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A Heuristic Rule-Based Approach for Dynamic Scheduling of Flexible Manufacturing Systems

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1. Introduction

Operations planning and scheduling (OPS) problems in flexible manufacturing systems (FMSs), are composed of a set of interrelated problems, such as part-type batching, machine grouping, part routing, tool loading, part input sequencing, and resource assignment. The performance of an FMS is highly dependent on the efficient allocation of the limited resources to the tasks, and it is strongly affected by the effective choice of scheduling rules. In this study, a heuristic ruled based approach for dynamic scheduling of FMSs, which integrates loading, part inputting, routing, and dispatching issues of the OPS is presented, and the implementation results are compared with several dispatching rules.

Scheduling is a decision making process and it concerns the allocation of the limited resources to tasks over time [1]. In a manufacturing system, resources represent machines, operators, robots, tools, buffers etc., and activities are the processing of products on machines, the transportation of products among workstations, or loading/unloading the parts from/to machines by the operators. The scheduling problems in FMSs, relate to the execution of production orders and include raw part input sequencing, machine, material handling device and operator scheduling, part routing, monitoring the system performance and taking the necessary corrective actions [2]. Since FMSs comprise very diverse properties and constraints (e.g. the availability of alternative machines to perform the same operation(s), multi-layer resource sharing, and product varieties), scheduling problems in FMSs are more complex than job-shop or flow-shop problems and often very difficult to be solved by conventional optimization techniques. Prior studies on FMS scheduling problem point out the great impact of scheduling decisions to the system performance [3-5]. Scheduling decisions and the effective choice of dispatching rules are influenced by the performance criterion and existing shop-floor conditions such as process plans, due date requirements, release dates, job priorities, machine setup requirements, and the availability of system resources. Scheduling/dispatching control decisions in an FMS must be capable of handling simultaneously these diverse factors on a real-time basis. Therefore, rather than designing an optimum scheduler, there is a definitive need for a flexible and integrated scheduling in order to handle the dynamic and stochastic nature of real-world problems, and computationally efficient compared to analytical methods.

In this study, a heuristic rule-based approach is proposed to solve the resource contention problem in an FMS, and to determine the best route(s) of the parts, which have routing

flexibility. The paper is organized as follows. Section 2 describes the resource contention problem considered in this study. The proposed heuristic rule based system is presented in the following section. In section 4, the dynamic scheduling methodology is illustrated on an example FMS, and the performance of the proposed rule-based system is compared with single dispatching rules. Finally, conclusions and future research directions are given in the last section.

2. Problem Statement

Due to the unavailability of sufficiently large problem sets, the researchers studying on FMSs mostly generate their specific systems [6]. In this study, an FMS with alternative operations and setup times is employed to explain the proposed decision support system for dynamic shop-floor scheduling and control problem. The FMS operational policy is under push paradigm that machines process parts whenever they are available. Some operations of the product types can be performed by alternative machines. From the point of part flow view three different types of products are processed simultaneously in the system, and each product is allowed to have flexible routing (i.e. two or more machines have the ability to perform the same operation of a part). Employing flexible routing requires a two-level hierarchical decision making process: assignment and sequencing. In the first level, the next destination of a job is determined; in the second level the sequencing decisions of a part waiting for the limited resources such as workstations, operators, and transporter is taken.

For scheduling of automated manufacturing systems, supplementary resources such as material handling system, operators and buffer spaces should also be taken into consideration while taking scheduling decisions. However, this will increase the problem complexity, since deadlocks may arise from distinct recognition of multilayer resource sharing. In the system considered, when the part type is changed, a setup operation is needed. Therefore, we also have to introduce setup requirements of the machines into the rule-based system while solving the conflict problems.

In order to achieve the efficient utilization of the resources, and to find out the best operation sequence of each task, a real-time resource allocation policy is needed to be adapted, thus to assign resources to the jobs as they advance through the system. Moreover, the scheduling decisions should consider the prevailing conditions of the shop-floor in an integrated framework. Since a variety of part types have alternative routes on the machines, and multiple resources can be selected in a given set, a conflict or deadlock may often arise when more than one part is contesting for the same resources such as machines, material handling devices, and operators. Thus, the problem is the allocation of limited resources to a set of tasks, that is determination of the best route of each task in the system according to the current shop-floor condition (i.e. due dates, release dates, order quantities, tardiness penalties, inventory levels, priorities, and setup times). However, formulation of real-life scheduling problem using traditional methods becomes very complex when part routing flexibility, machine setup operations, operator and material handling system constraints are also considered.

