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MODELING OF A TOOL SHARED FLEXIBLE MANUFACTURING SYSTEM

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ABSTRACT

This research investigates the impact of control rules for tool selection and initial work release on the performance of a manufacturing system in a tool shared environment. A "look ahead" policy was used to determine the requirement of tools. Various rules for tool sharing were studied with makespan and tool transporter utilization as performance measures. Makespan of a schedule is defined as the time required to complete all jobs in a given batch. Impact of tool duplication, i.e., availability of multiple copies of tools in the system was also addressed. Simulation was used for modeling the system. Design of experiments techniques were used to analyze simulation outputs. The analysis of results indicated certain request selection rules resulted in increased system performance, while initial work release rules had no impact on the system.

1 INTRODUCTION

Modern FMS is a group of versatile machines that allows for the performance of more than one operation on a workpiece without its removal from the machine. This eliminates intermediate setups since the workpiece does not have to leave the machine until all its operations are complete. This also reduces the need to move parts to various machines for their processing. However, we need to have required tools on a machine magazine to process all the parts that may arrive. After the tool completes its operation on a part, it is returned to the tool magazine where it remains idle until another operation requiring the same tool is initiated on the machine. In such cases utilization of tools is very low. These idle tools can be shared among machines increasing tool utilization and reducing the total number of tools in the system. However, this may lead to situations where machines may be forced to wait for the want of required tools. Gaalman, Nawijn and Platzer [1987], ElMaraghy [1985], Han, Na and Hogg [1989] have addressed the above situation.

2 PREVIOUS RESEARCH

Tool management is having the right tools on the right machines at the right time to manufacture workpieces in the right quantities. The parameters that influence tool management for an FMS are part variety, operation times, number of operations, number of work stations and tool life [Little, Kehoe and Al-Maliki, 1988; Gray, Seidmann and Stecke, 1993]. Tool information aids in the reduction of tool inventory by initiating replacement or reconditioning of tools when required. Little, Kehoe and Al-Maliki [1988], Garapati and Wang [1988], Anstiss [1988] and Ranky [1988] developed tool information models to manage tool data and to aid the process of tool planning. Hammer [1989], Kiran and Krason [1988], Carter [1985] and Ranky [1988] have described various methods of tool transportation ranging from the use of AGVs to change of entire tool magazines.

Tool sharing is considered an effective method to achieve reduction in tool inventory and associated costs. ElMaraghy [1985] developed a simulation model (TOLSIM) to study the sharing of tools between the machine tool magazine, intermediate tool storage and a central tool storage. The objectives were to reduce distance traveled by the tool transporter, minimize machine idle time, maximize equipment utilization and reduce tool redundancy. Using simulation to study the feasibility of tool sharing in an FMS, Gaalman, Nawijn and Platzer [1987] showed that tool sharing created savings on the overall cost of an FMS. A "look ahead" policy was used to determine both the requirement of a tool at a machine center and the availability of tools before actual operation took place. Machine idle time due to non-availability of tools was used as a measure to study the effect of tool sharing and number of tool replications. Han, Na and Hogg [1989] developed a mathematical model for tool loading with the objective of maximizing throughput. They approximated the model performance by developing a heuristic. The performance of the heuristic was compared to the mathematical model using simulation. Carrie and Perrera [1986] developed a model to reduce the number of tool changes due to part variety. Tool sharing was not explicitly modeled, but change of tools due to tool wear or in part variety was considered.

Montazeri and Van Wassenhove [1990] analyzed several scheduling rules in an FMS using simulation. They used the following performance measures: machine utilization, buffer utilization, shuttle utilization, makespan and variance of waiting time. No single scheduling rule was found to be significant. They suggested that the user could implement any of the developed scheduling rules. O'Keefe and Kasirajan [1992] studied interaction between dispatching rules and next station selection rules. They proposed various rules for the initial selection of the machining station and then the next station for subsequent operations and used flowtime as a performance measure. The next station selection rule and the dispatching rules gave similar system performances. They also observed that material handling usage varied very little between the studied rules.

