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An Integrative Methodology for Simulation of FMS with Alternate Routings

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Abstract

This paper reports on a simulation study of a sample FMS with integration of two flexibility types: routing flexibility and scheduling flexibility. The paper describes development of an integrative methodology in which process planning system IMPlanner is integrated with FMS control module. IMPlanner's rule based process selection system and FMS's control simulation model perform real-time data exchange in terms of the system status and part routings. FMS is simulated in Arena with four different routing decision policies: a) static best, b) static random, c) routing dynamic, and d) feature focused dynamic and two process selection criteria, machine utilization and machine queue size. Simulation model has been executed on the same data set for four mentioned routing decision policies and for four dispatching policies (FIFO, SPT, SIPT, LIPT). Results of each simulation run in terms of three performance measures; i) resource utilization, ii) throughput, and iii) work in progress (WIP) have been compared in order to determine best routing alternative selection policy, corresponding dispatching policy, and identify the best combination of those two policies. Statistical analysis has been performed on the results to identify the most significant factors that determine the FMS performance in the case of alternate routings.

Key words: *Process planning, Alternate routing, Simulation, FMS*

1. INTRODUCTION

The profit margin of manufacturing industry, a vital component of economies of nations, has been significantly reduced by globalization. Therefore, productivity of manufacturing system and its ability to respond to the dynamically changing market demands, has become a key focus for both researchers and practitioners. Lean manufacturing, with focus on the continuous improvement of time, quality, cost, and flexibility [1], has been one of the most successful philosophies and methodologies recently and still huge potential of future deployment remains.

Flexible Manufacturing System (FMS) is one of the practical implementations of Lean philosophy. By dynamically respond to system statues, FMS is able to significantly reduce the percentage of idle capacity, improve the productivity, and quickly adjust ongoing production based on continuous changing market condition. To achieve the flexibilities included in FMS, machine, process, routing, operation, production, volume, layout, and production flexibilities [2], Dynamic Decision Making System (DDMS) plays a critical role by generating alternative process plan (routing), selecting process plan and dispatching policy based on current system status. The proposed methodology integrates IMPlanner, FMS with DDMS, and simulation model for testing purpose. The paper is organized as follows. Section 2 provides a brief overview of the previous work. Section 3 explains an integrative methodology that combines process planning and FMS control. Section 4 describes the experimentation which includes parameters, model creations, and output collection. Analysis of the results of simulation experiments is given in section 5, and the paper ends with conclusions in section 6 and list of references.

2. PREVIOUS WORK

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. A performance measure of each individual system varies depends upon the objective of the company or industry, or upon prevailing competitive environment

All dynamic systems that consider various dispatching rules select the next part to be processed from the queue, waiting in front of machine, depending on the current application of the rule. Researchers have developed and experimented variety of rules using simulation modeling approach. Chan et al [3] conducted experimental analysis of simulated FMS model with total of 14 dispatching rules and three performance measures. On the other hand, Vinod and Sridharan [4] have developed a simulation model for the job shop which considered 12 dispatching rules out of which five new setup dependent rules (SSPT, JSPT, JEDD, JEMDD, JSSPT) were introduced.

To introduce flexibility in terms of dynamic selection of the dispatching policy which optimizes the objective of the system, Jeong [5] has proposed a conceptual framework which integrates knowledge based system and genetic algorithm (GA) optimizer with the simulation model. Jeong, Lim and Kim [6] have developed an integrative framework where GA was used to provide optimized schedules to the simulation model for the execution of the job. In every effort of developing dynamic system with dispatching flexibility, researchers have found that various dispatching policies certainly optimize performance of the observed system.

Incorporation of dynamic dispatching rules into FMS system certainly increases the performance. However, to exploit the inherent flexibility of FMS, various researchers have investigated combined effect of dispatching decision and routing flexibility on the performance of the FMS. Routing flexibility in FMS means alternative machines are available for the same operation in the system. This routing flexibility also brings the trade-off of having higher processing time on the alternative machines when compared to the original machine for the operation Chan [7] developed simulated FMS model using package SIMFACTORY II.5. Model has implemented three routing flexibility policies (NARs, ARDs and ARPs) and four dispatching rules (SPT, SIPT, LPT, and LIPT). Apart from experimenting combined effect of routing flexibility and dispatching rules, various researches have introduced interesting concepts in determining the routing flexibility. Ozmutlu and Harmonosky [8] developed a threshold based decision making approach to decide when to consider alternative operation. The developed system considers alternative machine for the part only if by routing part to the alternative machine brings the benefit in terms of the waiting time above the predefined threshold value. Similarly, Piplani and Talavage [9] introduced the concept of “entropy” of the system in decision making to select the next part to be operated when machine becomes idle. Entropy of the system is the sum of the entropy of each part that prevails in the system at some point of time. Entropy of each part depends upon the number of alternative operations available for each operation in the complete process plan for that part (higher the number of alternatives, higher the entropy).

3. METHODOLOGY

The proposed methodology is an integrative FMS structure, as shown in Figure 1. Alternative process plans are generated by IMPlanner [10], using rule-based system. Process Plan Selection Module is responsible for Process plan selection from a number of process plans generated by IMPlanner.

