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An Intuitive Approach to Eliminate Congestions in Cellular Manufacturing Systems

Mevlut Kizil

Department of Industrial Engineering, Selçuk University, Turkey
mkizil@selcuk.edu.tr

ABSTRACT

The design steps of cellular manufacturing systems (CMS) are usually performed sequentially without considering interactions between stages. There needs to be a certain feedback among different parts of CMS design so that the system can be designed simultaneously for a better functionality. In this paper, an intuitive approach to eliminate congestions in CMS was developed. Part routings were determined by a machine resource minimizing model, machines were grouped to form cells, and a simulation analysis was performed to determine the effects of fixed part routings on cell formation and the material handling system. A procedure to eliminate congestions in the material handling system by intelligently altering part routings was proposed. A sample problem was solved. Numerical results indicate that the proposed procedure is effective.

Keywords: Process plan selection, automated guided vehicles, cellular manufacturing, materials handling systems, simulation

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INTRODUCTION

The design of cellular manufacturing systems (CMS) are usually performed sequentially without considering interactions between stages. There needs to be a certain feedback among different parts of CMS design so that the system can be designed simultaneously for a better functionality. Process plan selection is one of design steps that must be performed strategically in the design of (CMS) as it shapes the physical configuration and the operation of the system. Determining part routings is a part of process plan selection for which there are many criteria to be considered given that there are usually alternative ways of manufacturing parts. One of these criteria is the total work content that includes machine setup and processing times. The use of the work content criterion will ensure that the total workload of the system is minimized. However, part routings selected with this criterion may not result in an optimum solution for cell formation and a balanced operation of material handling system. The objective of this paper is to determine interactions among process plan selection, cell formation, and the performance of the material handling system. The suggested procedure determines part routings by minimizing the work content using a mixed-integer model, group machines to form cells by employing the well-known rank order clustering algorithm (ROC), investigates the effects of the selected process plans to the material handling system by a simulation model, and develops an intuitive approach to eliminate congestions in the material handling system. In the literature, the process plans were usually assumed to be given in a wide variety of research papers. Some authors have focused on distributing the demand among alternative routes without considering the effects of fixed part routings on other parts of the manufacturing system. Linear programming models are often used for the process plan selection problem. An approach was developed for integrated process planning and scheduling. A tabu search based method to integrate process planning and scheduling was studied [1]. Selection of process plans in automated manufacturing systems was studied [2]. A model was suggested for the process plan selection problem considering part mix and production volume [3]. A model was developed where only machine capacity constraints considered in selecting among alternative process plans [4]. Route selection problem for cell formation under alternative process plans was also studied in [5]. Some models combined the problem of 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 in [6]. A model was developed for cell formation and machine loading in the presence of alternative process plans [7]. Parallel machines were considered in some research papers. A heuristic was considered for cell formation when there are alternative (parallel) machines and alternative routings. They focused on assigning parts to cells after the cell formation problem is solved [8]. A process plan selection problem was studied in three dimensions; time/order, variability/alternatives, and aggregation [9]. An algorithm for cell formation was developed considering machine replications and alternative process plans in [10]. The algorithm considers the problem of cell formation to minimize the sum of costs of intercell moves, machine investment and machine operating costs. A multi-criteria approach was suggested to identify the number of cells formed considering setup cost, alternative process plans, and intercell movement [11]. A tree search method was developed for cell formation problem for which the location of machines were determined using the quadratic assignment problem [12]. A model was proposed two p-median models for cell formation under alternative routings. New measures of similarity between machine pairs were used; with/without prespecified number of cells [13]. In a model for which a fuzzy part-feature and fuzzy feature-machine relationships were used to establish the fuzzy part - machine relationship. A block seriation approach was used to perform the decomposition to form the cells [14]. A model was considered cell formation using operation sequences and production volume. A two stage method was applied. In the first stage, a 0-1 linear program is solved to minimize the intercell flow, and in the second stage, part-machine processing matrix is formed reflecting parts requiring operation outside their cells. Cells were formed using the matrix obatained in the second stage [15]. A model was formulated for process plan selection in designing automated manufacturing systems. An integrated approach was considered for the different segments of the process plan selection problem [16]. A genetic algorithm based multi objective model in which processing, setup, and material handling time minimized was also studied [17]. Dynamic cellular manufacturing systems, simulation models in cellular manufacturing systems, and layout problems were studied in various research papers [18-20]. An integrated approach for the cell formation and layout design in cellular manufacturing systems was offered [21]. A method to decrease cell load variation in dynamic cellular manufacturing systems was studied [22]. Cell formation is the process of identifying part families with similar processing requirements. A detailed review of the procedure can be found in [23-24]. A multi-objective simulation model to form machining cells in cellular manufacuring systems was also considered [25]. The next sections provide a model for the process plan selection, and an intuitive approach to eliminate congestions at load transfer stations. Sample problem and simulation analysis were given in section 3. In the final section, conclusions were discussed.

