LOADING FLEXIBLE CELLS: TABU SEARCH BASED SIMULATION OPTIMISATION APPROACH

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Key Words: Cellular manufacturing, Cell loading, Multiple objective simulation optimisation, Tabu search

ABSTRACT

In this work a tabu search-based "multi-objective simulation optimisation model" is proposed for loading flexible cell production systems. The problem is formally stated as a goal-programming model hybrid in nature. Some objectives and parameters are determined analytically others are determined from the developed simulation model. The model is solved utilising a tabu search algorithm developed by the author. In the developed methodology parts are assigned to the cells to achieve required performance levels. A capability-based approach is used to define processing requirements of products and processing capabilities of production resources. Parts are assigned to cells such that load is balanced between cells and individual production resources within the cells, cell interactions are kept to a minimum, required system performance levels satisfied (when feasible). Example application is provided to explain the developed methodology.

1. INTRODUCTION

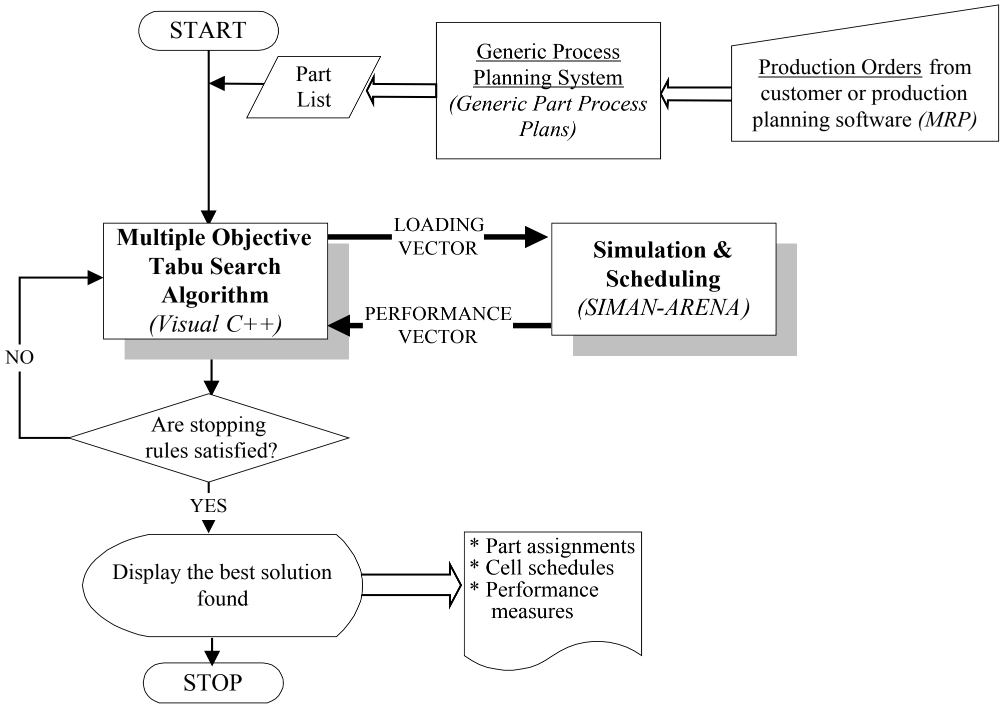
Manufacturing firms are implementing modern production strategies like flexible and cellular manufacturing in order to sustain their competitiveness under increasingly unpredictable market conditions. However, the implementation of these systems alone, cannot achieve the expected levels of agility and competitiveness. An effective control and management system is also necessary. Such a system should be able to load, schedule and reconfigure the overall system dynamically taking into account changing production requirements.