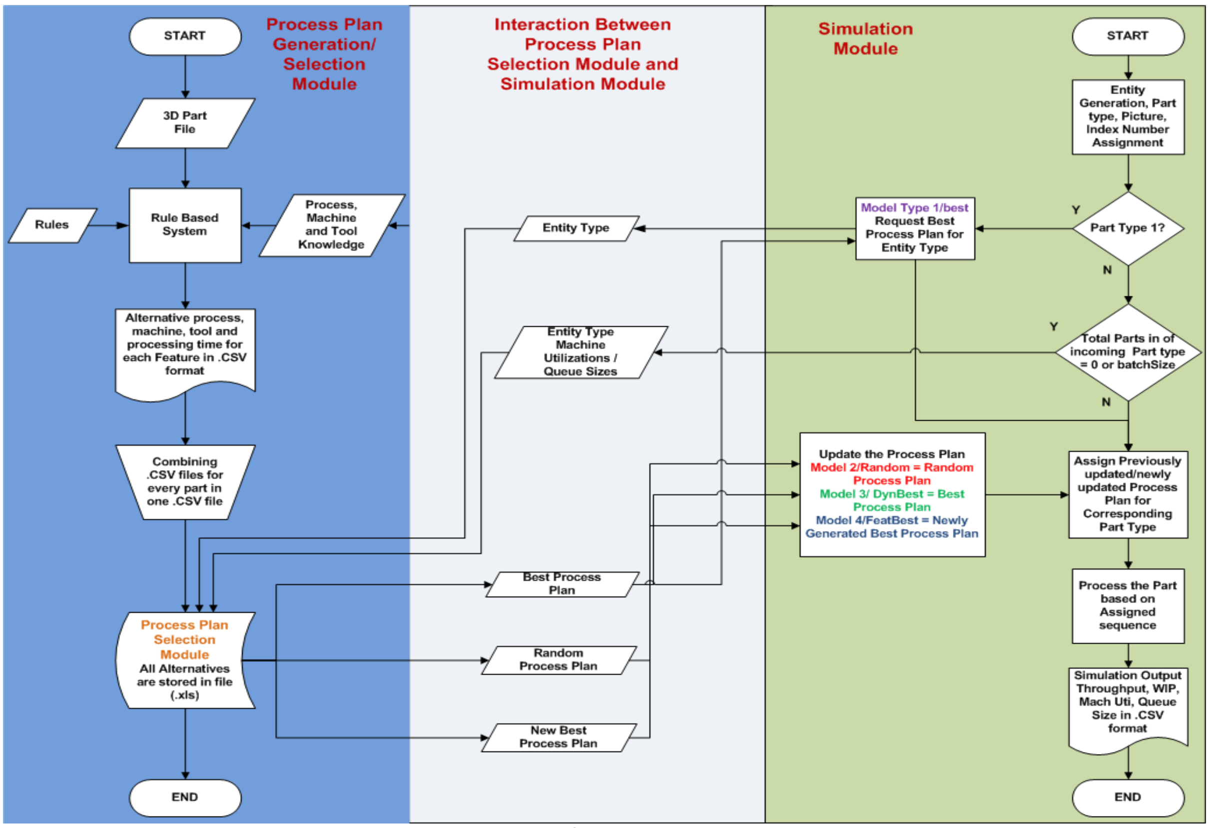


Figure 1. Flow of Integrated Framework

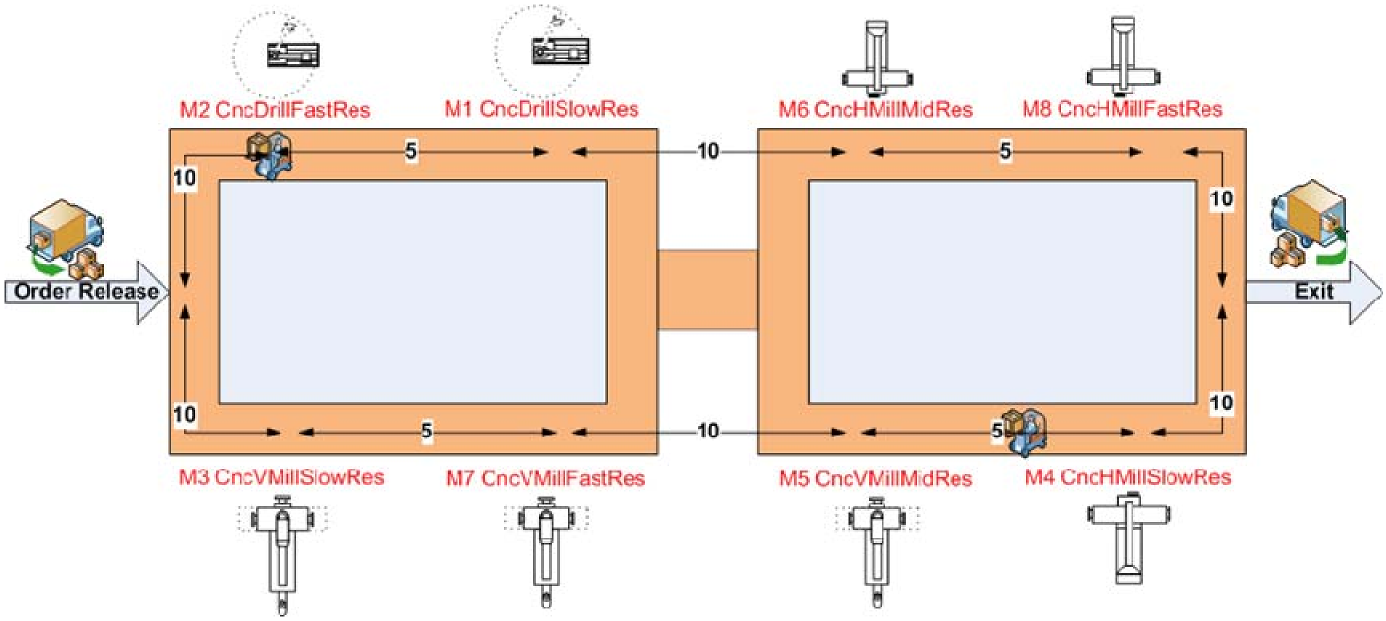


Figure 2. FMS Configuration

Four different models for the FMS control are developed: Static Best Model, Static Random Model, Routing Dynamic Model, and Feature Focused Dynamic Model. Four different dispatching policies are also deployed in terms of part priority selection on different machines. In dynamic models, Process Plan Selection Module also monitors the entire systems status and changes between different plans to avoid long waiting queue at decision points in order to increase the utilization of every available machine. Machine utilization and other output of the system are recorded after running all combinations of different routing and dispatching policies, then analysis is performed to determine the best performing model type and dispatching policy.