PROBLEM FORMULATION

The problem in this paper consist of designing a CMS considering interactions among process plan selection, cell formation, and material handling systems in the presence of alternative process plans. The manufacturing system consists of four machining cells as shown in figure 1. The material handling system is served by looping AGVs, and rotatable conveyors for the intercell and intracell handling respectively. A load transfer station is used for each cell as an interface between the intercell and the intracell handling system.

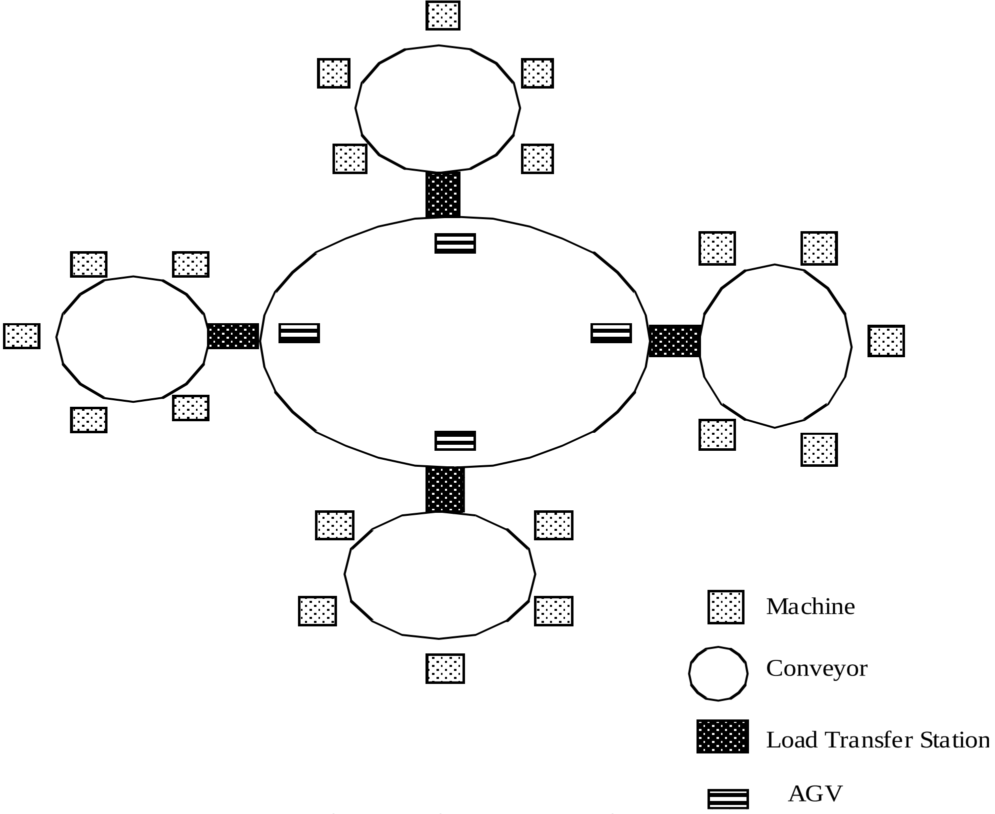

Fig. 1 Configuration of the cellular manufacturing system

Process Plan Selection Model

The process plan selection model in the presence of alternative process plans is developed under following assumptions.

