seifoddini	89	69	41,350 hours

The grouping results obtained for the illustrative examples using the proposed heuristic and the similarity coefficient method are shown in Tables 3,4,5 and 6 respectively.

Table 3

Machine Cells and Associated Part Family for
Problem 1 Using Proposed Algorithm

Cell Number	Machine Members	Part Number
C1	4, 6, 14	06, 14, 19, 23, 29,
C2	7, 8, 10, 13, 12	01, 03, 08, 11, 12, 13, 15, 24, 25, 26, 31, 39
C3	1, 2, 9, 16	02, 04, 10, 18, 28, 32, 37, 38, 40, 42
C4	5, 11, 15	05, 09, 16, 20, 21, 22, 27, 30, 33, 41, 43
C5	3	07, 17, 34, 35, 36

Table 4

Machine Cells and Associated Part Family for
Problem 2 Using Proposed Algorithm

Cell Number	Machine Members	Part Number
C1	1, 5, 6	1, 2, 4, 8, 11, 12, 17,18, 19, 22, 25, 27, 29
C2	8	3, 7, 9, 10, 26
C3	3	13, 20, 30
C4	7, 2, 4	5, 6, 14, 15, 16, 21, 23, 24, 28

Table 5

Machine Cells and Associated Part Family for Problem 1
Using Similarity Coefficient Approach
by Gupta and Seifoddini

Cell Number	Machine Members	Part Number
C1	1, 2, 9, 16	02, 04, 10, 18, 28, 37, 38, 40, 42
C2	3, 6, 10, 14, 15	06, 07, 13, 14, 17, 19, 26, 31, 34, 35, 36, 39, 43
C3	4, 5, 8, 11	01, 03, 05, 08, 09, 11, 12, 15, 16, 20, 21, 23, 24, 27, 29,30, 33, 41
C4	7	25
C5	12, 13	22

Economic Impact

From the results Table 1 and 2 the proposed heuristic is successful in reducing makespan. The reduced makespan leads to (a) improved customer delivery, (b) reduced work-in-process inventory, and (c) cost savings in resources. The savings in the resources can be quantified if the operating cost of each machine is known. For example, for the illustrative problem 1, let us assume that average overhead cost and operating cost of each machine is $25 per hour. Thus the savings for 16 machine per hour is $400 per hour. From the Table 1 the savings in the makespan using the proposed heuristic compared to other heuristic is 172 hours. Thus, total savings only through resource utilization using the proposed heuristic can be quantified to $68800.00 with above assumptions. Other intangible benefits, such as improved customer delivery and reduced WIP cost are also realized through makespan improvement. Thus, the proposed heuristic may attain a more economical viable cellular manufacturing system than the other heuristic.

Table 6

Machine Cells and Associated Part Family for Problem 2
using Similarity Coefficient Approach
by Gupta and Seifoddini

Cell Number	Machine Members	Part Number
C1	1, 2, 6	1, 5, 8, 9, 12, 18, 23, 24, 28
C2	3	20, 13, 30
C3	4, 7, 8	3, 6, 7, 10, 14, 15,16, 21, 22, 26, 27
C4	5	2, 4, 11, 17, 19, 25, 29

CHAPTER VI

SUMMARY AND CONCLUSIONS

In this study, a heuristic procedure is developed to solve the machine and part grouping problem for a cellular manufacturing system. The developed heuristic considers several aspects of the system, such as intercellular and intracellular movements, processing time, sequence of operation, alternative routing, set-up time and dynamic shop condition during the machine-part grouping process.

The developed heuristic aims to reduce the intercellular movements while identifying key machines. Simulation modeling technique tools was used to take into consideration the dynamic condition of the system. Grouping of machines and parts was done simultaneously; parts grouping was done on the basis of maximum of intracellular moves. The proposed heuristic also enables the decision maker to evaluate the performance measures and to choose the best alternative available. The prime performance measure for grouping machines was the makespan. Selecting an alternative with minimum makespan will also results in the reduced work-in-process inventory.