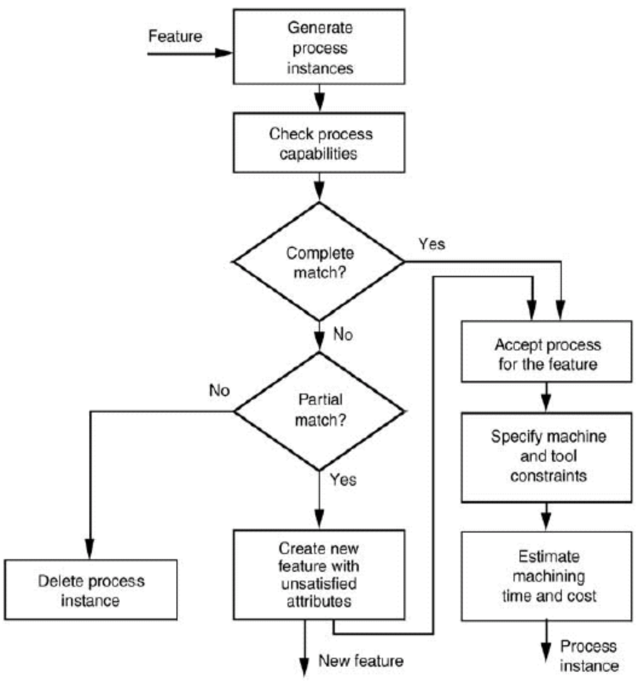


Figure 3. Rule based system algorithm [12]

3.2 Process Plan Generation/Selection

In this study, Process plan is generated by Rule Based System (RBS), developed by Sormaz and others [11] [12], as shown in Figure 3. Features of different parts are obtained from their CAD models, machines, tools and cutting parameters are obtained from a predefined knowledge base. By running Rule Based System, triggered rules are able to generate available alternative process plans based on system facts. The best process plan is generated and three other alternatives (randomly selected) are generated for each part, stored in the process plan selection module, along with system status sent by simulation model. The selection of process plan will be performed by process plan selection module based on both alternative process plans and the current system status.

3.3 Simulation

Simulation model is implemented as a template capable of producing four different model types that correspond to various routing policies. This template has been developed on the platform of Arena and VBA [13], representing the logic of i) routing policy, ii) dispatching rule, iii) process plan review, iv) process plan assignment, and v) system status update in terms of machine utilization and queue size. There are three sub-models in every simulation model, Part Arrival Model, Manufacturing Model, and Exit Model,. Process plan selection is triggered at every predefined decision making points based on the current system status.

The four model types are defined as below:

Static Best: - Selecting best process plans in terms of lowest total processing time for each part at the beginning of simulation and assigning it to all entities of same part type to follow, as shown in Figure 4.

Static Random: - Selecting random process plan out of alternatives for each part type at every process selection decision point (PSDP) and assigning that

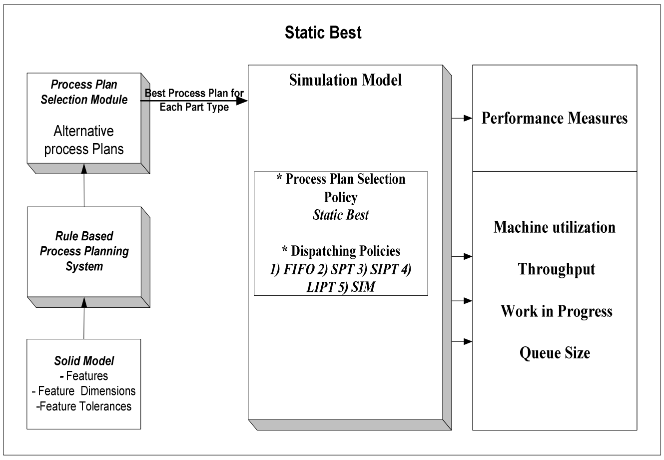


Figure 4. Static Best Model

process plan to corresponding entities between two consecutive decision points, as shown in Figure 5.

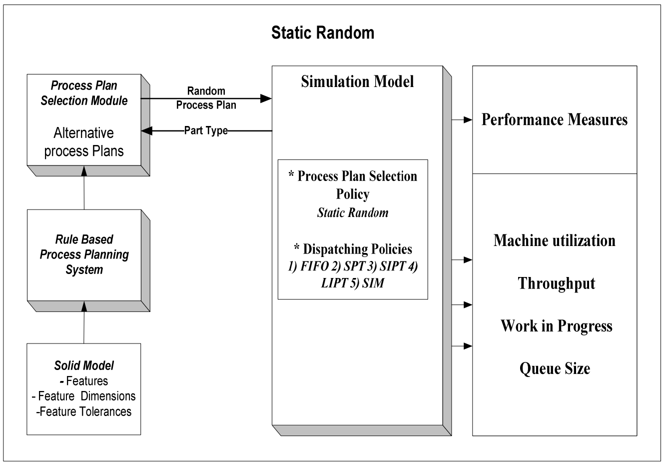


Figure 5. Static Random Model

Routing Dynamic Best: - Selecting best process plan, in terms of plan containing machines with lowest machine utilization or lowest queue size, out of alternatives for each part type at every PSDP and assigning that process plan to corresponding entities between two consecutive decision points, as shown in Figure 6.