3 PROPOSED RESEARCH

In a tool shared environment machine idle time due to non availability of required tools occurs because these tools are either available on other machine magazines awaiting transportation or are in use. To reduce this idle time, it is essential to initiate tool movement even while the current operation is being completed. A "look ahead" policy would determine the tool required for the next operation. The requirement may be obtained from the process plan of the workpiece. Once the required tool has been identified, the machine issues a request to a central controller. The controller collects these tool requests. A control rule is then used for selecting a tool request. A tool selection rule is then applied when a tool is available at more than one machine. The various rules studied are:

Request Selection Rules which select a request from a pool of requests issued by various machines. Some suggested rules for request selection are:

i. First Come First Served (FCFS): Handle requests from various machines in the order of arrival.
ii. Least Number of Operations Remaining(LOR): Select the tool request from the machine having the least number of remaining operations next.
iii. Shortest Imminent Process Time (SIPT): Select tool request from the machine having a part with the smallest processing next.
iv. Shortest Imminent Ratio (SDT): Select job with the smallest ratio of processing time of imminent operation to the total processing time.

For the sake of completeness, the complements of the above mentioned rules namely, Most Number of Operation Remaining (MOR), Longest Imminent Processing Time (LIPT) and Longest Imminent Ratio (LDT) are also included. The focus of this research is to study the above mentioned rules in a tool sharing situation.

Tool Selection Rules which select the machine from which tool is to be transported to fulfil a selected request. "Shortest Distance Travelled" rule was used as the tool selection rule throughout the study as this was determined significant from previous research [Kashyap and Khator, 1993]. This rule satisfies a tool request based on the distance to be traveled by the tool transporter to get and deliver the tool. Tool selection rules are applied only when the number of copies of tools are greater than one. When there is only one copy of tool then request selection rules are alone applied.

Initial release of jobs into the system can also be a factor in determining the performance of the manufacturing system. Some of the suggested rules for initial work release are:

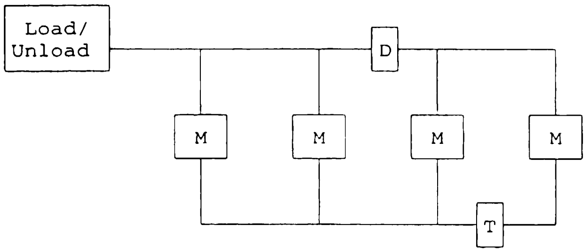
i. First In First Out (FIFO): The jobs would be released to the machines based on the order in which they arrived into the system. In a case where all the jobs to be processed during a planning horizon are available, this rule would essentially behave like a random rule.
ii. Least Number of Total Operations (LTO): Jobs with the fewest number of operations would be released into the system with a higher priority.
iii. Most Number of Total Operations (MTO): Jobs with the most number of operations would be released into the system with a higher priority.

In addition to the above traditional scheduling rules based on duedate, slack, slack/operation, slack/total processing time, etc. could also be used for selecting the tool request as well as the release of jobs into the system.

4 INPUT DATA AND MODELING

A four machine FMS system is studied in this research. ElMaraghy [1985], Gaalman, Nawijn and Platzer [1987], Montazeri and Van Wassenhove

[1990] and O'Keefe and Kasirajan [1992] have studied similar systems. The machines are assumed identical and can perform all the operations on a job type without removing it, as long as necessary tools are available. A linear track for tool transfer has been used as shown in Figure 1. This layout avoids any interaction between the tool transporter and the workpiece transporter.



D - Material Handling Transporter
T - Automatic Tool Transporter

Velocity of Transporter	3.00 m/s
Acceleration/Deceleration	3.00 m/s^2
M - Machine	
Distance between machines and load/unload station	7.00 m
Distance between transporters and machine	1.50 m
Load time/Unload time per job	10/5 min.

Figure 1: Layout of FMS

In the absence of reliable industrial data, the number of operations for a job type, the processing times for these operations and the operation sequence have been determined by sampling from a uniform distribution. There were ten tools used in the system, randomly assigned to each operation. The total number of operations for each job varied between 14 to 18. The processing times for each operation was between 10 to 200 minutes. Automated Guided Vehicles (AGVs) are used for the transportation of workpiece and tools because of their flexibility in transportation and adaptability to future changes. Load/unload times, velocity and acceleration of AGVs is also shown in Figure 1.