In order to test and demonstrate the effectiveness of the proposed heuristic, two sample problems were solved and the total makespan of parts was determined. The outcome of grouping is shown in Tables 3, 4, 5, and 6. The summary of comparisons is shown in Tables 1 and 2. For the first problem set, among 43 parts, makespan of 19 parts is reduced using the proposed heuristic (compared to the other heuristic solution). The total makespan of all 43 parts using proposed heuristic is 4605 hours and using the similarity coefficient method the total makespan is 4778 hours. For the second problem set, the total makespan is 40,793 using the proposed heuristic and 41,350 hours using the similarity coefficient method. Therefore, in general, the solution obtained with the proposed heuristic is superior to the other heuristic with respect to minimizing the makespan time of parts

In conclusion, the results are promising for both the total makespan time and the work-in-process inventory cost. From the results and summary tables, the developed heuristic attains better results with respect to the total makespan of parts. The benefits of the reduced makespan are reduction in work-in-process, inventory cost, and material handling cost. In addition, improved delivery time and faster response to market changes are two other important improvements that can be achieved.

Some of the important implications of the developed heuristic procedure can be enumerated as follows:

1. The heuristic procedure ensures minimum make span for the

product mix used as a basis for designing the system. This is of critical importance in the age of time based competition.

2. The conventional cell design procedures aim at minimizing total material handling cost. With large scale integration in manufacturing system, material handling cost may become insignificant.

3. The use of a simulator is particularly important for an efficient implementation of the developed heuristics.

4. The approach developed in this research is general and can be adopted for a variety of performance indicators, the selection of which is left to the discretion of the system designer.

Appendix A

Production Data of Illustrative Example

Table 1

Part Routing Sequence and the Unit Operations Time for the 16-Machine and 43-Part Problem (Gupta and Seifoddini,1990)

Part Number	Routing Sequence							
01	6	10	7	8	6			
	3.5	5.0	10.5	23.0	3.0			
02	2	9	6	9	8	16	14	2
	3.5	4.0	12.0	10.0	5.5	6.4	22.4	
11.0								
03	8	13	11	8				
	2.5	6.7	4.8	23.0				
04	9							
	6.8							
05	4	15	5	4				
	18.0	4.0	14.0	10.0				
06	6	14						
	22.0	11.4						
07	3	6	16	3				
	2.3	4.7	6.6	3.5				
08	8	5	6					
	6.0	8.0	6.2					
09	4	11	5	8	4			
	7.4	9.2	4.1	10.5	2.5			
10	9	2	16					
	4.5	3.5	26.0					
11	8	12						
	14.0	6.5						
12	8	6	10	8				
	3.0	5.6	9.0	14.0				
13	7	6	10					
	7.0	6.0	10					
14	4	6	5	6				
	4.5	6.8	2.4	3.5				
15	5	8						
	4.0	8.5						

continued to next page ..

Table 1. (Continued)

Part Number	Routing Sequence					
16	5					
	8.0					
17	3	14	6	3		
	3.4	5.6	2.5	12.0		
18	9	16				
	24.0	5.3				
19	4	6	8	5	6	15
	2.0	4.8	1.4	15.0	12.0	5.0
20	8	11				
	10.0	5.0				
21	4	8	5	15	4	
	8.0	11.0	3.5	14.0	20.5	
22	5	12				
	4.7	3.5				
23	4	6	5	8		
	34.0	4.5	6.9	12.0		
24	8	11	13	12	8	
	3.5	3.6	7.5	12.5	22.0	
25	7	10				
	13.0	4.5				
26	10					
	2.4					
27	11	12	8			
	22.5	4.5	8.5			
28	2	9	8			
	3.5	6.7	8.5			
29	4	5				
	30.5	2.5				
30	11	12				
	12.0	3.5				
31	8	10				
	4.5	15.0				
32	2	9	6	16	9	
	22.0	4.5	6.3	9.5	12.5	
33	5	15	6	5		
	5.0	6.4	7.8	9.4		

continued to next page ..

Table 1. (Continued)

Part Number	Routing Sequence						
34	3	6					
35	14	3					
	5.0	10.0					
36	3						
	5.0						
37	1	2	9	8	6	16	9
	4.5	3.5	7.5	8.0	32.6	21.0	5.7
38	2	9	8	16	9		
	4.0	9.5	7.8	2.5	3.5		
39	6	10					
	6.0	20.0					
40	9	2	6	9			
	12.0	4.0	8.9	11.0			
41	5	8	15				
	3.0	4.5	6.5				
42	1	2	9	6	2	16	1
	2.5	12.0	4.5	8.5	6.5	9.5	4.3
43	5	6	8	15	6		
	3.0	5.0	8.0	15.0	6.0		

Table 2

Part Routing Sequence and the Unit Operations Time for the 16-Machine and 43-Part Problem (Gupta and Seifoddini,1990)

