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Evaluating Process Plan Selection Trade-offs for Cellular Manufacturing

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ABSTRACT

Solving the process plan selection problem is one of the prerequisites in the design of cellular manufacturing systems even though part routings are often assumed to be given in the literature. In this paper, a mixed integer program was developed to select a single or multiple routes for parts in order to evaluate trade-offs between the total system workload and volume of intercell movement. Manufacturing cells were formed with the objective of minimizing the intercell material movement. Alternatives for the total system workload and volume of intercell material movement constitute a decision problem for which the most suitable one for the system has to be chosen. A sample problem is given to illustrate the decision process.

Key words: Total workload, process plan selection, cell formation

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INTRODUCTION

Solving the process plan selection problem is one of the prerequisites in the design of cellular manufacturing systems even though part routings are often assumed to be given in the literature. Given the versatile features of today's machines/workstations, it is possible to process parts using alternative routes. Process plan selection problem could be solved by choosing a unique route for each part as well as distributing the demand among alternative routes. Having specified route/routes, the next step is to form manufacturing cells with the objective of minimizing the total intercell material movement. There are many research papers published in the area of cellular manufacturing systems. In majority of these papers, static routings were assumed for parts for which the cell formation was performed. For background information, a useful taxonomy is to give a review for process plan selection problem first followed by cell formation problem in the presence of alternative process plans. Linear programming models are often used for the process plan selection problem. A mixed-integer programming model to select among alternative process plans was developed [1]. The total workload of the system including setup and processing times was minimized under machining capacity, available setup time and demand constraints. An algorithm was developed to evaluate cell formation trade-offs when using alternative process plans. Selecting a part mix was also studied in many research papers in the literature. The problem of process plan selection considering part mix and production volume was studied [2]. Machine capacity constraints were often considered when choosing among alternative process plans. A model where machine capacity constraints considered for selecting among alternative process plans [3]. Alternative process plans were often considered. A route selection problem for cell formation under alternative process plans wasstudied [4]. Some models combined the process plan selection and cell formation. An integrated approach using group technology, process planning and cell formation with an application in a health system was studied [5].Machine loading issue was also considered in the literature. A model for cell formation and machine loading in the presence of alternative process plans was developed [6]. Parallel machines were considered in some research papers. A heuristic for cell formation was developed when there are alternative (parallel) machines and alternative routings [7]. Aggregation was also investigated in the literature. The process plan selection problem in three dimensions; time/order, variability/alternatives, and aggregation was considered [8]. Machine replication was considered in some research papers. An algorithm for cell formation was developed considering machine replications and alternative process plans [9]. The algorithm considers the problem of cellformation to minimize the sum of costs of intercell moves, machine investment and machine operating costs. A multi-criteria approach was developed to identify the number of cells formed considering setup cost, alternative process plans, and intercell movement [10]. A tree search method was developed for cell formation problem for which the location of machines were also determined using the quadratic assignment problem [11]. Cell formation under alternative routings was often studied in the literature. A method was proposed two p-median models for cell formation under alternative routings [12]. New measures of similarity between machine pairs were used; one with pre-specified number of cells and the other without the pre-specified number of cells. Part-machine relationships were considered in some research papers. A method in which a fuzzy part-feature and fuzzy feature-machine relationships was developed to establish the fuzzy part - machine relationship. A block seriation approach was used to perform the decomposition to form the cells [13]. Operation sequences are an important issue even though dependencies were not often considered. A two-stage method was developed for cell formation using operation sequences and production volume. In the first stage, a 0-1 linear program was solved to minimize the intercell flow, and in the second stage, part-machine processing matrix was formed reflecting parts requiring operation outside their cells [14]. Cells are formed using the matrix obtained in the second stage. Copies of tools and machines were considered in some research papers. A mixed integer program was formulated to form part/machine groups, to identify number of machines and number of copies of tools required with the objective of minimizing the overall system cost [15].