A simulation model to capture the effect of these rules on tool sharing was developed using SIMAN IV [Pegden, Shanon and Sadowski, 1990]. At the start of simulation, the system is loaded with the required number of jobs. These jobs are then ranked based on the initial work release rules. The necessary tools are also loaded into various machine magazines. Tools are distributed on various machines and no more than one copy of a tool is allocated to a machine. Parts are released when a machine and a material handling transporter is available. If a tool is available on the machine, processing starts immediately. In case of non-availability of the tool in the magazine, a request is issued for the required tool. Decision rules discussed earlier are applied and transportation of the tool is carried out. In the event the required tool is busy, the request is stored until a tool is available. The tool requirement for the next operation is determined. If the needed tool for the next operation is available in the machine magazine, it is reserved. Otherwise, a request for this tool is issued. Simulation stops when all parts in the system are processed. The simulation modeling logic is shown in Figure 2.

The system was studied for different scenarios ranging from the availability of only one copy of tool in the system to a maximum of three copies each. Tool life is an important parameter with regards to cutting tools. Tool life for the various tools were obtained from tool life distributions proposed by [Wagner and Barash, 1971 and Ramalingam, 1977]. Tool lives are assumed to be lognormally distributed.

5 MODELING ASSUMPTIONS

Since it is impossible to incorporate every detail of the system into the simulation model certain assumptions were made. The following are the assumptions made in the model.

1. The machines are initially idle and jobs are at the load area.
2. All job types and required tools are initially available in the system.
3. The material transporter is initially staged at the load station and is subsequently staged at the station where material is dropped off.
4. The tool transporter is initially staged at machine one and is subsequently staged at the station where tool is dropped off.
5. Initial work release rules are applied at the time of creation of parts.
6. The rules for request selection are predefined and are not changed during the manufacturing cycle.
7. Shortest Distance rule was used as the tool selection rule.
8. The part is not unloaded from the machine until all operations are complete.
9. Bi-directional guidepaths are assumed for material and tool transporter.