Part Number	Operation Sequence/time						Lot Size
01	1						250
	0.3						
02	5	8	1	8	5		40
	38.1	37.4	0.4	3.1	3.6		
03	8						1200
	2.8						
04	5	6	5	1	2		450
	4.2	1.9	62.1	11.6	12.5		
05	7	2	4	6			550
	0.6	2.5	14.6	31.4			
06	7	5	8				750
	28.5	0.8	17.9				
07	8						950
	20.2						
08	2	3	4	6	3	8	300
	19.4	6.4	4.3	28.3	3.4	6.4	
09	2	8	7	3	6		250
	11.4	23.8	4.3	11.9	22		
10	8						100
	2.8						
11	4	5	3	7	1		800
	3.1	18.7	10.5	1	2.4		
12	1	6	5	2			1000
	33.8	9.4	30.6	99.2			
13	8	2	6	1	3		750
	0.7	0.2	1.5	5.4	27.4		
14	5	2	4	8	1		700
	9.7	4.6	8.6	3.1	.6		
15	2	8	7	2	5		300
	6.5	7.1	24.3	2.7	.9		
16	8	4	8	4	7		450
	35.7	1.6	1.7	1	10.2		
17	5	3					1100
	29.5	21.9					

continued to next page ..

Table 2 (Continued)

Part Number	Operations Sequence								Lot Size
18	6	3	6						50
	28	14.6	12.2						
19	4	5	2	1					650
	12.4	56	3.3	0.8					
20	1	3	6	2					700
	5.8	12.2	2.5	14.3					
21	7								600
	1.5								
22	8	7	6	1	4	1	3	4	1000
	7.1	24.5	2.6	6.4	62.8	20.4	4.2	18.7	
23	7	1	4	2					1250
	1.9	29.3	10.8	2.7					
24	2	4							1250
	22.2	9.5							
25	7	5	8	5	1	6	3		1000
	4.3	26	1.3	20	1.2	0.7	1.4		
26	8	7	8	3	8				450
	10.9	3	15	8.5	2.6				
27	1	8							300
	1.3	65.6							
28	2	3	4	1	2	4			300
	26.9	1.1	18.6	10.3	11.8	14.7			
29	5	1	3						150
	49	.8	23.6						
30	7	6	1	5	3	5	3		50
	.1	.2	24.1	.6	.8	1.4	19.4		

Appendix B

An *Illustrative* Example

AN ILLUSTRATIVE EXAMPLE

A sample problem frequently cited in the GT literature was solved using the proposed algorithm. This problem was also solved by using the similarity coefficient method. The problem involves 16 machines and 43 parts and the data set is generated by a simulation program. The production data developed by the simulation is given in Appendix A.

Identifying Key Machines

For identifying the first key machine, step one of the developed procedure was performed, Table 1 was used to identify machine processing maximum number of parts. From Table 1, machines M6 and M8 perform twenty three parts, machine M6 was selected as it performs higher number of operations. Thus machine M6 was the first key machine, and assigned to cell C1.

Step 2 of the heuristic identified M8 as the next key machine, as it processes maximum number of parts which were not processed on machine M8. From Table 1 it can be determined that M8 process 12 parts which were not processed on machine M6. Thus, second key machine M8, was assigned to cell C2.

Table 1. Continued

M/C No.	Part Number												
	31	32	33	34	35	36	37	38	39	40	41	42	43
1							1					1	
2		1					1			1		1	
3				1	1	1							
4													
5			1								1		1
6		1	1	1			1		1			1	
7													
8	1						1	1		1		1	
9		1					1	1		1		1	
10		1							1				
11	1												
12													
13													
14					1								
15											1		1
16			1				1	1				1	

Table 1. The Machine-Componei. .rt for a 16-machine and 43-part Problem (Gupta and Seifoddini).

