Manufacturing Real-time Process Plan Selection Based on System Performance
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Abstract
Today’s fast-pace manufacturing company environment requires that manufacturing decisions be made at the time when their impact will be the most relevant for the operations. The importance of the proper information and knowledge necessary for such decision can not be overstated. This paper discusses a procedure for the selection of process plans in real-time, during the manufacturing execution. Necessary data and knowledge for successful decision are elaborated. Process planning procedure is preprocessed for the knowledge intensive component using rule-based system, but the final decision related to machine and tool assignment has been postponed for manufacturing in real time. Rule-based system is developed using expert systems shell tools with knowledge related to manufacturing features, machining processes and process capabilities. The result of preprocessing is a process plan network of alternatives plans. Real time selection consults the process plan network and selects next processing task (feature). Three step procedure for selection of the feature, its process parameters, machines, and tools based on the system performance in real time (due dates, the current cycle times, utilization, and WIP) is explained. The feature is selected based on feature precedence network (FPN). Process, machine and tool are selected after ranking the current machine utilization or WIP of all candidate resources and selected the least loaded resource. The procedure is repeated at predefined decision points in order to increase output and balance resource utilization. The procedure has been developed in context of FMS supported by data collection about the system status (utilization and WIP). The procedure is supported by few illustrative examples of simulated FMS system.

1. Introduction

Because of global competition, manufacturing industries are undergoing change in their structure by embedding latest technologies, optimizing plants, and incorporating advanced knowledge and algorithms to exploit resources to the most. Industries are competing to satisfy customers with their individual requirement to surmount the competition. This competition led manufacturing industries in transition period from mass manufacturing, through flexible manufacturing, to lean manufacturing.

High rate of change in the manufacturing systems these days caused static decision making procedure to become unviable for the optimum performance of the system. Various decisions have to be made simultaneously when an unexpected event occurs during production process. This paper reports a research which concentrates on the development of new dynamic route selection system in the context of FMS control. This dynamic system will make decision of selecting appropriate machine for operation from a set of available alternatives depending upon the current status of manufacturing system, and applies various scheduling rules for prioritizing the selection of the part for processing from the queue in front of each machine. The paper are organized as: Section 2 presents a review of previous work. Section 3 describes the applied methodology. Section 4 illustrates the methodology on an illustrative example and shows its benefits. The paper ends with conclusions and references.

2. Previous work

Due to high requirement for variety in products and reduction in lead-time of the product, most of the manufacturing systems have started transforming to the system which is highly automated, responsive, and flexible in nature. Flexible Manufacturing Systems (FMS) are gaining more and more recognition in
today’s world because of their flexibility in variety of ways [8]. Significant research efforts have been devoted to analyze the combined effect of routing flexibility and scheduling flexibility (dispatching rules) on the performance of FMS. Various researchers have contributed to explanation of both combined and individual effect of routing flexibility and dispatching rules on the performance criteria of the FMS. For example, paper [6] conducted experimental analysis of simulated FMS model with total of 14 dispatching rules and three performance measures. The results demonstrated that dynamic scheduling decision increased the overall performance of the system when compared with the performance generated by running the system with only one dispatching rule. Routing flexibility in FMS means alternative machines are available for the same operation in the system. Several researchers investigated the effect of only routing flexibility on the performance of the FMS: the effect of alternative routings and fixed routing of the parts on the performance of the FMS [7], the effect of routing flexibility with alternative machines of identical type [1], consideration of infinite buffer capacity defining a threshold based decision making approach to decide when to consider alternative operation [11], basing the machine selection rules on the processing cost, processing time and combination of the both [12], or experimentation with three control policies (auction-bidding, job sequencing, or their combination) [10]. Availability of alternative process plans for each part in advance helps scheduler in rerouting part in case of events like machine breakdown, long waiting queue for operation, and failure of system objective a methodology which generates complete process plan network for each part and also extracts an optimal process plan in terms of cost and manufacturing time out of it has been developed in [2]. The rule based system for the selection of appropriate machining processes for given feature set has been described in [3].

3. Methodology

In this paper, the rule-based selection methodology is built into FMS. It incorporates basic knowledge and dataset of the manufacturing system, and generates selection alternatives. Then, based on the current system status, it helps to select best process plan to each part type for next production cycle. The new assignment of process plans is based on system status which considers the current FMS performance measures in making real-time plan selection.

