MULTI-CRITERIA DYNAMIC SCHEDULING AND SIMULATION-BASED CONTROL IN FLEXIBLE MANUFACTURING SYSTEMS

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ABSTRACT

This study presents the development of a multi-criteria control methodology for flexible manufacturing systems (FMSs). The control methodology is based on a two-tier decision making mechanism. The first tier is designed to select a dominant decision criterion using a rule-based algorithm. In the second tier, using a look-a-head multi-pass simulation, a scheduling rule that best advances the selected criterion is determined. The decision-making mechanism was integrated with the shop floor control module that comprises a real-time simulation model at the top control level and RapidCIM methodology at the low equipment control level. The proposed control methodology was compared to a selected group of scheduling rules/policies using DEA. The results demonstrated the superiority of the suggested control methodology as well as its capacity to cope with a fast changing environment.

Keywords: Dynamic scheduling

1. INTRODUCTION

The increasing demand for a larger variety of products, smaller production lots and frequent model changes caused flexibility and efficiency to become essential requirements in manufacturing systems in order to maintain a high level of productivity in face of fast changing market demands.

Flexibility was made possible largely due to the use of versatile and/or redundant machines and these in turn, enabled alternative routing in the system. The introduction of alternative routing made it possible to better balance machine workload and to achieve higher system robustness in face of machine failure. These steps were instrumental in achieving higher system productivity. As a result, it became clear to many professionals, that the system performance is highly dependent on the selection of the correct scheduling policy used to control the system. This is not a simple task, especially since these systems usually operate in a highly dynamic environment where product mix and overall system objectives are changing rapidly.

This research deals with a production system that operates in a highly dynamic environment, characterized by random arrivals of work orders, random machine breakdowns, and other disturbances. The literature argues that for these types of environments, an adaptive/dynamic scheduling approach seems to be more effective than other scheduling methods. In adaptive/dynamic scheduling, jobs are dispatched to machines using scheduling rules or algorithms that determine the jobs' priority at the specific moment of dispatching based on the information available at the moment of dispatching (Vieira et al. [1]). However, the shop floor control systems presented in earlier studies are only partially adaptable to the dynamic environment the FMS operates in. This study makes the case that in a dynamic environment, it is important not only to select a good scheduling rule, but also to determine an appropriate decision criterion upon which the performance of each scheduling rule is measured.

2. SUGGESTED CONTROL METHODOLOGY

This study focuses on developing and analyzing a multi-criteria adaptive scheduling methodology for controlling an FMS. In order to cope with the dynamic and multi-criteria environment in which an FMS operates, the proposed scheduling and control methodology uses a two-tier control scheme as illustrated in Figure 1.

Tier 1 is used to determine a dominant decision criterion from a predefined set of decision criteria created and updated by the system user. This selection is based on current shop floor status, production order requirements, and manufacturing system priorities. Based on the chosen decision criterion, a predefined relevant rule set (from a database of dispatching rules) is chosen, together with an appropriate performance measure that is subsequently used to evaluate these rules.

Tier 2 is used to select a scheduling rule from the set of relevant dispatching rules (established in tier 1) which best advances the chosen performance measure. The dispatching rule is chosen using a forecasting mechanism that is based on a look-ahead multi-pass simulation. This rule will be used by the Shop Floor Control System to dispatch work-orders during the next scheduling period.