Loading is one of the main controlling activity of cellular manufacturing systems (CMS). It is a complex problem, because it requires simultaneous solution of *part to cell assignment* and *cell scheduling* problems by considering specific system constraints, like cell interaction, cell processing capability etc. In CMS applications manufacturing cells are usually considered as independent production entities. Increased interaction between cells diminishes many of the proven advantages of CMS such as product quality, throughput, material handling cost etc. Therefore, CMS loading problem should be considered from this perspective. To optimise performance, part to cell assignment alternatives that result in minimum cell interaction should be determined and the one, which closely meets performance requirements, found in each loading period. Such an approach can enhance the efficiency of CMS in coping with unpredictable production requirements.

In this paper, a new approach for loading CMS is proposed. The system is composed of three main modules: *Generic Process Planning Module* [1] which determines processing requirements of parts in terms of Resource Elements (RE)[1]. The generated process plans are abstract process plans without specific machine. The final machine-based process plans are generated after considering the outcome of the cells loading conditions. *Multiple Objective Tabu Search Algorithm* [2] is used to generate and evaluate candidate part to cell assignment scenarios. *Simulation and Scheduling Module* [3] determines the performance of the generated part to cell assignment scenarios and cell schedules respectively.

2. PROBLEM STATEMENT AND MATHEMATICAL MODELLING

The framework for loading CMS is presented in Figure 1. There are a number of jobs in the current production period that must be assigned to suitable cells for processing. Generic process planning system determines the processing requirements of parts in the *parts list* in terms of REs. The machining capability of cells is also defined in terms of REs. A part may or may not have one or more target cell that can satisfy all of its processing requirements. If there is no single cell can satisfy all processing requirements of a part type then inter-cell movement must be considered. A part assignment scenario that result in minimum cell interaction and



maximum system performance should be searched amongst alternative solutions. This kind of decision making process may frequently occur in a cellular shop under rapidly changing production requirements.

Figure 1. The simplified framework of the loading model

From its nature, the problem is a multiple objective type and there are priorities between certain objectives. In this paper, the loading problem is formally represented as a pre-emptive goal-programming model and minimising cell interaction is considered as top priority. A tabu search (TS) algorithm developed by Baykasoglu et. al.[2] is used to solve the model. The mathematical model is given as follows;

$$\textbf{Lexmin}\{(d_\alpha^+),(d_t^- + d_t^+),(d_u^- + d_u^+),(d_q^- + d_q^+),(d_\varepsilon^- + d_\varepsilon^+),(d_\omega^- + d_\omega^+)\} \quad (1)$$

$$\sum_{i=1}^{m}\sum_{o=1}^{NOP_i-1}\sum_{k=1}^{c}\left|X_{iok} - X_{i(o+1)k}\right| + d_\alpha^- - d_\alpha^+ = goal_\alpha \quad (2)$$

$$\boldsymbol{MT} + d_t^- - d_t^+ = goal\_t \quad (3)$$

$$\boldsymbol{MU} + d_u^- - d_u^+ = goal\_u \quad (4)$$

$$\boldsymbol{TT} + d_q^- - d_q^+ = goal\_q \quad (5)$$

$$\sum_{k=1}^{c}(CL_k - ACL)^2 / c + d_\varepsilon^- - d_\varepsilon^+ = goal_\varepsilon \quad (6)$$

$$\sum_{k=1}^{c}\left(\sum_{j\in k}(\boldsymbol{ML}_{jk} - CL_k)^2 / NM_k\right) + d_\omega^- - d_\omega^+ = goal_\omega \quad (7)$$

$$ACL - (1/c\sum_{k=1}^{c}CL_k) = 0 \quad (8)$$

$$CL_k - \sum_{j\in k}\boldsymbol{ML}_{jk} / NM_k = 0 \quad \forall k \quad (9)$$

$$\sum_{k=1}^{c}X_{iok} = 1 \quad \forall i,o \quad (10)$$

$$\sum_{k=1}^{c} C_{(R_{io})k} - X_{iok} \geq 0 \quad \forall i,o \tag{11}$$

$$X_{iok} \in \{0,1\} \quad \forall i,o,k \;\; \& \quad d_t^-, d_t^+, d_u^-, d_u^+, d_q^-, d_q^+, d_\alpha^-, d_\alpha^+, d_\varepsilon^-, d_\varepsilon^+, d_\omega^-, d_\omega^+ \geq 0 \tag{12}$$