PROCESS PLAN SELECTION MODEL AND CELL FORMATION

A mixed-integer program was developed for process plan selection problem. Given a profile of product demand, machine resources, and processing requirements, product routings could be obtained through a machine resource minimizing model as follows:

$$Min \sum_{p=1}^{P}\sum_{m=1}^{M}\sum_{r=1}^{R_p}\left[s_{pmr} + d_p t_{pmr}\right]x_{pr} \qquad (1)$$

s.t.

$$\sum_{p=1}^{P}\sum_{r=1}^{R_p} x_{pr} = 1 \qquad (2)$$

$$\sum_{p=1}^{P}\sum_{m=1}^{M}\sum_{r=1}^{R_p} s_{pmr}x_{pr} \le s_m \qquad (3)$$

$$\sum_{p=1}^{P}\sum_{r=1}^{R_p}\left[d_p t_{pmr}\right]x_{pr} \le h_m \qquad (4)$$

$$x_{pr} = 0 \text{ or } 1 \qquad (5)$$

where,

$p = 1,\ldots,P$	index set of parts produced
$m = 1,\ldots,M$	index set of machines available
$r = 1, \ldots, R_p$	index set of process plans available for producing part *p*
s_{pmr}	the setup time for part *p*on machine type *m* with process plan *r*
$d = 1,\ldots,D$	index set of demand for part *p*during the planning period
t_{pmr}	the processing time per unit for part pon machine type *m* with process plan *r*
x_{pr}	the binary decision variable where lindicates that routing *r* is used for part *p*during the planning period and 0 otherwise
h_m	the total number of machine hours available during the planning period for machine type *m*
s_m	an upper limit for total allowable setup time on machine *m*

The objective function minimizes the total workload of the system including total setup and processing times. Equation 2 makes sure that only one process plan is selected for every part. Equation 3 ensures that the upper limit for total setup times on each machine is not violated. Finally, the capacity constraint is satisfied by equation 4. This model provides for local optimization of capital costs as a starting point in system design and yields an initial set of routings. The model assumes that all units of a given part are manufactured through a single routing on a single production run and that setup times are not sequence dependent. Each of these assumptions could be relaxed by appropriate modifications of the formulation and/or data. For example, the assumption that each part is processed using a single route could be relaxed by removing equation 5. In this case, it is possible to distribute the demand for each part among available routes. This relaxation provides total workload trade-offs.

The results of the first phase of system design yield a lower bound on total machine requirements by type and the part machine processing matrix used in cell formation. Using the outputs of the routing model, the CMS design procedure generates machine groupings using the well known the rank order clustering technique (ROC). There are two alternatives from the result of the routing model, one with single route for each part and the case where the demand for some parts is distributed among alternative routes. In this case, parts are split and considered as if there are more than one part to form the part-machine processing matrix.

Sample Problem

A sample problem of 20 parts and 20 machines was used. Table 1 illustrates parts, available routes, and unit loads. The setup times for parts on machines are uniformly generated over the interval 2 and 3.7 min. The processing times for operations are also uniformly generated over the interval 2 and 3.5 min. The machine capacities are given as 14,400 minutes for the given planning period, and the demand for each part is 550 units. Each machine is restricted to have a maximum of 35 minutes setup time. It is possible to generate 186,624 possible different manufacturing scenarios for the problem of all possible routings is considered. However, it is not practical to solve for all cell/machine location problems due to the immense computing time needed.

Table -1 Part routings

Part	Route 1	Route 2	Route 3	Unit Load
1	19-1-3-5-4-2-15-14-13-11-10	6-5-4-3-2-1-8-12-11-10-15-18-17-10-20	20-18-2-4-3-7-5-14-6-16-9-8	2
2	3-20-10-9-8-6-5-4-14	5-4-2-1-9-11-13-19-17-18-16		3
3	13-15-16-20-19-18-6-3-1-5			1
4	3-20-1-2-7-8-10-14-17-18-19	4-8-10-12-13-14-7-15-16-6-19		2
5	20-17-1-2-3-4-6-12-14-18-17-19	20-2-6-13-12-18-17-19	2-3-4-8-7-11-10-13-15-14-19-18	1
6	18-4-6-7-8-9-10-15-13-19-20	5-3-1-8-10-16-19-18		2
7	1-2-3-6-5-8-13-16-20-17			2
8	1-2-3-4-7-6-10-15-14-13-12-20-19	20-16-15-11-9-10-4-2-3-1	10-8-6-4-2-1-19-15-18	3
9	1-2-4-5-6-7-10-9-13-14-12-16-19	19-14-13-12-11-8-6-3		3
10	20-3-7-6-5-9-10-16-18-17			1
11	20-17-1-5-6-7-8-12-19-18	9-3-6-8-14-17-19-20		2
12	4-3-7-6-11-12-10-13-19	20-7-6-4-10-11-12-15-14	8-7-4-5-12-11-16-17-18	2
13	2-5-1-9-10-8-15-13-12-18-19-20			2
14	15-14-17-16-2-4-6-7-10-11-8-9	19-4-17-18-13-6	3-4-5-6-8-10-9-11-19-18-15-17-16	4
15	2-1-7-6-10-11-12-13-18-20	2-1-4-6-7-8-9-10-11-13-20-17-19-18		3
16	3-1-7-8-9-10-14-13-16	2-3-7-5-9-11-20-14	1-5-6-11-8-9-10-17-19-13	5
17	1-2-4-5-3-13-8-16-20-19-18			4
18	17-20-13-14-15-16-11-10-9-2-5-20	1-2-3-4-5-8-7-10-13-14-15-17-19		3
19	5-4-3-2-1-7-8-19-18-9-15			3
20	3-2-1-6-5-10-11-12-15-16-20-18-19	5-1-7-10-14-12-15-18		2