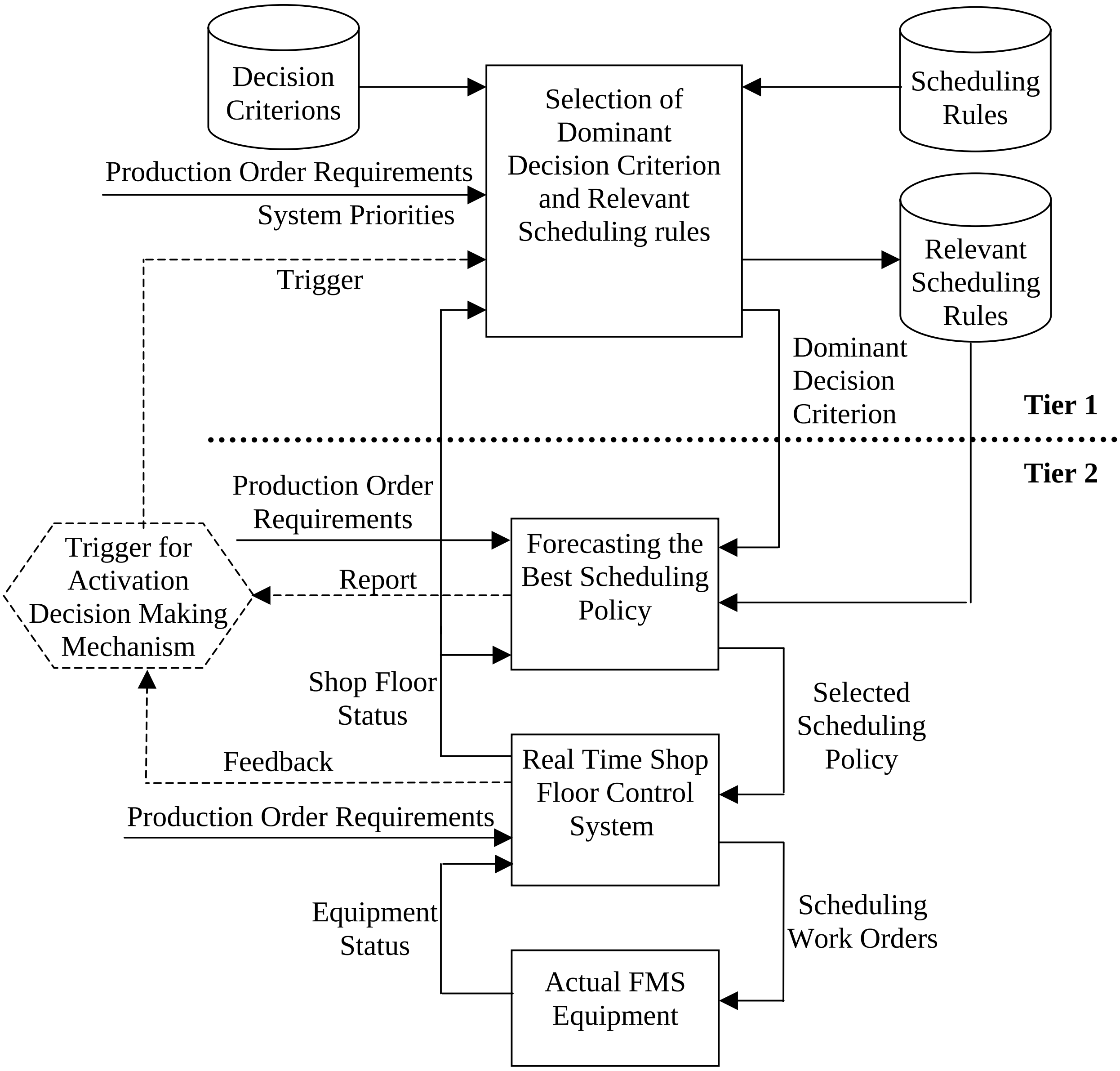

Figure 1. The two-tier control scheme

3. IMPLEMENTATION MECHANISM

The implementation mechanism, illustrated in Figure 2, consists of several separate modules operating in cooperation.

3.1 The shop floor management module

The shop floor management module that serves as the FMS controller was implemented using the Arena RT simulation tool. This module is responsible for sending messages containing instructions on the required activities to the lower level equipment controllers. This module also receives the “execution completed” messages back from the equipment controllers and keeps track of the current equipment status. The Arena simulation model is developed in a manner that supports alternative routings and enables, if necessary, the dynamic exchange of scheduling policies (according to instructions sent from the decision making mechanism that will be explained later), without interrupting the system's operation.

During operation, the shop floor control module keeps track of jobs moving from the WIP central buffer to the different machining centers and back. This information is collected in a database and appropriate tables in the database are updated accordingly to reflect the current state of the shop floor.