3. A Heuristic Rule-Based System for Dynamic Scheduling

The system control and scheduling approach in the proposed methodology uses a heuristic rule-based system to solve resource contention problems and to determine the best route(s)

of the parts, which have routing flexibility. The part routing control system aims to handle material handling, operator and setup operation constraints together with the machine constraints, thus to solve both sequencing and resource sharing problem effectively at the same time. The proposed approach is modeled with the help of the high-level Petri Net (PN) model of the system by the sequence of execution of transitions [7]. PNs, as a graphical and mathematical modeling tool, are well suited for representing FMS characteristics such as precedence relations, concurrency, conflicts, and synchronization [8-9].

In the developed scheduling system, part flow between workstations are controlled and managed by a scheduler module. All the information of each part which is ready to be transported in the system is sent to the scheduler module. In the scheduler module, the next destination of a part is determined dynamically based on the existing shop-floor conditions and the proposed heuristics, then sends a request for AGV assignment. The Scheduler module examines the system state at every discrete event when there is a change in the status of the system and makes a decision applying scheduling rules in the knowledge base then passes the decision to the system. Thus, it provides a computerized support to the user so that the decision is taken after comparing the different available options of scheduling which are better in respect to the different aspects such as due dates, overhead costs, minimum tardiness, and flow time. A set of production rules in the form of "IF..... THEN....." statements have been constructed based on the heuristics developed for this work to assign the resources to the parts, and to determine the best route(s) of the parts thus to solve the resource contention problem. A production rule which is a means of expressing reasoning links between facts expresses the behavior of objects in the system of interest [10].

$$\text{IF } (c_1, c_2, ..., c_m) \text{ THEN } (r_1, r_2, ..., r_{rn})$$

where, the c_j (j =1,2,..., m) are predicates known as conditions, and the r_k (k = 1,2,..., n) are to as consequences.

A predicate checks the state of the system, such as the process plan of the parts, the number of conflicting part types, their remaining number of operations, their remaining process times, and the setup status of the machines, then selects the next part to be processed from a set of parts awaiting according to some priority rules. When the IF portion of a production rule (predicate) is satisfied by the conditions, the action specified by the THEN portion is performed. When this happens, the rule is said to be fired. In scheduler module, a rule interpreter compares the IF portion of each rule with the facts and executes the rules whose IF portions match the facts. Each rule in this scheme corresponds to the use of a routing control strategy subject to the existence of certain conditions.

Instead of using a single dispatching rule, it is more expedient to apply one from a set of dispatching rules according to the decision point and system characteristics. In the IF...-THEN... statements, the following dispatching procedural rules are used in decision making process;