M/C No.	Part Number																													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1																														
2		1								1																		1		
3							1										1													
4					1				1					1					1		1		1						1	
5					1			1	1					1	1	1			1			1	1						1	
6	1	1				1	1	1				1	1	1			1		1				1							
7	1												1												1					
8	1	1	1					1	1		1	1			1				1	1	1		1	1			1	1		
9		1		1						1								1										1		
10	1											1	1												1	1				
11			1						1											1					1			1		
12											1											1		1			1			1
13			1																					1						
14		1				1	1										1													
15					1			1											1		1									
16		1																1												

Step 2 was repeated to identify other three key machines. Five key machines for five cells were identified; key machines and cells formed are shown in Table 2

Table 2

Cells and key Machines Identified Using Proposed Algorithm

Cell Number	Key Machine
C1	M6
C2	M8
C3	M9
C4	M5
C5	M3

Next step was developing the simulation model. In this particular case, the main objective was to evaluate the makespan of parts in the system at each intermediate design step. That was to evaluate the total time taken by each part to get processed completely. The production data shown in Appendix A was used for developing the simulation model. Assumptions were made as mentioned in the assumptions section. The next step was to develop a simulation model. This was done using the software, Simfactory.

The sample output for the developed model is given in the appendix C.

Clustering Stage

After selecting the key machines, parts completely processable at this step were identified and allotted to part family. Part number of selected parts' are 06, 17, 11, 22, 18, 7, 29, 14, 23, 26, 31, 12, 28, 40, 41, 33, 43. Next step in the heuristic was identifying the machine, processing maximum parts and same parts not requiring already grouped machines. From Table 1, machine M10 performs five (five parts was maximum number, compared to other machines) parts which were not processed on already selected key machines. Thus, machine M10 was selected as next machine to come into the simulation model. The next step performed was assigning the machine M10 to suitable cells, running simulation, and recording the makespan time of parts. The output of simulation run are shown in Table 3. Alternative making high makespan are entered as "X" in Table 3. From Table 3, by assigning M10 to C1, total makespan of all parts in system is 287 hours and changing position to C2 the makespan recorded is 268 hours. Thus, machine M10 was allotted to cell C2 and parts were allotted on the basis of intracellular moves. Table 3. shows total makespan made by each machine, by allotting to different cells. Similar procedure was followed for grouping all remaining machines and parts. The final results (machine cells and associated part family) attained using the developed heuristic procedure is given in Table 4.

Table 3

Total Average Makespan Time in Hours Made by Parts in Different Alternative Cells

Machine	C1	C2	C3	C4	C5
M10	287	268	X	X	X
M15	643	633	X	640	X
M4	1510	1678	X	1546	X
M14	1859	X	X	X	1859
M7	2283	2189	X	X	X
M2	2266	X	2153	X	X
M16	3170	X	3130	X	X
M1	X	X	3465	X	X
M11	X	4231	X	3515	X
M13	X	3865	X	3958	X
M12	X	4604	X	4705	X

Table 4
Machine Cells and Associated Parts Family for
Problem 1 using Proposed Algorithm

Cell Number	Machine Members	Part Number
C1	4, 6, 14	06, 14, 19, 23, 29,
C2	7, 8, 10, 13	01, 03, 08, 11, 12, 13, 15, 24, 25, 26, 31, 39
C3	1, 2, 9, 12, 16	02, 04, 10, 18, 28, 32, 37, 38, 40, 42
C4	5, 11, 15	05, 09, 16, 20, 21, 22, 27, 30, 33, 41, 43
C5	3	07, 17, 34, 35, 36

Appendix C

Simulation Sample Output Summary Report

PROFINAL Summary Part Status Report
(Data collected for +5E+005 MINUTES in 4 replications)
Degree of Confidence - 95.0%

Final Products

Part Name	Statistic	Number Made	Product Make Span Minimum	Product Make Span Average	Product Make Span Maximum
P01MAC6B	Mean	1.00	8625.00	9036.25	9875.00
	Std. Dev.	0.00		589.36	
	Lower C.I.	1.00		8342.87	
	Upper C.I.	1.00		9729.63	
P02MAC2SB	Mean	1.00	17207.50	18493.75	20717.50
	Std. Dev.	0.00		1670.88	
	Lower C.I.	1.00		16527.96	
	Upper C.I.	1.00		20459.54	
P03MAC8B	Mean	1.00	9767.50	10791.88	12040.00
	Std. Dev.	0.00		1150.19	
	Lower C.I.	1.00		9438.68	
	Upper C.I.	1.00		12145.07	
P04RMAC9B	Mean	1.00	340.00	340.00	340.00
	Std. Dev.	0.00		0.00	
	Lower C.I.	1.00		340.00	
	Upper C.I.	1.00		340.00	
P05MAC4B	Mean	1.00	11620.00	12406.25	13220.00
	Std. Dev.	0.00		874.85	
	Lower C.I.	1.00		11376.99	
	Upper C.I.	1.00		13435.51	
P06MAC14B	Mean	1.00	3340.00	3340.00	3340.00
	Std. Dev.	0.00		0.00	
	Lower C.I.	1.00		3340.00	
	Upper C.I.	1.00		3340.00	
P07MAC3B	Mean	1.00	4465.00	5958.75	8435.00
	Std. Dev.	0.00		1719.08	
	Lower C.I.	1.00		3936.25	
	Upper C.I.	1.00		7981.25	
P08MAC6B	Mean	1.00	1575.00	3718.12	4472.50
	Std. Dev.	0.00		1429.03	
	Lower C.I.	1.00		2036.87	
	Upper C.I.	1.00		5399.38	
P09MAC4SB	Mean	1.00	7800.00	15733.12	23752.50