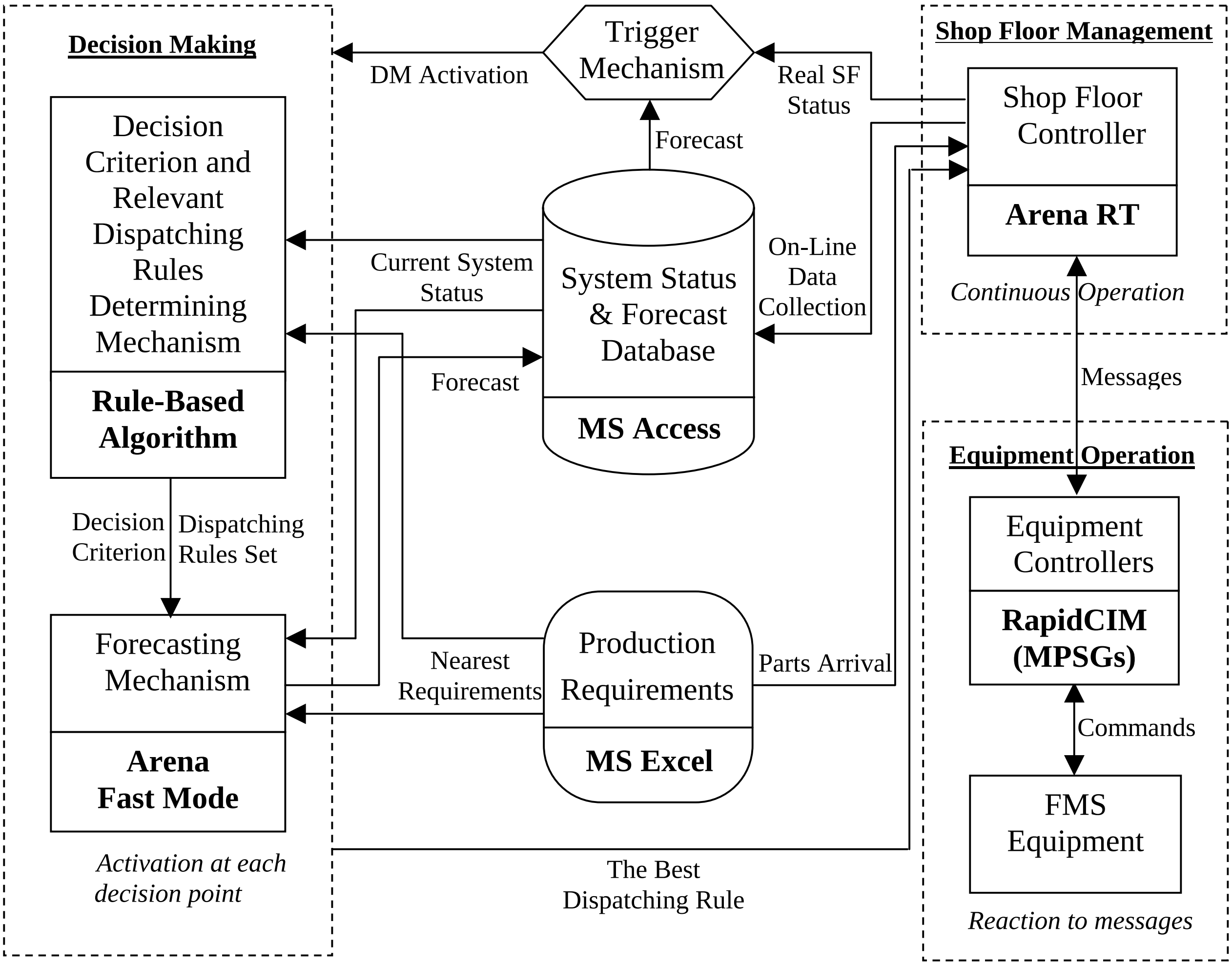

Figure 2. The implementation of the suggested two-tier control methodology.

3.2 The equipment operation module

The equipment controllers in the proposed scheme are C++ applications that are designated to receive messages from the shop floor control module, interpret these messages, send operation commands to the appropriate equipment unit and transfer the completion messages back to the shop floor control module. The equipment controllers were implemented using the RapidCIM methodology (Wysk et al. [2]).