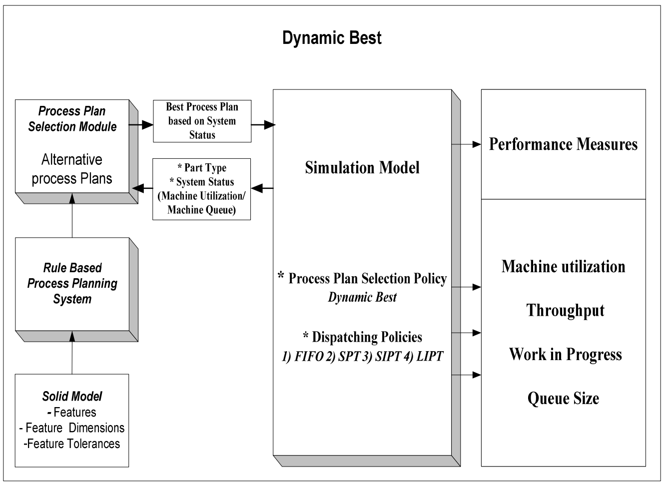


Figure 6. Dynamic Best

Feature Focused Dynamic Best: - Generating new best process plan, in terms of machines having lowest machine utilization or lowest queue size, for each part type at every PSDP and assigning that process plan to corresponding entities between two consecutive decision points, as shown in Figure 7.

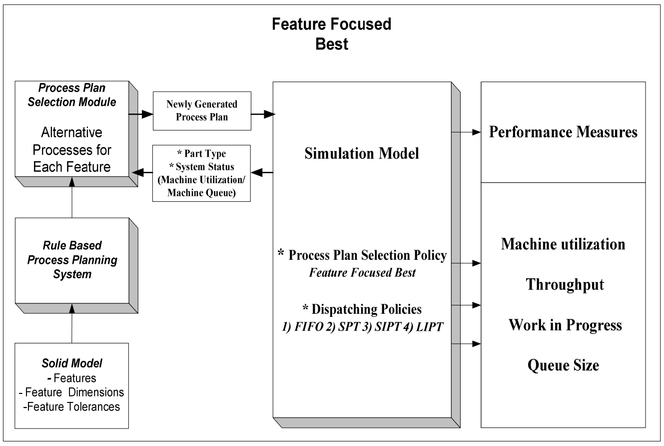


Figure 7. Feature Focused Best

Giving the priority to parts waiting in the queue, four dispatching policies are defined as below:

First in first out (FIFO):- first part that joins the queue is the first part that is sent to the machine,

Shortest processing time (SPT):- incoming parts are placed in the queue so that part having the lowest total processing time is sent to the machine first,

Shortest imminent processing time (SIPT):- incoming part is placed in the queue so that part having lowest processing time on the current machine is sent to the machine first,

Largest imminent processing time (LIPT):- incoming part is placed in the queue so that part having highest processing time on the current machine is sent to the machine first.

4. EXPERIMENTATION

In this section, the experimentation of the proposed integrated framework is explained.

4.1 Experimentation Parameters

- Replication length: - replication length of each run is calculated based on FMS industry working for two shifts a day for 250 days in a year. So, Total hours of production/year = 16 x 250 = 4000 hours.
- Number of replications: - each scenario is run for 10 replications.
- Inter-arrival distribution: - Exponential distribution with 7 minutes is selected for experimentation.
- Batch Size: - Three values for batch sizes: 100, 150, and 200 are used in this research. The batch size refers to the interval between decision points at which it is necessary to change part routing (process plans) according to the system performance. Those numbers are based on pilot run of simulation model which determines average number of parts out in every week, every eight days of production, and biweekly production for each part type.
- Warm-up period: - 2000 hours, which gives a total replication length of 6000 hours

4.2 Model Creation

Every simulation model is a combination of four attributes: routing policy/model type, dispatching rule, batch size, and performance criterion. The values of routing policy/model type is (1)Best, (2)Random, (3)Dynamic Best and (4)Feature Best; the values of dispatching policy includes (1)FIFO, (2)SPT, (3)SIPT and (4)LIPT; the batch size (threshold value) has three options, 100, 150 and 200; two types of performance criteria can be selected, (1)Machine Utilization and (2)Queue Size. Therefore, the total number of scenarios combining these attributes is, 4 x 4 x 3 x 2 = 96.

The process of model creation is shown in Figure 8. As the figure shows, all these scenarios are generated automatically from an Excel file which combines alternative process plans from rule-based process selection and for each scenario an input file for simulation is created. Scenario files are combined with real-time process selection module. Using VBA, simulation template imports simulation input parameters from the files of different scenarios, to create 96 simulation models based on input data. Scenario files also serve the purpose of dynamically selecting alternative routings and creating process plans for dynamic models.

4.3 Output and Analysis

During simulation runs, system outputs of every simulation model and its replications are recorded and combined into one file for analysis. Two methods are employed for result analysis: i) Multifactor ANOVA (Analysis of Variance) test and ii) Comparison through charting technique. ANOVA test is used to determine the most influential attributes, while charting technique is used to analyze and compare the performance of Feature Dynamic Best model with other three model types by plotting the system output of different routing selection and dispatching rules.

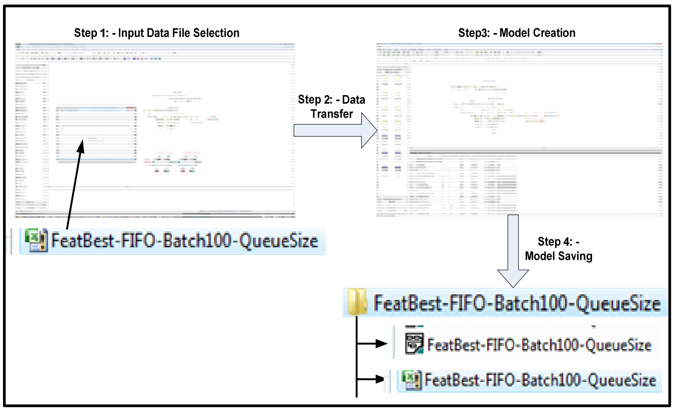


Figure 8. Model Creation

5. RESULT AND ANALYSIS

In this section the analysis of simulation results is described. ANOVA test is shown first in order to determine important parameters for the system performance, and then performance of various models, i.e. routing and dispatching policies is shown with corresponding conclusions.