In the mathematical model, Equation 1 represents lexicographical order of deviational variables to be minimised. Equation 2 represents inter-cell movement constraint. For a part assignment scenario this equation calculates the total number of inter-cell movements. Equations 3, 4 and 5 represent tardiness, system utilisation and throughput constraints. Equations 6 and 7 are cell and machine load balance constraints. For a part assignment scenario the values of $\boldsymbol{ML_{jk}}$, ***MT***, ***MU***, ***TT*** are determined by the simulation/scheduling module and returned to the optimisation module. Equations 8 and 9 calculate average cell load and total load in each cell. Equation 10 ensures that every operation on a part is assigned to only one cell. Equation 11 ensures that, if an operation on a part is assigned to a cell the RE corresponding to that operation is available in that cell.

Due to space limitations, the multi-objective tabu search algorithm is not explained here, for further detail refer to Baykasoglu et. al.[2].

3. CASE STUDY

The proposed system has been applied to a manufacturing facility containing 12 machine tools. There are four manufacturing cells. Each cell is represented as a collection of REs (see Table 1) and parts are dispatched to the system according to their RE-based routes (see Table 2). The parts and materials are transported in the system by a combination of forklift trucks and cranes.

Table 1. Manufacturing cells and their capabilities based on REs

		Capability Based Representation of the Cell. Manf. System (Resource Elements)										
Manuf. Cells	*Machine Tools*	*RE-1*	*RE-2*	*RE-3*	*RE-4*	*RE-5*	*RE-6*	*RE-7*	*RE-8*	*RE-9*	*RE-10*	*RE-11*
1	5-MHP Machining Centre-3	*	*	*				*	*	*	*	*
	6-CNC Grinding Machine-1					*	*					
	8-MHP Machining Centre-2	*	*	*				*	*	*	*	*
	11-Colchester Lathe-2	*	*		*			*				
2	7-MHP MT50 NC Lathe-1	*	*		*			*			*	
	12- J&S Surf. Grinder					*						
3	1-Drill Press-1	*										
	3-Colchester Lathe-1	*	*		*			*				
	4-MHP MT50 NC Lathe-2	*	*		*			*			*	
4	2-MHP Machining Centre-1	*	*	*				*	*	*	*	*
	9-CNC Grinding Machine-2					*	*					
	10-J&S Cyc. Grinder						*					

Production of 20 part types is required and parts arrival in the current production period is represented by an exponential distribution. Parts processing requirements and related technical information for the first five part types are represented in Table 2 in terms of REs (Gindy et. al.[1]).

Table 2. Generic part process plans

Part Type #	# Operations (NOP_I)	# RE	Operation # 1	Operation # 2	Operation # 3
1	3	3	RE1(60)*	RE2(80)	RE4(90)
2	3	3	RE1(50)	RE2(60)	RE3(40)
3	3	3	RE5(20)	RE6(60)	RE7(80)
4	3	3	RE8(40)	RE5(40)	RE9(30)
5	3	3	RE7(50)	RE4(60)	RE5(80)
* RE#(A): Resource Element number (Processing time + set up time)					

By using the data from Tables 1-2, candidate cell assignment scenarios are determined by the tabu search algorithm. The simulation module that is developed using SIMAN [3] determines performance of the candidate solutions and cell schedules. Each time TS algorithm generates a candidate part assignment scenario the simulation module is automatically updated to present the new scenario. After each simulation run the performance measures are passed to the multi-objective TS algorithm for evaluation. The best solution is determined through this simulation-optimisation iterations.