3.3 The Decision Making Mechanism

The decision-making mechanism, activated at every decision point, comprises two modules according to the proposed two-tier control scheme. The first module is implemented using a rule-based algorithm and its task is to determine the preferable decision criterion and relevant scheduling rules. This algorithm receives the current system state (shop floor status and nearest production requirements) and returns the chosen dominant decision criterion.

The literature reveals (see Shnits et al. [3]) that the two most frequently used criteria are mean flow time (system oriented) and mean tardiness (customer oriented). These two criteria were also chosen to serve, in the current study, as the FMS performance evaluation measures. As a result, a rule-based algorithm was developed to choose at any decision point one of these two criteria. Following is the notation and suggested rules.

- **Notation:**
- j – Part index 1,…, J
- t – Current time
- P_j – Average remaining processing time for a part j
- DD_j – Due date for part j
- M – Number of repaired machines
- CI_j – Critical index for part j, where $CI_j = P_j / (DD_j - t)$
- TC_j – Tardiness cost per time unit for part j
- K_1, K_2, K_3 – System coefficients, where $K_1 \geq 0, K_2 \geq 0, K_3 \leq 0$
- C_1, C_2 - Threshold levels for the tardiness costs

Rules:

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If $\frac{\sum_j P_j}{M} > K_1 \cdot \sum_j \frac{(DD_j - t)}{J}$ and $\frac{\sum_j TC_j}{J} > C_1$, then
    Choose Mean Tardiness as the dominant decision criterion
Else
    If $\exists\, j : CI_j > K_2$ or $\frac{1}{CI_j} < K_3$, then
        If $TC_j > C_2$, then
            Choose Mean Tardiness as the dominant decision criterion
        Else
            Choose Mean Flow Time as the dominant decision criterion
        End If
        Else
        Choose Mean Flow Time as the dominant decision criterion
    End If
End If
```

The expression $\sum_j P_j \big/ M$ denotes the average required time to complete the jobs that are processed in the system at that point in time. This expression is compared to the average time to the due-date $\sum_j (DD_j - t) \big/ J$ of these jobs. If the former is greater than the latter, the system may have a problem meeting all the jobs' due-dates. In such a case, it seems logical to determine processing priorities that minimize the jobs' mean tardiness. On the other hand, if it turns out that there is enough time to complete jobs in the system without violating the agreed upon due-dates, it makes more sense to try and minimize the jobs' mean flow time.

It should be noted that even if, on average, there is no time pressure in the system (first condition), there may be some urgent jobs that are in danger of missing their due-dates or have missed them already. These cases can be detected through the use of the critical index CI_j (second condition). If there are such jobs in the system, the mean tardiness criterion is chosen over the mean flow time criterion.

The coefficients K_1, K_2, and K_3 reflect the system priorities by defining the relative importance of the considered criteria. Coefficient K_1 refers to the overall system status, while the coefficients K_2 and K_3 refer to parts individually.