Assumptions

- All units of a given part are manufactured in unit loads.
- Setup times are not sequence dependent.
- The capacities for machines are known and constant.
- The demands for parts are known and deterministic.
- The machines are universal and can perform variety of operations.

Notation

$p = 1,\ldots,P$	index set of parts
$m = 1,\ldots,M$	index set of machines
$r = 1, \ldots, R_p$	index set of process plans available for producing part *p*
s_{pmr}	the setup time for part *p* on machine type *m* in process plan *r*
$d_p = 1,\ldots,p$	index set of demand for part *p* during the planning period
t_{pmr}	the processing time for part p on machine type *m* with process plan *r*
x_{pr}	the binary decision variable where l indicates that routing *r* is used for part *p* during the planning period and 0 otherwise
c_m	the capacity of machine *m*
s_m	an upper limit for total allowable setup time on machine *m*

Mathematical Model

The linear mixed-integer model is presented as follows:

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

subject to

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

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

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

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

The objective function minimizes the total workload of the system which includes total processing and setup times. Equation (2) guarantees that only one process plan is selected for each part. Equation (3) ensures that the upper limit for total setup times on each machine is not violated. The machine capacity constraint is satisfied by equation (4). The binary decision variable x_{pr} is 1 if the process plan r is selected for part p and 0 otherwise. The next subsection covers the intuitive approach to eliminate congestions at transfer stations.

An Intuitive Approach to Eliminate Congestions at Load Transfer Stations

An intuitive approach was developed to eliminate congestions at load transfer stations by intelligently altering part routings with the objective of reducing total unit loads. It was assumed that there is sufficient machine resource capacity for any combination of alternative part routings. The procedure is given as follows:

Step 1 Select the cell with congested load transfer station
Step 2 Calculate total incoming unit loads to the cell, $\sum_{i=1}^{s} TIL_i$, for parts, 1,…s
Step 3 For every part, j=1..k, that visits the congested cell, check to see if an alternative route(s) is available, calculate incoming unit loads for all alternative routes, select the route with the lowest unit load, ATL_j
Step 4 If $\sum_{j=1}^{k} ATL_j < \sum_{i=1}^{s} TIL_i$, and
If setup and processing constraints violated, allocate sufficient resources for setup and processing times. Replace the current routes with the alternative routes.
Step 5 Verify that the load transfer station is not overloaded by running the simulation. If all cells with congested load transfer stations are evaluated, stop, otherwise go to Step 1.

Illustrative example

A randomly generated sample problem (SP) with 20 parts and 20 machines was solved here to demonstrate the design procedure. The data required for the process plan selection model includes part routings, part/machine incidence matrix for each route, setup times of machines, demand for parts, processing times, and machine capacities. Part routings are given in table 1. The setup times for machines are uniformly generated over the interval (2, 3.7) minutes. The processing times for machines are also uniformly generated over the interval (2, 3.5) minutes. The capacity for each machine is 3200 minutes for the given planning period, and the demand for each part is given in table 2. Each machine is restricted to have a maximum of 25 minutes' setup time. The process plan selection model was coded in AMPL [26] and solved by the CPLEX solver, the selected process plans for each part are presented in table 3.