- *First come, first served, (FCFS or FIFO)*
- *Earliest due date, (EDD)*
- *Smallest number of remaining operations, (SNRO)*
- *Largest number of remaining operations, (LNRO)*
- *Shortest processing time, (SPT)*
- *Job of identical setup, (JIS)*
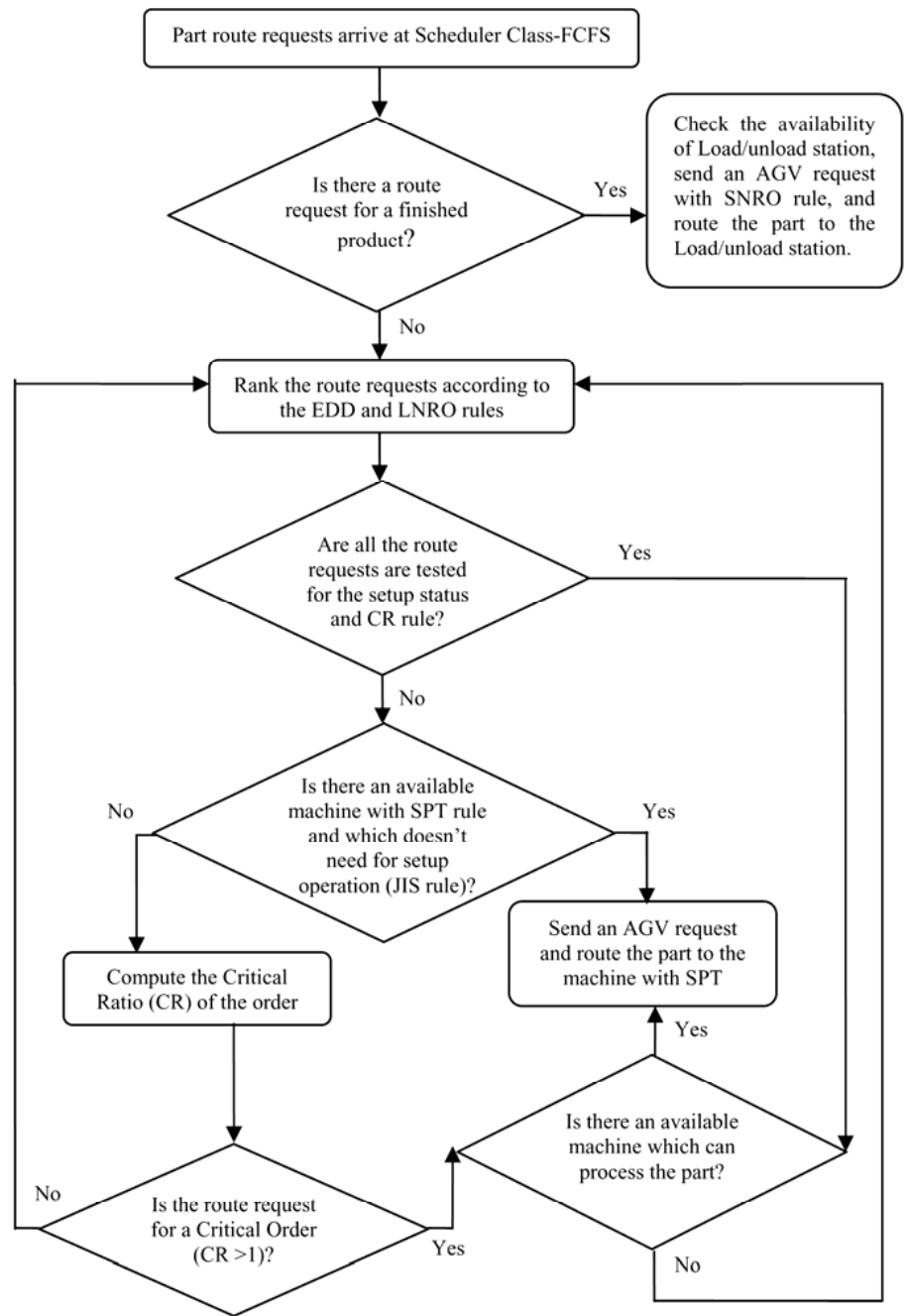- *Critical Ratio scheduling, (CR)*

Figure 1. Flow Chart of the Routing Control Process

The procedure for scheduling operations on the machines is executed whenever a raw part for a new order is delivered to the load storage buffer at Load/unload station or a workstation completes performing of its current operation and becomes available for the next task assignment. When a part is processed at a workstation, it is transferred to the work-in-process (WIP) storage area which has a limited capacity and a route request with the product data such as product type, due date, and process plan information of the part, is sent to the scheduler module for this part. In the scheduler class, all route requests that are sent from the workstations and load/unload station are put in order, and replied by considering the prevailing system conditions and the rule based system. Once a route request is replied, the destination of the pallet is informed back to the station which sent the route request and an AGV request is forwarded to the transportation module. By this way, if there is an available AGV, it can be directed to the workstation which the part waiting to be transferred its next destination. The route requests which are not satisfied join a waiting queue, and once a new route request arrives to the scheduler module, all the route request including newly arriving one are re-tested in the new system status. This procedure is repeated until all route requests are replied.

Figure 1 illustrates the flow diagram of part routing control process based on the heuristics. This algorithm attempts to further reduce the mean flow times of the jobs by reducing the setup times incurred while the product types change.

4. Performance Evaluation of the Dynamic Scheduling Based on the Rule-based System

A high-level PN based simulation analysis is performed for the performance evaluation of the part routing, and resource allocation strategies under different levels of system parameters. The input data to the PN models consists of part types to be processed, machines, load/unload station, material handling device, and operators. Input data for the performance analysis of the example FMS are as follows:

PARTS:

Parameter	Value
Number of product types	$3(P_1, P_2, P_3)$
Order batch size	1
Product type arrival ratio	(% 30, P_1); (% 40, P_2); (% 30, P_3)
Order inter arrival time	Exponential with mean 30 min.
Due date	Arrival time + (100+ uniform (0;2)* max.total processing time)

MACHINES:

Parameter	Value
Number of machines	9
Machine setup time	20 min.
Loading/unloading parts to/from machines	0.2 min.

LOAD/ UNLOAD PROCESS:

Parameter	Value
Loading / unloading parts to/from pallets	0.3 min.
Moving pallets to load / unload storage buffers	0.2 min.

MATERIAL HANDLING SYSTEM:

Parameter	Value
Number of AGVs	1
Transfer time between the stations	1.5 min.