The following operating assumptions are made in the simulation: Processing times are deterministic, no machine breakdowns during production, set-up is included in the operation time, due-dates are calculated using Total Work Content approach, the dispatcher uses Earliest Due-Date rule.

The convergence of the loading system while searching for a solution is presented in Figure 2 below. As it can be seen from the figure all objectives are converging simultaneously. The output of the program presents part type assignment for each cell and their production schedule.

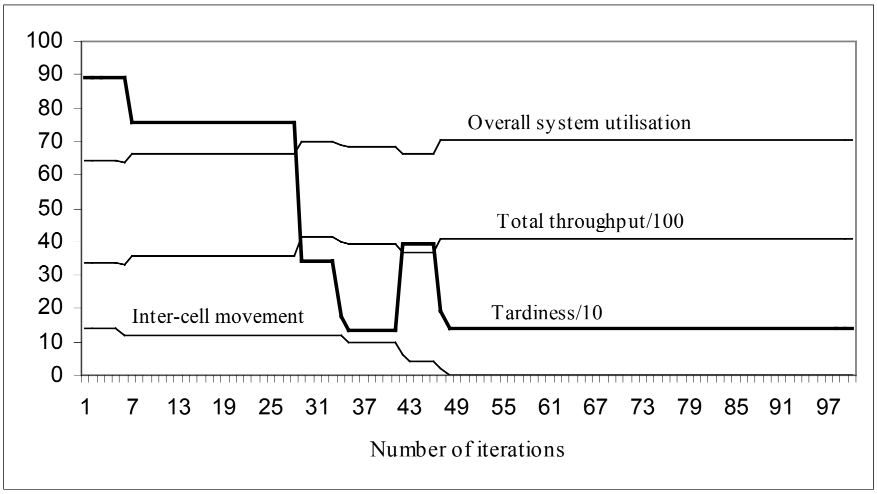


Figure 2. Conversion behaviour of performance measures

4. CONCLUSIONS

In the present study, a TS based multi-objective simulation optimisation technique is developed for solving CMS loading problems. The importance of the problem and the proposed loading framework is explained briefly through a test case study. The results show that the proposed approach can be used for loading CMS under rapidly changing production requirements and helps to improve cell performance levels.

TERMINOLOGY

i,o,j,k are part index, operation index, machine index and cell index respectively, *m* is the number of parts, *c* is the number of cells, NOP_i is the number of operations in part *i* (each operation corresponds to an RE), *ACL* is average cell load in the CM shop, CL_k is total load in cell *k*, NM_k is number of machines in cell *k*, R_{io} is the RE number corresponding the *o*'th operation of part *i*, $C_{(Rio)k}$ is equal to ‘1’ If RE corresponding the *o*'th operation of part *i* is available in cell *k* ‘0’ otherwise, $\boldsymbol{ML_{jk}}$ is the total load on machine *j* in cell *k*, ***MT*** is the mean tardiness in the CM system, ***MU*** is the mean utilisation of the CM system, ***TT*** is the total throughput in the CM system, $goal_\alpha$ is *a*cceptable level of inter-cell movement, *goal_t* is the acceptable limit for tardiness, *goal_u* is desired level of system utilisation, *goal_q* is the desired level of throughput, $goal_\varepsilon$ is the acceptable level of load imbalance between cells, $goal_\omega$ is the acceptable level of load imbalance between machines in each cell, X_{iok} is equal to 1 if *o*'th operation (corresponding RE) of part *i* is assigned to cell *k*, 0 otherwise, d_α^-, d_α^+ are under and over achievement for $goal_\alpha$, d_t^-, d_t^+ are under and over achievement for *goal_t*, d_u^-, d_u^+ are under and over achievement for *goal_u*, d_q^-, d_q^+ are under and over achievement for *goal_q*, $d_\varepsilon^-, d_\varepsilon^+$ are under and over achievement for $goal_\varepsilon$, d_ω^-, d_ω^+ are under and over achievement for $goal_\omega$.

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