5.1 ANOVA Test

Multi-Factor ANOVA test is utilized to determine the most influential attributes. The results are shown in Table 1. As can be seen from Table 1, individual and combined effect of attributes routing policy, dispatching rule, and performance criteria has major impact on the performance of the system (P value is less than 0.05). It is also observed from the table that every combination of batch size with other three attributes does not yield change in every performance measure of the system. Therefore, for further analysis combined effects of attributes: routing policy, dispatching rule, and performance criteria are used because they affect all the performance measure of the system. Batch size is ignored in further analysis.

Table 1 ANOVA Analysis of simulation results

	P-Value/Performance Measure			
Source	**Throughput**	**Total WIP**	**Machine Utilization**	**Count**
A	0.000	0.000	0.000	3
B	0.000	0.000	0.000	3
C	0.000	0.000	0.230	2
D	0.000	0.000	0.000	3
A * B	0.000	0.000	0.000	3
A * C	0.000	0.000	0.000	3
A * D	0.000	0.000	0.000	3
B * C	0.578	0.011	0.798	1
B * D	0.000	0.000	0.000	3
C * D	0.002	0.207	0.222	1
A * B * C	0.449	0.060	0.312	0
A * B * D	0.000	0.000	0.000	3
B * C * D	0.448	0.185	0.583	0
A * C * D	0.004	0.000	0.014	3

Legend: A – Routing Policy, B – Dispatching Rule, C – Batch Size, D – Performance Criteria

Count = Number of performance measures affected by individual or combined attributes

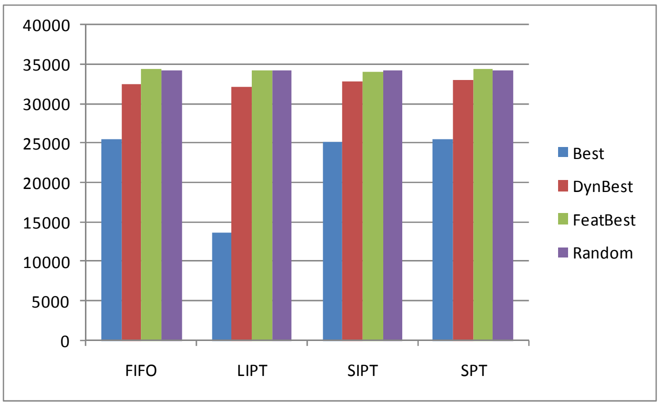
5.2 Throughput

The throughput of the proposed system is studied under two performance criteria, machine utilization and queue size. The result is shown in Figure 9.

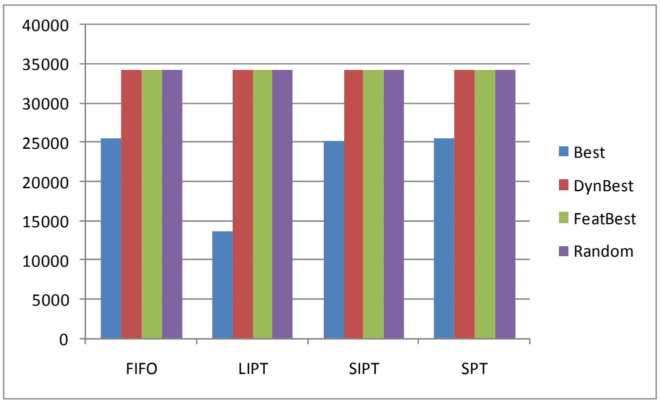
As shown in Figure 9, StaticBest routing policy yields very low throughput in comparison to other three model types for every combination with dispatching rule in both the criteria. This is because other model types are much more dynamic in selection of process plan than StaticBest model.

By visual inspection of Figure 9 it can be concluded that for machine utilization as performance criteria, FeatureBest routing policy outperform all other routing policies when combined with dispatching rule FIFO and SPT. Similarly for queue size as performance criteria, DynamicBest, FeatureBest and StaticRandom have equal throughput when combined with any dispatching rule.

When compared for maximum percentage increase in throughput between the models for dispatching rule in both the performance criteria. It is observed that, for machine utilization as performance criteria, FeatureBest model outperforms StaticBest model by 150% and DynamicBest model by 7% in terms of increase in throughput for LIPT. Similarly for queu size as performance criteria, FeatureBest model outperforms StaticBest model by 149% and DynamicBest model by 0% in terms of increase in throughput for LIPT.



a)



b)

Figure 9. System Throughput a) Performance Criteria-Queue Size, b) Performance Criteria-Machine Utilization

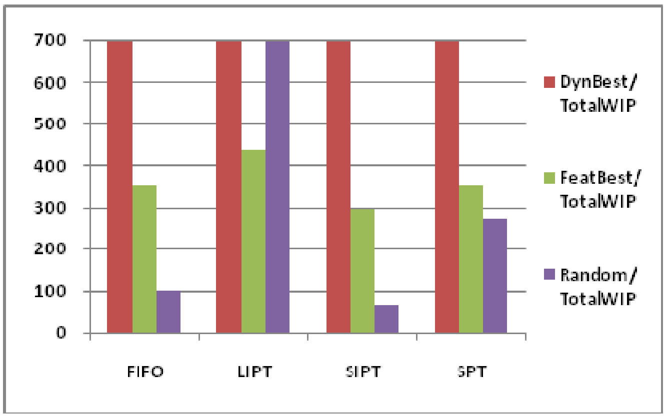
5.3 Total WIP (Work In Progress)

Similarly, the total WIP is also studied under two performance criteria, machine utilization and queue size. The result is shown in Figure 10.