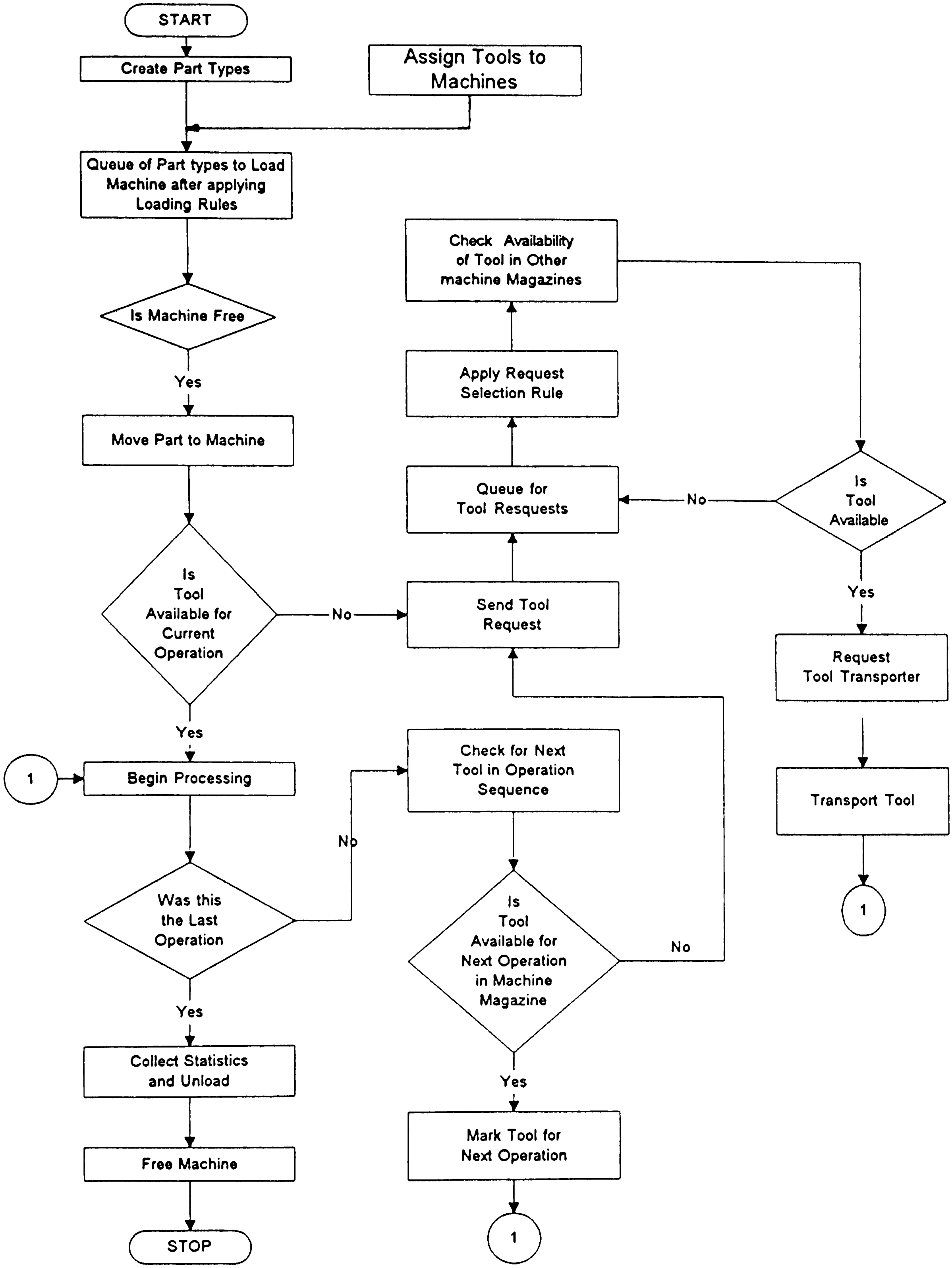


Figure 2: Simulation Logic

6 EXPERIMENTAL DESIGN AND RESULTS

The following factors were considered in the experimental design of the system:

1. Request selection
2. Initial work release
3. Tool duplication

Factor 1 has seven levels each while factors 2 and 3 have three levels each. A complete randomized design was used resulting in sixty-three (7x3x3) experiments. Five replications of each experiment led to a total of 315 simulation runs, thus providing sufficient degrees of freedom for the error term. The output of these runs was analyzed using ANOVA to ascertain the significance of each factor and their interactions. The performance measures studied were makespan and tool transporter utilization. Significance of the results were studied at 5% alpha error. Further, a test of means was conducted on the significant results to ascertain which of the rules performed better. The results (makespan and transporter utilization) from various runs are provided in Tables 1 and 2. Mean as well as standard deviation are indicated in these tables. The request selection rules were plotted, respectively, for makespan and tool transporter utilization under initial work release rules and tool duplication.

1. Tool duplication significantly affects the performance of the system for both makespan and tool transporter utilization.

As expected, duplication of tools affects the makespan and tool transporter utilization. The more copies of tools in the system, the lower the probability of a part having to wait for a tool in order to complete its operations since a required tool is found in the machine magazine. This results in shorter makespan. In the case of a single set of tools, the various job types will have to wait till a tool is made available to carry out their operations. Increasing the number of copies of each tool from one to two reduces makespan by about 23.4%. However, increasing the number of tool copies from two to three results in a marginal reduction in makespan by about 3%.

The tool transporter utilization increases by about 13.9% when the number of tool copies are increased from one to two. With the increased copies, tools are available to satisfy tool requests resulting in higher transporter utilization. However, when the number of copies of each tool is increased from two to three the transporter utilization drops by 12%. The tool transporter utilization in this situation is similar to that when the number of tool copies are one. The machines are more likely to have a required tool, hence issuing less requests leading to reduced tool transporter utilization.

2. Request Selection Rules significantly affects both utilization and makespan when there is one copy of tools. However, there is no difference in their performance when there are multiple copies of tools. The presence of more than one copy of a tool lowers the probability of a tool request being issued thereby inhibiting the chances of applying these rules.

The request selection rules, under single copy situation were compared and ranked based on Duncan's multiple range test with makespan as a performance measure. It was found that First Come First Served (FCFS), Shortest Imminent Processing Time (SIPT) and Shortest Imminent Ratio (SDT) significantly differed from Longest Imminent Processing Time (LIPT). Also FCFS and SIPT were significantly different from Largest Imminent Ratio (LDT). The rules can be ranked as indicating FCFS to perform best followed by SIPT and SDT. The worst performers were LIPT and LDT.

In the case of tool transporter utilization FCFS significantly varied from LDT, LIPT and Least Operations Remaining (LOR), while SIPT differed significantly from LDT and LIPT. There was no significant difference between FCFS and SIPT. The results of the tool transporter utilization indicated the ranking of the rules in the reverse order of their makespan values, eg., FCFS achieved lowest makespan and highest tool transporter utilization while LDT and LIPT which had the largest makespans resulted into smallest transporter utilizations. These results can be noted from the plot of request selection rules versus makespan (Fig. 3.) and request selection rules versus tool transportation utilization (Fig. 4.). The effect of tool duplication can also be seen on these plots.