The second module of the decision making mechanism is the forecasting module that is used for selecting the best scheduling rule from the relevant (according to the dominant criteria measure) scheduling rule set. The forecasting module is developed using the Arena 7 simulation tool and is similar to the model that serves as the shop floor controller. A scheduling rule is chosen after the simulation model evaluates (look-ahead) all the relevant scheduling rules in the given rule set. Each evaluation run begins with the current shop floor status that is supplied by the system status database. The forecasting mechanism also takes into account the estimated production requirements i.e., the new jobs that are expected to arrive at the shop during the evaluation run. Once the best scheduling rule is determined, it is passed on to the shop floor management module via a communications network. This rule will govern the shop floor controller's operation until a new decision will be required.

4. PERFORMANCE EVALUATION

The performance of the proposed dynamic scheduling and control mechanism was evaluated by comparing it to some known individual scheduling rules/policies and methods using DEA. The average flow time $\overline{FT}$ and average tardiness $\overline{TR}$ over 12 different scenarios were calculated for each scheduling rule/policy. These values were compared to the average flow time and average tardiness achieved by the manufacturing system operating using the proposed control methodology for different values of the control variable K_1 (the main coefficient of the decision making algorithm). In order to use the DEA approach, the average flow time and average tardiness obtained had to be normalized. The normalized flow time $\overline{FT}^{\mathrm{N}}$ and normalized tardiness $\overline{TR}^{\mathrm{N}}$ are illustrated in Figure 3.

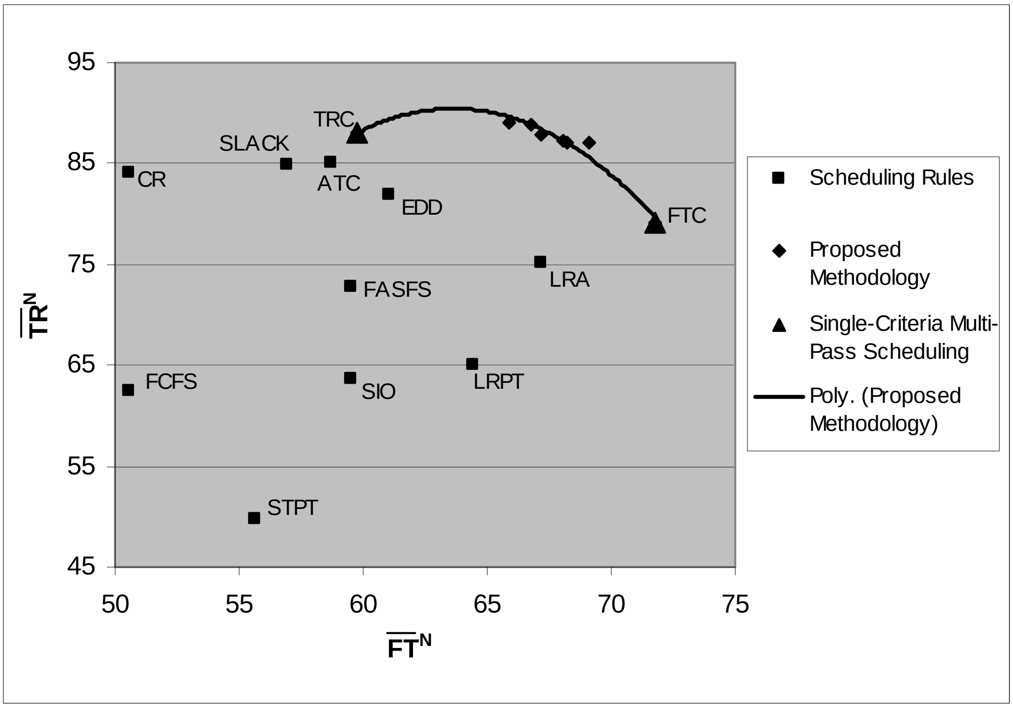

Figure 3. The performance of the proposed control methodology versus the performance of the individual scheduling rules/policies.

Figure 3 clearly shows that the results obtained for the proposed control methodology (using the different K_1 values) form an efficiency frontier. The two extreme points of this frontier represent the performance of the adaptive control methodology operating with a single criterion – flow time (FTC) or tardiness (TRC). Figure 3 demonstrates that the proposed methodology outperforms the other tested scheduling rules/policies. The DEA results, omitted here, confirm the overall superiority of the suggested two-tier control methodology. According to the DEA, the efficiency of the proposed scheduling mechanism is equal to 1 or very close to 1 (for all K_1 values) and is higher compared to the efficiency of the individual scheduling rules.

5. CONCLUSIONS

This study presents a new multi-criteria dynamic scheduling methodology for controlling FMSs. In order to cope with the unpredictable environment in which an FMS operates, the proposed control scheme uses a two-tier decision making mechanism. The implementation of the proposed control methodology is based on using similar simulation models for decision-making as well as for the direct control of the actual manufacturing system.

The proposed control methodology was evaluated and compared to individual scheduling rules/policies and to an adaptive single-criteria scheduling method. The results obtained demonstrate the superiority of the suggested control methodology as well as its capability to cope with a fast changing environment.

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