The mixed-integer program that was introduced above was used to solve the process plan selection problem. The problem was formulated using AMPL [16] and solved with CPLEX solver. Table 2 and Table 3 shows selected routes when using a single route and distributed on different routes respectively. The objective function value is 610,334.046 min. for the single route problem. When the demand is distributed among alternative routes, the objective function value becomes 602,868.30 min. We see that there is a saving of 7465.75 min when we distribute the demand over different routes.

Table -2 Selected single process plans for each part

Part	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
P.Plan	3	2	1	2	1	1	1	1	2	1	2	3	1	1	1	1	1	1	1	2

Legend: P.Plan = Process Plan

Table -3 Distributed process plans for each part

Part/Route	Route1 (%)	Route-2 (%)	Route-3 (%)
1			100
2	14	86	
3	100		
4		100	
5			100
6		100	
7	100		
8	50	40	10
9	71	29	
10	100		
11		100	
12		70	30
13	100		
14	25	75	
15	100		
16	16	66	18
17	100		
18	100		
19	100		
20	100		

We now need to solve the cell formation problem using selected routes for the two cases. The rank order clustering algorithm was used to form cells as mentioned previously. For the case of single route for each part, the selected process plans are transformed into a part machine processing matrix. Parts are split and treated as a separate part with the corresponding percentage if there is more than one route is used. Table 4 and 5 show machine cells for single route and multiple routes respectively. There are a total of 28 parts for the case of multiple route consideration.

Table -4 Formed cells and machines for single route for each part

Cells	Machines in Cells
1	1, 2, 3, 19, 4
2	18,5, 16, 8, 7
3	9, 20, 12, 13, 6
4	14, 10, 15, 17, 11

Table -5 Formed cells and machines for multiple routes

Cells	Machines in Cells
1	10, 12, 3, 4, 6
2	1, 5, 8, 11, 9
3	2, 20, 18, 7, 14
4	16, 17, 19, 15, 13

The total intercell movement for the single route case is 351 unit loads per hour whereas it is 383 unit loads for the case of multiple routes. We see that there is a decrease of 32 unit loads per hour when we select a single route for each part. The trade-off between total workload of the system and the total intercell movement needs to be carefully analysed. A clear comparison can be made if the total workload savings and the decrease in total intercell movement can be translated into a monetary value. Assuming a trivial number for conversion unit may result in a biased decision. One useful method of comparing these two values can be the fact that only 5% of a product’s life span is spent in manufacturing. Given that there is enough machining capacity, one may consider to choose an option for which there is less material movement. On the other hand, the minimum workload of the system may be chosen If the flow time is a more important issue than material movement.