Table -1 Part Routings

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

Table -2 Demand for Parts

Part	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Demand	95	125	105	135	140	120	140	150	95	85	90	105	125	135	90	130	85	75	100	110

Table -3 Selected Process Plans for Parts

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

Table -4 Formed cells

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

Table -6 Machine Cells after Route Changes

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

Table -5 Route Changes for Parts

Part	Previous Route Number	New Route Number	New Route Sequence
2	2	1	14-4-5-6-8-9-10-20-3
4	1	2	19-6-26-15-7-14-13-12-8-4
8	3	2	3-2-4-10-9-11-15-16-20
9	1	2	3-6-8-11-12-13-14-19
12	3	2	14-15-12-11-10-4-6-7-20
15	2	1	20-18-13-12-11-10-6-7-1-2

The optimum solution results with an objective function value of 106,934.89 minutes minimizing the total workload of the system including the total setup times for machines. The next step is to solve the cell formation problem based on the selected process plans. The part-machine processing matrix was generated. The ROC algorithm was used to form cells and the resulting machine cells were presented in table 4. The total intercell material movement with this solution is 308 unit loads. The next section covers the analysis of the material handling system by a simulation model to determine the effects of selected process plans and the formed cells to the material handling system.

Simulation Analysis of the Cellular System

A simulation model of the CMS was built and executed in SIMAN [27]. There are 4 looping AGVs with a speed of 180 feet/min., the perimeter of the intercell handling system is 360 feet. Each load transfer station has a capacity of 10 unit loads. It is assumed that the arrival rate for each part is uniformly distributed over the interval (50, 150) minutes. The processing times for machines are also uniformly distributed over the interval (2, 3.5) minutes, all unit loads are available at the beginning of the work cycle, and that the conveyors have enough capacity with negligible rotation times. The developed model was simulated for 200,000 time units and replicated 20 times. The initial 10,000 time units were considered as a warm-up period. Although the capacity of load transfer station was 10 unit loads, it was set to be infinite to determine if congestions occur. The simulation model was run and the results show that the maximum queue lengths at transfer stations reached a level of 7, 16, 9, and 8 unit loads for cells 1, 2, 3, and 4 respectively indicating that the load transfer station in cell 2 exceeded the capacity for 6 unit loads. The intuitive approach discussed in section 2 was used to eliminate this congestion. The number of intercell unit loads originally coming to cell 2 was 51 unit loads; it became 37 unit loads with 6 route changes by applying the steps of the intuitive approach. The resulting route changes were shown in table 5.

The total machine setup capacity was sufficient but the total machining capacity had to be increased 1047.12 minutes to obtain a feasible solution. The modified problem (MP) was formed by replacing the new routes to the previous process plan shown in table 3 and new cell formation problem was solved. Other input parameter values that were used in solving the problem (SP) remains the same. The simulation model was executed and the resulting maximum queue lengths at transfer stations became 8, 6, 9, and 7 unit loads for the cells 1, 2, 3, 4 respectively. The intuitive approach ensured that the load transfer station capacities for all cells were not violated. The difference in work contents between the SP and the MP problems was about 18 hours of processing time. Allowing extra 18 hours of machining time is favorable instead of having shutdowns in the material handling system. The result of cell formation for problem MP is given in table 6.