		Std. Dev.		0.00	6522.56	
		Lower C.I.		1.00	8059.33	
		Upper C.I.		1.00	23406.92	
P10MAC16B	Mean		1.00	1700.00	2033.75	2445.00
		Std. Dev.		0.00	307.53	
		Lower C.I.		1.00	1671.94	
		Upper C.I.		1.00	2395.56	
P11MAC12B	Mean		1.00	5125.00	5125.00	5125.00
		Std. Dev.		0.00	0.00	
		Lower C.I.		1.00	5125.00	
		Upper C.I.		1.00	5125.00	
P12MAC8B	Mean		1.00	3340.00	3822.50	5270.00
		Std. Dev.		0.00	965.00	
		Lower C.I.		1.00	2687.18	
		Upper C.I.		1.00	4957.82	
P13MAC10B	Mean		1.00	4270.00	4332.50	4520.00
		Std. Dev.		0.00	125.01	
		Lower C.I.		1.00	4185.43	
		Upper C.I.		1.00	4479.57	
P14MAC6SB	Mean		1.00	1410.00	3907.50	7805.00
		Std. Dev.		0.00	2818.75	
		Lower C.I.		1.00	591.24	
		Upper C.I.		1.00	7223.76	
P15MAC8B	Mean		1.00	6750.00	7256.25	8030.00
		Std. Dev.		0.00	552.59	
		Lower C.I.		1.00	6606.13	
		Upper C.I.		1.00	7906.37	
P16RMAC5B	Mean		1.00	400.00	400.00	400.00
		Std. Dev.		0.00	0.00	
		Lower C.I.		1.00	400.00	
		Upper C.I.		1.00	400.00	
P17MAC3SB	Mean		1.00	7220.00	7793.12	8557.50
		Std. Dev.		0.00	557.72	
		Lower C.I.		1.00	7136.97	
		Upper C.I.		1.00	8449.28	
P18MAC16B	Mean		1.00	2930.00	2930.00	2930.00
		Std. Dev.		0.00	0.00	
		Lower C.I.		1.00	2930.00	
		Upper C.I.		1.00	2930.00	
P19MAC15B	Mean		1.00	6942.50	9057.50	10310.00
		Std. Dev.		0.00	1490.44	

		Lower C.I.		1.00		7304.00
		Upper C.I.		1.00		10811.00
P20MAC11B	Mean		1.00	1185.00	1266.25	1510.00
		Std. Dev.		0.00		162.50
		Lower C.I.		1.00		1075.07
		Upper C.I.		1.00		1457.43
P21MAC4SB	Mean		1.00	9180.00	12370.63	18017.50
		Std. Dev.		0.00		3936.44
		Lower C.I.		1.00		7739.40
		Upper C.I.		1.00		17001.85
P22MAC12B	Mean		1.00	1290.00	1330.00	1370.00
		Std. Dev.		0.00		46.19
		Lower C.I.		1.00		1275.66
		Upper C.I.		1.00		1384.34
P23MAC8B	Mean		1.00	14670.00	17569.38	20557.50
		Std. Dev.		0.00		3259.10
		Lower C.I.		1.00		13735.04
		Upper C.I.		1.00		21403.71
P24MAC8SB	Mean		1.00	3910.00	4392.50	5840.00
		Std. Dev.		0.00		965.00
		Lower C.I.		1.00		3257.18
		Upper C.I.		1.00		5527.82
P25MAC10B	Mean		1.00	387.50	387.50	387.50
		Std. Dev.		0.00		0.00
		Lower C.I.		1.00		387.50
		Upper C.I.		1.00		387.50
P26RMAC10B	Mean		1.00	180.00	180.00	180.00
		Std. Dev.		0.00		0.00
		Lower C.I.		1.00		180.00
		Upper C.I.		1.00		180.00
P27MAC8B	Mean		1.00	12105.00	13176.25	15615.00
		Std. Dev.		0.00		1639.37
		Lower C.I.		1.00		11247.53
		Upper C.I.		1.00		15104.97
P28MAC8B	Mean		1.00	8377.50	10068.75	11607.50
		Std. Dev.		0.00		1329.06
		Lower C.I.		1.00		8505.11
		Upper C.I.		1.00		11632.39
P29MAC5B	Mean		1.00	8310.00	8310.00	8310.00
		Std. Dev.		0.00		0.00
		Lower C.I.		1.00		8310.00