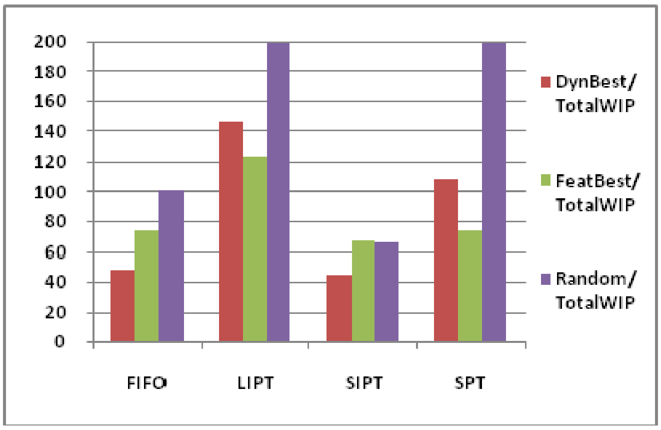
In this chart data for StaticBest model are not presented as they did not perform well in comparison to other three models and for better visual comparison between other three model types.

As can be seen from Figure 10, FeatureBest model outperform DynamicBest model with very large difference in total WIP for machine utilization as performance criteria, whereas queue size as performance criteria FeatureBest policy surpasses DynamicBest only when combined with LIPT and SPT. Random model outperforms other models significantly.

Reason behind exceptional performance of FeatureBest routing policy when machine utilization as performance criteria selected is in fact that FeatureBest model generates new best process plan having machines with lowest utilization and machine changeover, whereas DynamicBest model has already fixed process plans with fixed machine change over. Because of these fixed process plans, when selecting best process plan for next phase of production in DynamicBest, process plan having overall lowest machine utilization compared to other alternatives is selected. There is a possibility that process plan selected may have lowest machine utilization according to selection criteria but might have higher queue size. Therefore DynamicBest model underperformed than FeatureBest model in terms of total WIP.



a)



b)

Figure 10. Total WIP: a) machine utilization performance, b) queue size performance

In case where queue size as performance criteria selected, selection of dispatching rule impact the queue size (i.e. LIPT has higher queue than SIPT because SIPT gives priority to parts having lowest processing time and thus have lower total queue size and waiting time of parts) and thus influence the selection of process plan for the next phase of production in both FeatureBest and DynamicBest models.

In this case FeatureBest has tendency of selecting machine for operation in hierarchical order; fast machine has the highest, medium machine has medium and slow machine has lowest priority in selection. This hierarchical structure led FeatureBest routing policy to surpass DynamicBest policy when combined with LIPT and SPT.When compared for maximum percentage reduction in total WIP between the models for dispatching rule in both the performance criteria. It is observed that, for machine utilization as performance criteria, FeatureBest model outperforms StaticBest model by 98% and DynamicBest model by 78% in terms of reduction in total WIP for LIPT. Similarly for queue size as performance criteria, DynamicBest model outperforms FeatureBest model by 34% in terms of reduction in total WIP for FIFO.

5.4 Machine Utilization

Similarly, the average machine utilization is also studied under two performance criteria, machine utilization and queue size. The results are shown in Figure 11 and Figure 12.

As can be seen from Figure 11 for machine utilization as performance criteria, average machine utilization for FeatureBest routing policy is balanced between all the alternative machines of same type. On the other hand, DynamicBest and StaticRandom policies load fastest machine more and does not distribute load to other alternative machines of same type.

Similarly for case where queue size is the performance criteria, FeatureBest policy distributes load equally for drilling operation between CNCDillFast and CNCDrillSlow machine, whereas for milling operations it distributes load sequentially from fastest machine to slowest machine.

When compared for maximum percentage increase in average machine utilization between the models for dispatching rule in both the performance criteria. It is observed that, for machine utilization as performance criteria, FeatureBest model outperforms StaticBest model by 70% and DynamicBest model by 21% in terms of increase in average machine utilization for FIFO. Similarly for queue size as performance criteria, DynamicBest model outperforms FeatureBest model by 4% in terms of increase in average machine utilization for every dispatching policy

6. CONCLUSIONS

This research has presented successful development of dynamic integrative framework between process plan selection and simulated FMS model. FMS model template was created to simulate variety of scenarios having unique combination of routing policy and dispatching rule. In this research four routing policies (Static Best, Static Random, Routing Dynamic Best, and Feature Focused Dynamic Best) and four dispatching rules (FIFO, LIPT, SIPT, and SPT) are implemented to observer their combined effect on FMS in terms of improvement in predefined performance measure of the system. Out of four routing policies three of them (Static Best, Static Random, and Routing Dynamic Best) generates process plans for parts statically, whereas developed Feature Focused Dynamic Best policy generates new process plan for next phase of production based on system status in term of either average machine utilization or total queue size at every process selection decision point. This newly generated process plan has not only improved the predefined performance measures of the system but also has balanced load between the overloaded machine and alternative machines of similar type. Feature Focused Dynamic Best routing policy has outperformed Static Best and Routing Dynamic Best routing policies in terms of balancing load between the machines, increasing throughput, and reducing total WIP of the system.