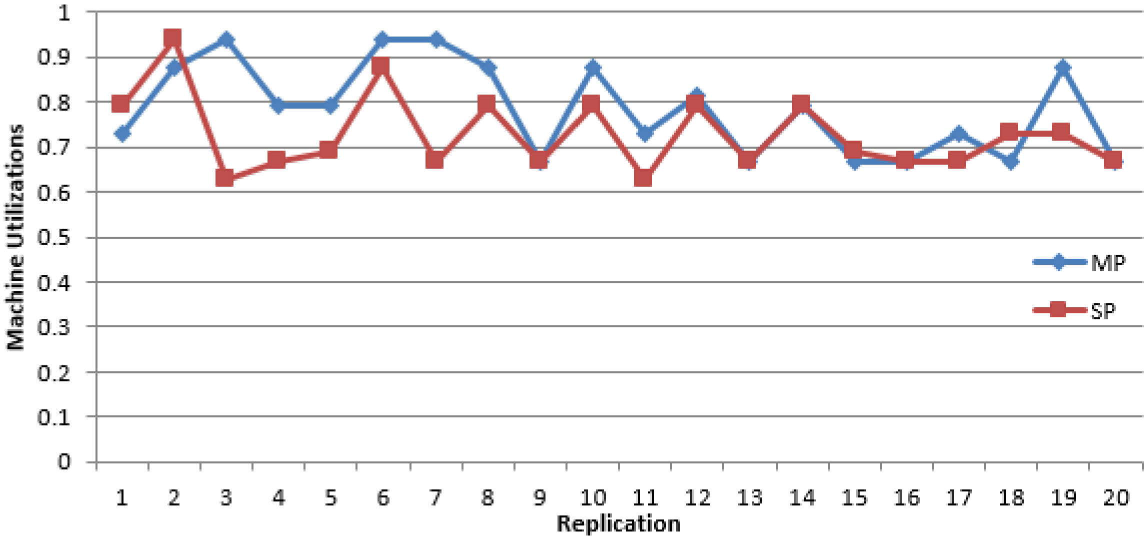

Fig. 2 Average machine utilizations

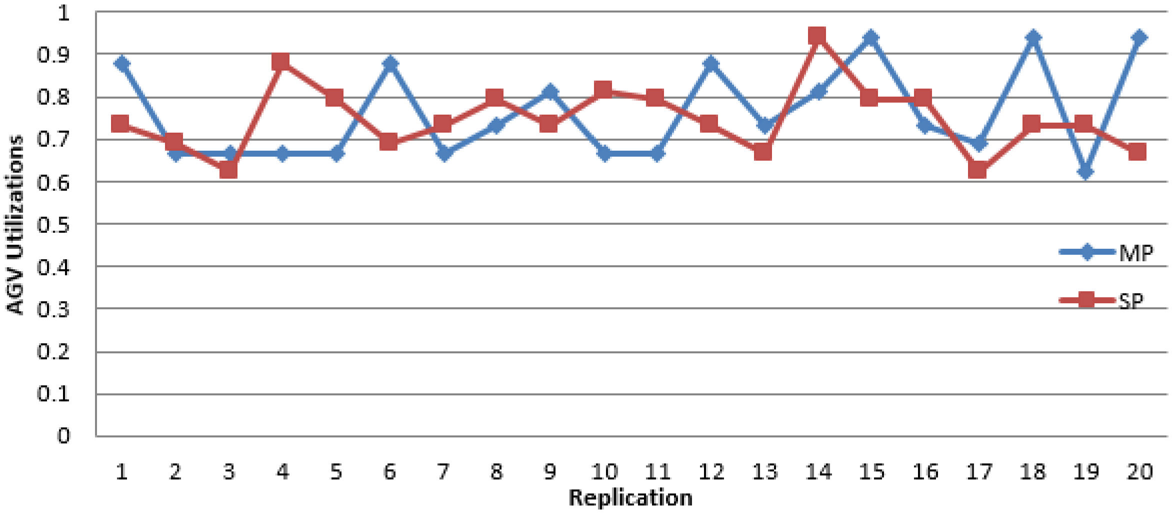

Fig. 3 Average AGV utilizations

The number of intercell material movement resulted as 285 unit loads, a decrease of 23 unit loads compared to the problem SP. The average machine and AGV utilizations for problems SP and MP were given figures 2 and 3. It was observed that machine utilizations for both problems slightly differ. According to the results, there was a slight variation in the average AGV utilizations. This is largely because the difference between the total workloads of problems SP and MP is marginal.

CONCLUSION

Cellular manufacturing systems are generally designed sequentially without considering interactions among different stages. A well-designed system may be inoperative due to materials handling system congestions. There needs to be a certain feedback among different parts of CMS design so that the system can be designed for a better functionality. An intuitive approach was developed to analyze the effects of process plan selection in the design of CMS particularly on material handling systems. The results of the sample problem indicated that the process plans selected by minimizing machining and setup time were not sufficient in order to have a balanced materials handling. Indeed, there were material handling congestions at load transfer stations. These congestions were eliminated by intelligently altering part routings and considering total unit loads. The developed intuitive approach enables us to detect congestions in the material handling system at the early design stages so that potential problems can be eliminated before the system is put in practice.

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