		Upper C.I.	1.00			8310.00
P30MAC12B	Mean		1.00	1610.00	1692.50	1775.00
		Std. Dev.	0.00			95.26
		Lower C.I.	1.00			1580.42
		Upper C.I.	1.00			1804.58
P31MAC10B	Mean		1.00	487.50	487.50	487.50
		Std. Dev.	0.00			0.00
		Lower C.I.	1.00			487.50
		Upper C.I.	1.00			487.50
P32MAC9SB	Mean		1.00	8095.00	8563.75	9360.00
		Std. Dev.	0.00			561.30
		Lower C.I.	1.00			7903.39
		Upper C.I.	1.00			9224.11
P33MAC5SB	Mean		1.00	5412.50	6032.50	6547.50
		Std. Dev.	0.00			532.43
		Lower C.I.	1.00			5406.10
		Upper C.I.	1.00			6658.90
P34MAC6B	Mean		1.00	4125.00	4125.00	4125.00
		Std. Dev.	0.00			0.00
		Lower C.I.	1.00			4125.00
		Upper C.I.	1.00			4125.00
P35MAC3B	Mean		1.00	3327.50	3752.50	4177.50
		Std. Dev.	0.00			490.75
		Lower C.I.	1.00			3175.14
		Upper C.I.	1.00			4329.86
P36RMAC3B	Mean		1.00	500.00	500.00	500.00
		Std. Dev.	0.00			0.00
		Lower C.I.	1.00			500.00
		Upper C.I.	1.00			500.00
P37MAC9SB	Mean		1.00	13372.50	15076.25	18455.00
		Std. Dev.	0.00			2360.73
		Lower C.I.	1.00			12298.85
		Upper C.I.	1.00			17853.65
P38MAC9SB	Mean		1.00	10642.50	11305.00	12655.00
		Std. Dev.	0.00			912.48
		Lower C.I.	1.00			10231.46
		Upper C.I.	1.00			12378.54
P39MAC10B	Mean		1.00	3960.00	3960.00	3960.00
		Std. Dev.	0.00			0.00
		Lower C.I.	1.00			3960.00
		Upper C.I.	1.00			3960.00

P40MAC9SB	Mean		1.00	3820.00	4440.63	5987.50
		Std. Dev.	0.00		1035.50	
		Lower C.I.	1.00		3222.36	
		Upper C.I.	1.00		5658.89	
P41MAC15B	Mean		1.00	7840.00	8685.00	9295.00
		Std. Dev.	0.00		644.56	
		Lower C.I.	1.00		7926.68	
		Upper C.I.	1.00		9443.32	
P42MAC1SB	Mean		1.00	9337.50	10378.13	11327.50
		Std. Dev.	0.00		829.35	
		Lower C.I.	1.00		9402.40	
		Upper C.I.	1.00		11353.85	
P43MACSB	Mean		1.00	10635.00	10800.62	10992.50
		Std. Dev.	0.00		149.15	
		Lower C.I.	1.00		10625.15	
		Upper C.I.	1.00		10976.10	

GUPTAFIN Summary Part Status Report
(Data collected for +5E+005 MINUTES in 4 replications)
Degree of Confidence - 95.0%