3.1 Rule-based system

Rule based system in process planning context is the system which generates alternative processes/machines for each part feature by utilizing available facts (knowledge) about the processes, machines and decision logic (rules to make decision based on part design requirements). Feature in this context is defined as geometrical shape which is manufactured using single tool.

Knowledge of the system is detailed knowledge of i) manufacturing processes - manufacturing capability of processes like: drilling, reaming, milling, grinding etc., ii) machine and tool facts - available machines and tools with their specifications, iii) feature knowledge, which includes feature facts like: types of feature, feature dimensions, quality, tolerance and surface finish requirements. Steps in execution of rule based process planning system are shown in Figure 1, and they include process selection, machine selection, toll selection, and processing time calculation.

![Figure 1: Steps of rule execution](image-url)
Rules represent the logic for decision making. Just like in certain situation human makes decision based on the prevailing condition, rules are also fired (executed) based on the input feature parameters and feature requirements, to select processes which satisfy all the requirements of the feature. Examples of the rules are shown in [3].

3.2 Plan alternatives

When rule based system is run, working memory of the system is populated with process facts, machine facts, tool facts, inserted feature facts and available rules. Based on these facts, several rules are activated and fired; they in turn create or modify the existing facts in the working memory. These creation and modification of facts trigger other rules to execute and chain reaction of executing rules continuous until there are no rules to fire, which signifies the completion of process planning procedure.

By running the rule based system, depending upon available knowledge, the topology and the tolerance requirement of each feature, alternative processes (machines) capable of machining that feature are generated with machining time and tool requirement information. Rule based process selection logic has been described in [3]. Algorithm for the process selection enables the selection of multiple processes for a single feature if its tolerances so require (for example for a high quality hole, processes like drilling, reaming, and boring may be selected). When the complete match is found, it selects that process to make that feature and specifies the machine requirement with the tool constraints. After the selection of the machine and tool constraints it estimates the machining time and cost of manufacturing the feature. If the system cannot find the complete match, it selects the process which can partially satisfy feature and considers it as the final process and generates a new feature out of the unsatisfied attributes of the previous feature. Now this new feature is fed back to the rule based system for the generation of sub process (in-process) for the original feature.

3.3 Real-time selection

Real time process selection can be performed in two ways: selection of one of several alternative routings for each part, or selection of a process for each feature. Both methods can be applied on different performance measures of the FMS system. The method will be explained on selecting processes for each individual feature using machine utilization as performance measure. In order to explain the procedure, consider the data given in Table 1 and 2.

Table 1. System status (Machine utilization)

<table>
<thead>
<tr>
<th>Machines</th>
<th>M1</th>
<th>M2</th>
<th>M3</th>
<th>M4</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Status (Machine Utilization)</td>
<td>0.9</td>
<td>0.2</td>
<td>0.6</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Table 2. Process plan selection

<table>
<thead>
<tr>
<th>Part Name</th>
<th>Feature</th>
<th>Machines</th>
<th>Tools</th>
<th>Processing Time</th>
<th>System Status</th>
<th>Best Machine</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>F1</td>
<td>M1</td>
<td>T001</td>
<td>10</td>
<td>0.9</td>
<td>M3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M3</td>
<td>T004</td>
<td>14</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>P1</td>
<td>F2</td>
<td>M2</td>
<td>T001</td>
<td>15</td>
<td>0.2</td>
<td>M2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M3</td>
<td>T002</td>
<td>10</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>P1</td>
<td>F3</td>
<td>M1</td>
<td>T002</td>
<td>5</td>
<td>0.9</td>
<td>M4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M4</td>
<td>T003</td>
<td>9</td>
<td>0.3</td>
<td></td>
</tr>
</tbody>
</table>

Table 1 shows machine utilization for each machine in the FMS, while table 2 shows processing alternatives for three features (F1, F2, and F3) of part P1, and results of selecting the machine with minimal utilization for each feature. In this case M3 is selected for F1, M2 is selected for F2, and M4 is selected for F3. This simple procedure is performed for all parts processed in FMS, and it is repeated at predefined time intervals, or part count intervals.
4. Example and results

An example is explained in this section demonstrating the application of this rule-based dynamic selection methodology. The example is based on simulation of FMS system with real-time process plan selection. Details of simulation model are given in [13] and only portion related to process plan selection is shown in this section.