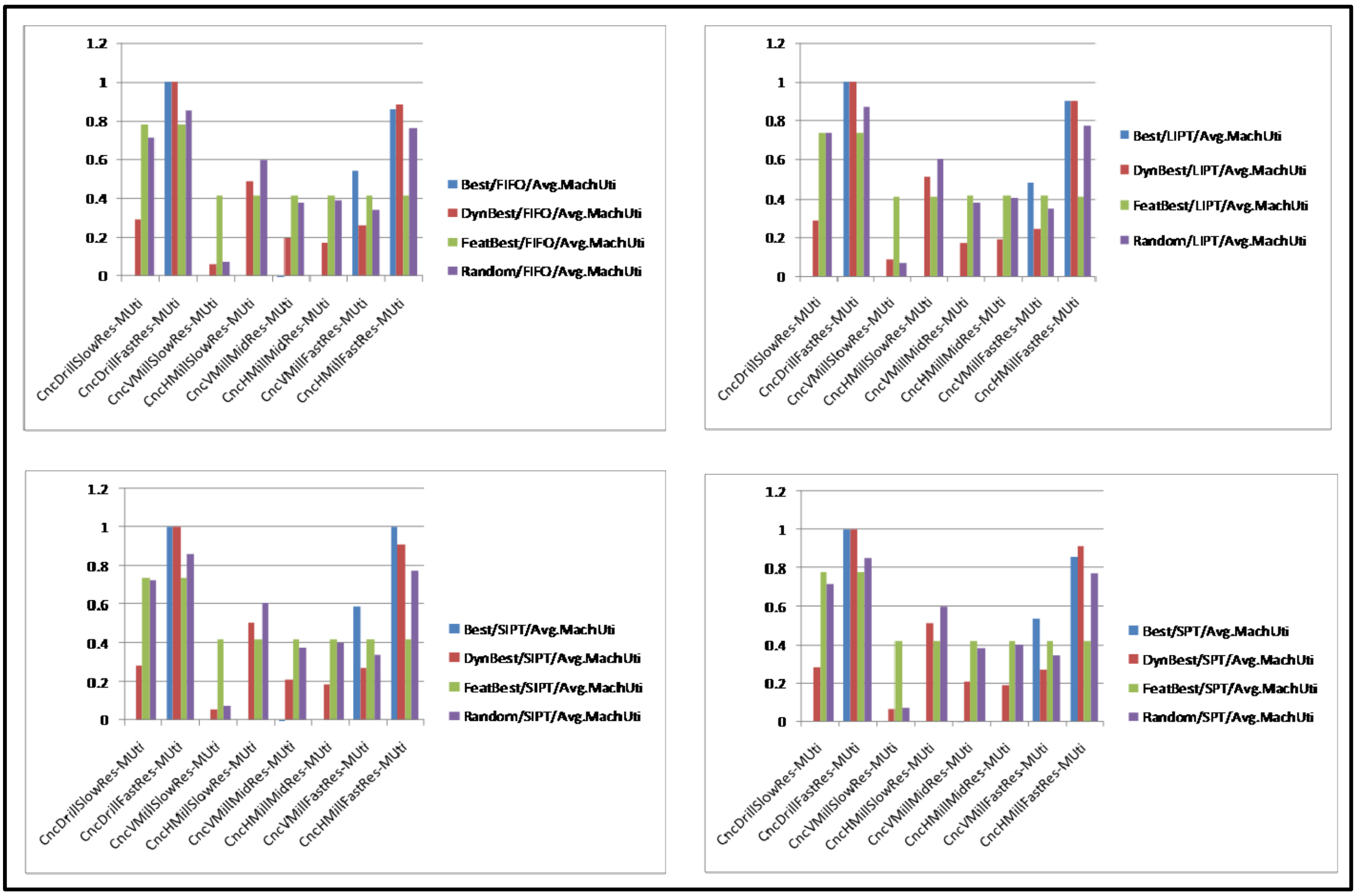


Figure 11. Average Machine Utilization (Performance Criteria-Machine Utilization)