Final Products					
		Number	---- Product Make Span -----		
Part Name	Statistic	Made	Minimum	Average	Maximum
P01MAC6B	Mean	1.00	8030.00	9169.37	10302.50
	Std. Dev.	0.00		1106.04	
	Lower C.I.	1.00		7868.12	
	Upper C.I.	1.00		10470.63	
P02MAC2SB	Mean	1.00	17207.50	17995.00	18782.50
	Std. Dev.	0.00		909.33	
	Lower C.I.	1.00		16925.17	
	Upper C.I.	1.00		19064.83	
P03MAC8B	Mean	1.00	9507.50	10931.25	12262.50
	Std. Dev.	0.00		1186.98	
	Lower C.I.	1.00		9534.77	
	Upper C.I.	1.00		12327.73	
P04RMAC9B	Mean	1.00	340.00	340.00	340.00
	Std. Dev.	0.00		0.00	
	Lower C.I.	1.00		340.00	
	Upper C.I.	1.00		340.00	
P05MAC4B	Mean	1.00	11680.00	12880.00	13280.00
	Std. Dev.	0.00		800.00	
	Lower C.I.	1.00		11938.80	
	Upper C.I.	1.00		13821.20	
P06MAC14B	Mean	1.00	3340.00	3340.00	3340.00
	Std. Dev.	0.00		0.00	
	Lower C.I.	1.00		3340.00	
	Upper C.I.	1.00		3340.00	
P07MAC3B	Mean	1.00	5307.50	5996.87	7865.00
	Std. Dev.	0.00		1248.98	
	Lower C.I.	1.00		4527.45	
	Upper C.I.	1.00		7466.30	
P08MAC6B	Mean	1.00	2485.00	4305.62	5012.50

	Std. Dev.		0.00		1221.96
	Lower C.I.		1.00		2867.99
	Upper C.I.		1.00		5743.26
P09MAC4SB	Mean	1.00	8970.00	15291.87	19132.50
	Std. Dev.		0.00		4523.50
	Lower C.I.		1.00		9969.98
	Upper C.I.		1.00		20613.77
P10MAC16B	Mean	1.00	2105.00	2225.00	2405.00
	Std. Dev.		0.00		146.97
	Lower C.I.		1.00		2052.09
	Upper C.I.		1.00		2397.91
P11MAC12B	Mean	1.00	5155.00	5155.00	5155.00
	Std. Dev.		0.00		0.00
	Lower C.I.		1.00		5155.00
	Upper C.I.		1.00		5155.00
P12MAC8B	Mean	1.00	3280.00	4170.00	6840.00
	Std. Dev.		0.00		1780.00
	Lower C.I.		1.00		2075.83
	Upper C.I.		1.00		6264.17
P13MAC10B	Mean	1.00	4400.00	4400.00	4400.00
	Std. Dev.		0.00		0.00
	Lower C.I.		1.00		4400.00
	Upper C.I.		1.00		4400.00
P14MAC6SB	Mean	1.00	1470.00	3051.87	3672.50
	Std. Dev.		0.00		1056.65
	Lower C.I.		1.00		1808.73
	Upper C.I.		1.00		4295.02
P15MAC8B	Mean	1.00	6535.00	6887.50	7850.00
	Std. Dev.		0.00		643.22
	Lower C.I.		1.00		6130.75
	Upper C.I.		1.00		7644.25
P16RMAC5B	Mean	1.00	400.00	400.00	400.00
	Std. Dev.		0.00		0.00
	Lower C.I.		1.00		400.00
	Upper C.I.		1.00		400.00
P17MAC3SB	Mean	1.00	7160.00	7493.75	7605.00
	Std. Dev.		0.00		222.50

	Lower C.I.		1.00			7231.97	
	Upper C.I.		1.00			7755.53	
P18MAC16B	Mean	1.00		2930.00	2930.00		2930.00
	Std. Dev.		0.00			0.00	
	Lower C.I.		1.00			2930.00	
	Upper C.I.		1.00			2930.00	
P19MAC15B	Mean	1.00		8890.00	10445.00		11330.00
	Std. Dev.		0.00			1159.12	
	Lower C.I.		1.00			9081.29	
	Upper C.I.		1.00			11808.71	
P20MAC11B	Mean	1.00		1125.00	1551.25		2830.00
	Std. Dev.		0.00			852.50	
	Lower C.I.		1.00			548.28	
	Upper C.I.		1.00			2554.22	
P21MAC4SB	Mean	1.00		12040.00	13796.88		18767.50
	Std. Dev.		0.00			3316.77	
	Lower C.I.		1.00			9894.70	
	Upper C.I.		1.00			17699.05	
P22MAC12B	Mean	1.00		1290.00	1290.00		1290.00
	Std. Dev.		0.00			0.00	
	Lower C.I.		1.00			1290.00	
	Upper C.I.		1.00			1290.00	
P23MAC8B	Mean	1.00		14470.00	19178.12		20902.50
	Std. Dev.		0.00			3146.40	
	Lower C.I.		1.00			15476.39	
	Upper C.I.		1.00			22879.86	
P24MAC8SB	Mean	1.00		3910.00	4800.00		7470.00
	Std. Dev.		0.00			1780.00	
	Lower C.I.		1.00			2705.83	
	Upper C.I.		1.00			6894.17	
P25MAC10B	Mean	1.00		447.50	447.50		447.50
	Std. Dev.		0.00			0.00	
	Lower C.I.		1.00			447.50	
	Upper C.I.		1.00			447.50	
P26RMAC10B	Mean	1.00		180.00	180.00		180.00
	Std. Dev.		0.00			0.00	
	Lower C.I.		1.00			180.00	
	Upper C.I.		1.00			180.00	