CONCLUSION

Process plan selection and cell formation are two important issues in the design of cellular manufacturing systems. There are many trade-offs arise between these two when a detailed design is considered including machining capacity, tools and fixtures, setup times, volume of intercell movement, storage spaces etc. The total workload of the system and the volume of intercell movement are considered in order to decide on the way the process plans are selected. It is expected that there would be a lower total workload when the demand of some parts are distributed among alternative routes. The saving is a result of less setup and processing time for parts. When a single route is selected for a part, the decision variable is fixed and potential savings in setup and processing times are missed. Moreover, machines may result in lower utilizations. On the other hand, the flow time may be higher when multiple routes for some parts are chosen. In order to make a clear evaluation of trade-offs, savings in total workload and intercell movement have to be in a monetary value. That is, a conversion unit for the total workload and the cost of unit material movement need to be determined. Assuming a trivial number for conversion may result in a biased decision. There are cases where savings in workload may be preferable to reduction in intercell movement. In such cases, a higher utilization of the intercell material handling equipment may be considered. The flow time may be a more important issue in some cases, that is, given that there is not much flexibility for product completion times, reductions in the total workload gain importance. If there is ample machining capacity, the decision maker might choose the option of less workload over reduction in intercell material movement considering that only 5% of a product’s life span is spent in actual manufacturing. When the cost of intercell material movement is high compare to the processing costs, then the decision maker is more likely to choose the option where there is less material movement. Moreover, congestions in the intercell material handling system may be avoided. Such congestions often cause system shutdowns and starvation/blocking of machines. Consequently, the specific requirements of the system on hand would affect the decision.

REFERENCES

[1]. M. Kizil, and M.Ozbayrak, A tradeoff analysis between process plan selection and cell formation in cellular manufacturing. International Journal of Advanced Manufacturing Technology, 2004, 23 (7-8), 501-506.
[2]. Y. Seo, J. P. Egbelu, Process plan selection based on product mix and production volume, International Journal of Production Research,1996, 34 (9), 2639-2655.
[3]. C. Caux,. R. Bruniaux, and H. Pierreval, Cell formation with alternative process plans and machine capacity constraints: A new combined approach. International Journal of Production Economics, 2000, 64 (1-3), 279-284.
[4]. H. Hwang, P. Ree, Routes selection for the cell formation problem with alternative part process plans. Computers & Industrial Engineering, 1996, 30 (3), 423-431.
[5]. B. Malakooti, N.R Malakooti, and Z. Yang, Integrated group technology, cell formation, process planning, and production planning with application to the emergency room.International Journal of Production Research, 2004, 42 (9), 1769-1786.
[6]. S. Lozano, I. Eguia, and L. Onieva, Cell design and loading in the presence of alternative routing. International Journal of Production Research, 1999, 37 (14), 3289-3304.
[7]. A.M. Mukattash, M.B. Adil, and K.K. Tahboub, Heuristic approaches for part assignment in cell formation. Computers and Industrial Engineering, 2002, 42 (2-4), 329-341.
[8]. D.N. Sormaz, J. Arumugam, and Rajaraman, S. Integrative process plan model and representation for intelligent distributed manufacturing planning. International Journal of Production Research, 2004, 42 (17), 3397-3417.
[9]. S. Jayaswal, and G.K. Adil, Efficient algorithm for cell formation with sequence data, machine replications and alternative process routings. International Journal of Production Research, 2004, 42 (12), 2419-2433.
[10]. B.B. Malakooti, Z. Yang, Machine-part cell formation: A multi-criteria approach. Industrial Engineering Research - Conference Proceedings, 1997, 222-227.
[11]. K. Spiliopoulos, S. Sofianopoulou, Optimal tree search method for the manufacturing systems cell formation problem. European Journal of Operational Research. 1998, 105 (3), 537-551.
[12]. Y. Won, New p-median approach to cell formation with alternative process plans. International Journal of Production Research. 2000, 38 (1), 229-240.
[13]. B. Mutel, E. Ostrosi, Feature-based manufacturing cell formation using a fuzzy-set approach. International Journal of Computer Integrated Manufacturing, 2002, 15, (2), 152-167.
[14]. Y. Won, K.C. Lee, Group technology cell formation considering operation sequences and production volumes. International Journal of Production Research. 2001, 39 (13), 2755-2768.
[15]. A.K. Jain, R.G. Kasilingam, and S.D. Bhole, Cell formation in flexible manufacturing systems under resource constraints. Computers & Industrial Engineering, 1990, 19 (14), 437-441.
[16]. R. Fourer, D.M. Gay and W.B. Kernighan. AMPL: a modeling language for mathematical programming. Duxbury Press / Brooks/Cole Publishing Company, 1993