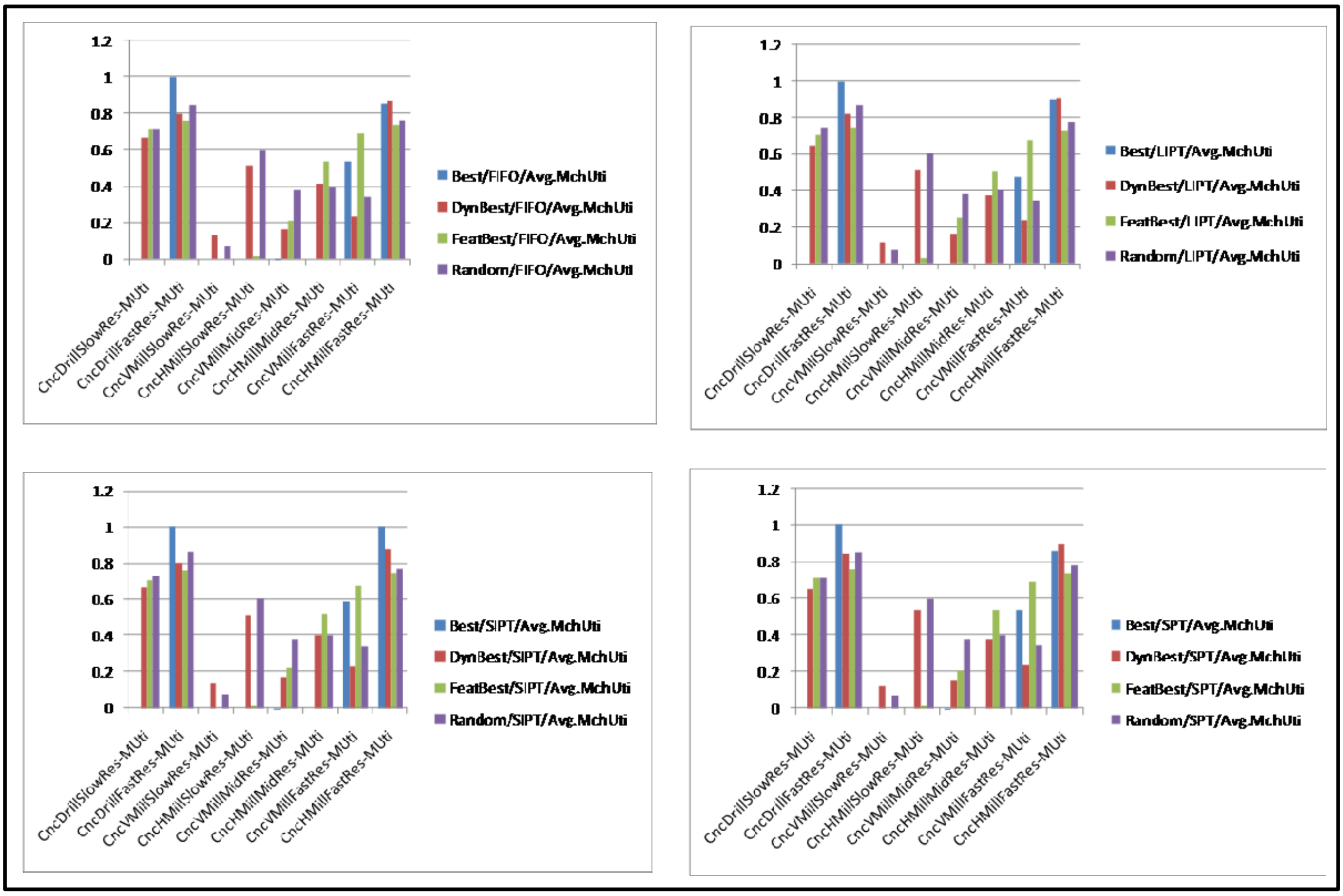


Figure 12 Average Machine Utilization (Performance Criteria-Queue Size)

7. REFERENCES

[1] C. T. Leondes, “Synchronization of production rate with demand rate in manufacturing systems,” in Optimization methods for manufacturing: computer-aided design, engineering, and manufacturing systems techniques and applications, IVth ed., CRC Pr I Llc, 2000, ch. 1, pp. 1-44.

[2] J. Browne, D. Dubois, K. Rathmill, P. Sethi, and KE. Stecke “Classification of flexible manufacturing systems,” FMS Mag., vol.114, no.7, April 1984.

[3] F. T. S. Chan, H. K. Chan, H. C. W. Lau, and R. W. L. Ip, “Analysis of dynamic dispatching rules for a flexible manufacturing system,” J. of Materials Processing Tech., vol.138, pp.325-331, 2003.

[4] V. Vinod, and R. Sridharan, “Scheduling a dynamic job shop production system with sequence-dependent setup: an experimental study,” Robotics and Computer-Integrated Manufacturing, vol.24, pp.435-449, 2008.

[5] K. Jeong, “Conceptual frame for development of optimized simulation-based scheduling systems,” Expert Systems with Applications, vol.18, pp.299-306, 2000.

[6] S. J. Jeong, S. J. Lim, and K. S. Kim, “Hybrid approach to production scheduling using genetic algorithm and simulation,” Int. J. Adv. Manuf. Technol., vol.28, pp.129-136, 2006.

[7] F. T. S. Chan, “Effects of dispatching and routeing decisions on the performance of a flexible manufacturing system,” Int. J. Adv. Manuf. Technol., vol.21, pp.328-338, 2003.

[8] S. Ozmutlu, and C. M. Harmonosky, “A real-time methodology for minimizing mean flowtime in FMSs with routing flexibility: Threshold-based alternate routing,” European J. of Operational Res., vol.166, pp.369-384, 2005.

[9] R. Piplani, and J. Talavage, “Launching and dispatching strategies for multi-criteria control of closed manufacturing systems with flexible routeing capability,” Int. J. of Prod. Res., vol.33, no.33, pp.2181-2196, 1995.

[10] D. N. Sormaz, J. Arumugam, S. Rajaraman, Integrative Process Plan Model and Representation for Intelligent Distributed Manufacturing Planning, International Journal of Production Research, Vol. 42, No. 17, p. 3397 - 3417, 2004.

[11] D. N. Sormaz, J. Arumugam, and A. Wadatkar, “Generation of Manufacturing features and alternative process plans,” Technical report for Delphi, OH, Athens, March 28, 2003.

[12] D. N. Sormaz, J. Arumugam, and C. Ganduri, Process Planning and Scheduling for Distributed Manufacturing, Springer London, 2007.

[13] R. P. Sadowski, W. Kelton, and D. T. Sturrock, Simulation with Arena, McGraw-Hill Science Engineering, 2007.

Integracijska metodologija za simulaciju FMS sa naizmeničnim rutiranjem

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Apstrakt

Ovaj rad izveštava o studiji simulacije uzorka FMS sa integracijom dva tipa fleksibilnosti: fleksibilnost rutiranja i fleksibilnost rasporeda. Rad opisuje razvoj integracijske metodologije u kojoj je sistem planiranja procesa IMPlanner integrisan sa FMS kontrolnim modulom. IMPlanner-ov sistem selekcije procesa baziran na pravilima i FMS-ov model simulacije kontrole vrše razmenu podataka u realnom vremenu kada se govori o rutiranju statusa i delova sistema. FMS je simuliran u Areni sa četiri različite metode donošenja odluka o rutiranju: a) najbolje statičko rutiranje, b) proizvoljno statičko rutiranje, c) dinamika rutiranja i d) dinamičko rutiranje određeno karakteristikama, kao i sa dva kriterijuma izbora procesa, upotrebom mašina i veličinom reda mašina. Model simulacije je izvršen na istom nizu podataka za četiri pomenute metode odlučivanja o rutiranju za tri mere performansi: i) upotreba resorsa, ii) propustljivost i iii) radovi u toku, i oni su upoređeni kako bi se odredila metoda alternativnog izbora najboljeg rutiranja, odgovarajuća metoda isporuke, kao i da bi se identifikovala najbolja kombinacija ove dve metode. Statistička analiza je izvršena na rezultatima kako bi se identifikovali najznačajniji faktori koji određuju performanse FMS u slučaju alternativnih rutiranja.

Ključne reči: *planiranje procesa, naizmenično rutiranje, simulacija, FMS*