4.1 System and database description

In this example total of six types of prismatic parts are considered for manufacturing (see Figure 2). These parts are selected such that every part has various combinations of total number and types of features: hole, slot, pocket, and feature array.

<table>
<thead>
<tr>
<th>Name</th>
<th>AES94</th>
<th>Plate</th>
<th>Netex</th>
<th>USC</th>
<th>Slider</th>
<th>Bracket</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Num. of features</td>
<td>10</td>
<td>11</td>
<td>7</td>
<td>6</td>
<td>18</td>
<td>11</td>
</tr>
</tbody>
</table>

**Figure 2: Part designs**

Based on these selected six prismatic parts, three types of machines CNC-Dill, CNC-Horizontal-Mill and CNC-Vertical-Mill (with total of 8 machines) are selected because of their capability to create variety of features like: hole, slot, pocket, and feature arrays. The machines are equipped with either all tools having same material or all tools having two types of material. Process, machine, and tool configuration is shown in Table 3. As shown, machines are limited to certain processes. For example, CNC- Horizontal Mill (HM) machine is limited to End Milling (EM) Slotting, Side Milling (SM) Slotting, and End Milling (EM) Peripheral, whereas CNC Drill machine is limited to perform only drilling operations. Tools which can be accessed by individual machine are also shown in column Tool Number.

**Table 3. Machine, process, and tool configurations**

<table>
<thead>
<tr>
<th>Tool Material</th>
<th>Machines</th>
<th>Process</th>
<th>Tool Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbide</td>
<td>CNC - HM</td>
<td>Drilling, EM Slotting</td>
<td>(T601 - T619), (T701 - T704)</td>
</tr>
<tr>
<td>HSS</td>
<td>CNC - HM</td>
<td>Drilling, EM Slotting</td>
<td>(T201 - T219), (T301 - T304)</td>
</tr>
<tr>
<td>Both (Carbide &amp; HSS)</td>
<td>CNC - HM</td>
<td>Drilling, EM Slotting</td>
<td>(T2-01,03,05,07,09,11,13,15,17,19), (T101 - T112)</td>
</tr>
</tbody>
</table>

HM = Horizontal Mill, VM = Vertical Mill, EM = End Milling, SM = Side Milling

4.2 Rule-based process planning

For a given part set and FMS database, rule-based process selection is performed through the following steps:

*Step 1:* - Load part and stock model as a 3D CAD model of the part and stock. Data from CAD model is used to create feature-based part model.
Step 2: Run Process selection engine which triggers rule based system to execute (fire) rules based upon available facts in the working memory. These rules are fired until there are no more unused facts remain in the working memory. The final output is in the form of alternatives for each feature with machine, tool and processing time information as shown in Figure 3a. The results from RBPP are exported into .CSV file for the use by process plan selection module.

Figure 3. Process planning output: a) RBPP output for part AES-94, b) Real-time plan selection file

Step 3: Generation of real-time selection input file in which these alternatives are combined in one file to represent it as process plan selection module (9b). This process plan selection module is responsible for i) generating best and alternative process plans, ii) recording system status sent by simulation model, and iii) identifying and transferring appropriate (best) process plan to simulation model based on system status.

Step 4: Real-time selection of alternatives from real-time selection file according to predefined performance measure using procedure described earlier.

4.3 Results

Base on the implemented system described above, experiments were conducted via an integrated simulation framework [13][12]. Different routing policies (Best, Random, DynamicBest, FeatureBest) for selection of process plans where combined with different dispatching rules. Real time process selection has been performed using two performance criteria: 1) machine utilization and 2) queue size. Comparison between the routing policies and dispatching rules for each performance measure has been carried out. The partial results shown in Figure 4 display effect of routing policy and dispatching rules on total output and total WIP for machine utilization as performance measure. The results show improvement in both total output and WIP for all routing policies which allow real-time process selection. Particularly, featureBest routing policy shows improvement over other policies.

5. Conclusion

The paper describes development and implementation of a process selection procedure with two stages: knowledge-based process plan alternative generation, and real-time, performance based, process selection. The procedure is illustrated with an example in which simulation of FMS with real-time process selection provides significant benefit on overall system output.
6. References