P27MAC8B	Mean		1.00	12105.00	12348.75	12560.00
		Std. Dev.		0.00		186.72
		Lower C.I.		1.00		12129.07
		Upper C.I.		1.00		12568.43
P28MAC8B	Mean		1.00	9852.50	10040.00	10227.50
		Std. Dev.		0.00		153.08
		Lower C.I.		1.00		9859.90
		Upper C.I.		1.00		10220.10
P29MAC5B	Mean		1.00	8250.00	8250.00	8250.00
		Std. Dev.		0.00		0.00
		Lower C.I.		1.00		8250.00
		Upper C.I.		1.00		8250.00
P30MAC12B	Mean		1.00	1610.00	1733.75	1775.00
		Std. Dev.		0.00		82.50
		Lower C.I.		1.00		1636.69
		Upper C.I.		1.00		1830.81
P31MAC10B	Mean		1.00	547.50	547.50	547.50
		Std. Dev.		0.00		0.00
		Lower C.I.		1.00		547.50
		Upper C.I.		1.00		547.50
P32MAC9SB	Mean		1.00	8095.00	8513.13	8680.00
		Std. Dev.		0.00		281.44
		Lower C.I.		1.00		8182.01
		Upper C.I.		1.00		8844.24
P33MAC5SB	Mean		1.00	5772.50	6043.12	6510.00
		Std. Dev.		0.00		351.18
		Lower C.I.		1.00		5629.96
		Upper C.I.		1.00		6456.29
P34MAC6B	Mean		1.00	4125.00	4125.00	4125.00
		Std. Dev.		0.00		0.00
		Lower C.I.		1.00		4125.00
		Upper C.I.		1.00		4125.00
P35MAC3B	Mean		1.00	3267.50	3480.00	4117.50
		Std. Dev.		0.00		425.00
		Lower C.I.		1.00		2979.99
		Upper C.I.		1.00		3980.01
P36RMAC3B	Mean		1.00	500.00	500.00	500.00
		Std. Dev.		0.00		0.00

		Lower C.I.		1.00		500.00
		Upper C.I.		1.00		500.00
P37MAC9SB	Mean		1.00	11252.50	13468.13	15107.50
		Std. Dev.		0.00		1904.50
		Lower C.I.		1.00		11227.49
		Upper C.I.		1.00		15708.76
P38MAC9SB	Mean		1.00	10842.50	11433.75	12417.50
		Std. Dev.		0.00		704.50
		Lower C.I.		1.00		10604.90
		Upper C.I.		1.00		12262.60
P39MAC10B	Mean		1.00	3900.00	3900.00	3900.00
		Std. Dev.		0.00		0.00
		Lower C.I.		1.00		3900.00
		Upper C.I.		1.00		3900.00
P40MAC9SB	Mean		1.00	4102.50	4521.25	4967.50
		Std. Dev.		0.00		484.05
		Lower C.I.		1.00		3951.76
		Upper C.I.		1.00		5090.74
P41MAC15B	Mean		1.00	7780.00	8143.75	8530.00
		Std. Dev.		0.00		420.43
		Lower C.I.		1.00		7649.12
		Upper C.I.		1.00		8638.38
P42MAC1SB	Mean		1.00	9337.50	9642.50	10557.50
		Std. Dev.		0.00		610.00
		Lower C.I.		1.00		8924.84
		Upper C.I.		1.00		10360.16
P43MACSB	Mean		1.00	10255.00	11346.25	12800.00
		Std. Dev.		0.00		1071.16
		Lower C.I.		1.00		10086.04
		Upper C.I.		1.00		12606.46

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