OPERATORS:

Parameter	Value
Number of operators	8
Operator transfer time between workstations	0.5 min

For each product type, Tables 1 and 2 show the operational sequences with required resources and processing times without setup times.

Operations	Machine required - Processing time
O-l	M-l (4.5 min.) / M-3 (3.2 min.)
O-2	M-2 (4.5 min.) / M-4 (3.2 min.)
O-3	M-5 (9 min.) / M-6 (5.2 min.) / M-7 (6 min.) / M-3 (3.6 min.)
O-4	M-8 (2 min.)
O-5	M-9(1.5min.)

Table 1. Process plan of product type 1 (P_1)

Operations	Machine required - Processing time
O-l	M-3 (3.7 min)
O-2	M-4 (5.3 min.)
O-3	M-5 (13 min.) / M-6 (7.5 min. for P_2; 8.5 min. for P_3) / M-3 (5.25 min.)
O-4	M-8 (2 min.)
O-5	M-9(1.5min.)

Table 2. Process plan of product type 2 and 3 *(P_2 and P_3)*

Ten independent replications for each dispatching strategies were run for 180.000 operating minutes (125 days with three 8 hr shifts) during the simulation of the PN model. In each run, the shop is continuously loaded with job-orders that are numbered on arrival, and each run produced one observation for each performance measure. Different random number seeds were used to prevent correlation between the parallel runs of the factorial experiment. In

order to ascertain when the system reaches a steady state, the shop parameters, such as mean flow time of jobs and utilization level of machines, were observed, and it has been found that the system became stable after a warm-up period of 43.200 simulated minutes (30 days with three 8 hr shifts). Thus, for each replication, the first 43.200 minutes was discarded to remove the effect of the start-up condition, which was an idle and empty state.

Performance of the proposed rule-based system was compared with single dispatching rules such EDD, FIFO, SNRO, and LNRO with respect to mean flow time of jobs, mean tardiness, percentage of tardy jobs, and number of tardy jobs. In these cases, the jobs waiting for the next operations in the central buffer are ranked by only considering a fixed dispatching rule, and the job which is ranked first is routed to the available machine which can process part with the smallest processing time (SPT) among the alternative process plans. Therefore, we only make modification on the scheduler module to replace by a single dispatching rule instead of the rule-base, and the simulation model of the system is used in the same way. Table 3 summarizes the performance analysis results that are obtained by taking the mean over 10 replications for each procedure.

	EDD	FIFO	SNRO	LNRO	Rule-based System
Mean job flow time (min)	133.12	134.13	141.71	138.38	115.04
Mean job tardiness (min)	28.58	26.11	34.76	32.19	19.74
Proportion of tardy jobs (%)	48.6	55.6	53.3	51.8	32.3
Number of tardy jobs	2225	2577	2460	2366	1499

Table 3. Performance analysis results

Implementation results show that, the proposed dynamic routing heuristics usable for real-time scheduling/dispatching and control of FMSs yield better results compared to the fixed dispatching rules and be computationally efficient and easier to apply than optimization-based approaches in real-life problems.

5. Conclusions

In this study, a new and simple alternate routing heuristics, which would be superior to the conventional routing strategies in terms of various system performance measures and easier to apply practically, was presented. Because of the high investment costs of FMSs, it is also definitely worth choosing the best operating policy and system configuration by analyzing the system model, and adapting to changes over time. In future research, the heuristic rule base will be extended to include other supplementary constraints such as dynamic tool allocation and sequence dependent setup times. For practical implementation of the proposed decision support system, additional research in the area of human interfaces could be useful to develop more user friendly system which automatically constructs simulation model of the system from the knowledge base of a production system.

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Multiprocessor Scheduling, Theory and Applications

Edited by Eugene Levner

A major goal of the book is to continue a good tradition - to bring together reputable researchers from different countries in order to provide a comprehensive coverage of advanced and modern topics in scheduling not yet reflected by other books. The virtual consortium of the authors has been created by using electronic exchanges; it comprises 50 authors from 18 different countries who have submitted 23 contributions to this collective product. In this sense, the volume can be added to a bookshelf with similar collective publications in scheduling, started by Coffman (1976) and successfully continued by Chretienne et al. (1995), Gutin and Punnen (2002), and Leung (2004). This volume contains four major parts that cover the following directions: the state of the art in theory and algorithms for classical and non-standard scheduling problems; new exact optimization algorithms, approximation algorithms with performance guarantees, heuristics and metaheuristics; novel models and approaches to scheduling; and, last but least, several real-life applications and case studies.

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