3. Initial Work Release Rules do not significantly affect the tool transporter utilization and makespan.

The initial work release rules prioritized the release of parts into the system. Since the performance measure being studied is makespan the parts in the system have to be completed in any case and hence would not matter what the priority of various parts were. However the effect of these rules would be more evident if the performance measure studied was flow time and the jobs were created and brought into the system through out the manufacturing horizon. The plots shown in figures 3 and 4 were obtained under least number of total operations (LTO) as the initial work release rule.

Table 1: Average and Standard Deviation of Makespan (hrs.)

Initial Work Release	Tool Copies	Request Selection Rules						
		FCFS	MOR	LOR	SIPT	LIPT	SDT	LDT
First In First Out	1	1344, 18	1365, 32	1373, 17	1348, 18	1387, 32	1373, 18	1356, 27
	2	1049, 115	1050, 19	1048, 22	1047, 15	1048, 18	1053, 5	1048, 16
	3	1006, 15	1006, 16	1014, 13	1005, 20	1005, 18	1005, 18	1005, 17
Least No. Total Oper.	1	1337, 25	1355, 23	1374, 25	1338, 26	1386, 11	1388, 19	1355, 19
	2	1049, 15	1038, 19	1046, 11	1052, 16	1051, 15	1048, 15	1039, 15
	3	1006, 13	1002, 11	1003, 11	1002, 18	1008, 12	1006, 10	1008, 11
Most No. Total Oper.	1	1334, 39	1354, 13	1360, 25	1349, 30	1398, 20	1396, 22	1352, 16
	2	1048, 21	1049, 13	1049, 12	1053, 13	1048, 19	1054, 23	1054, 18
	3	1009, 13	1007, 21	1004, 15	1007, 20	1006, 15	1006, 15	1010, 10

Table 2: Average and Standard Deviation of Tool Transporter Utilization (%)

Initial Work Release	Tool Copies	Request Selection Rules						
		FCFS	MOR	LOR	SIPT	LIPT	SDT	LDT
First In First Out	1	49.0, 0.65	48.0, 0.96	47.7, 0.54	48.9, 0.37	47.0, 0.79	47.1, 0.69	48.3, 0.87
	2	54.4, 2.42	54.6, 0.95	54.5, 1.05	54.5, 1.16	54.6, 1.81	54.2, 1.03	55.2, 0.80
	3	47.9, 0.39	48.5, 1.05	47.7, 0.53	48.5, 0.49	48.3, 0.43	48.3, 0.43	48.5, 0.37
Least No. Total Oper.	1	49.3, 0.80	48.3, 0.67	47.9, 0.86	49.1, 0.69	47.2, 0.68	46.6, 0.51	48.6, 0.92
	2	55.3, 0.85	54.9, 1.12	54.8, 0.39	55.0, 0.53	54.4, 0.89	54.7, 0.79	55.2, 0.26
	3	47.4, 0.71	48.0, 0.50	47.8, 0.65	48.0, 0.60	48.0, 0.75	48.2, 0.76	48.0, 0.97
Most No. Total Oper.	1	49.0, 1.38	48.3, 0.67	47.1, 0.30	48.5, 0.70	46.8, 0.45	46.7, 0.88	48.3, 0.25
	2	55.0, 0.81	54.6, 0.28	54.6, 0.93	54.4, 0.52	54.4, 0.45	54.0, 1.31	54.7, 1.05
	3	48.3, 0.92	48.2, 0.94	48.4, 0.76	48.0, 0.45	47.9, 0.72	48.0, 0.95	48.0, 0.42

Key:

Request Selection Rule:
- FCFS - First Come First Served
- MOR - Most Number of Operations Remaining
- LOR - Least Number of Operations Remaining
- SIPT - Shortest Imminent Processing Time
- LIPT - Longest Imminent Processing Time
- SDT - Shortest Imminent Ratio
- LDT - Longest Imminent Ratio

7. CONCLUSIONS

This work has examined rules for tool sharing in an FMS. Rules for request selection along with initial work release were examined. A simulation model logic to implement a look ahead policy is presented. It was found that tool duplication significantly affected the makespan and tool transporter utilization. The request selection rules were found significant when only one copy of a tool was available in the system. Initial work release rules do not affect the system performance primarily because of the nature in which the

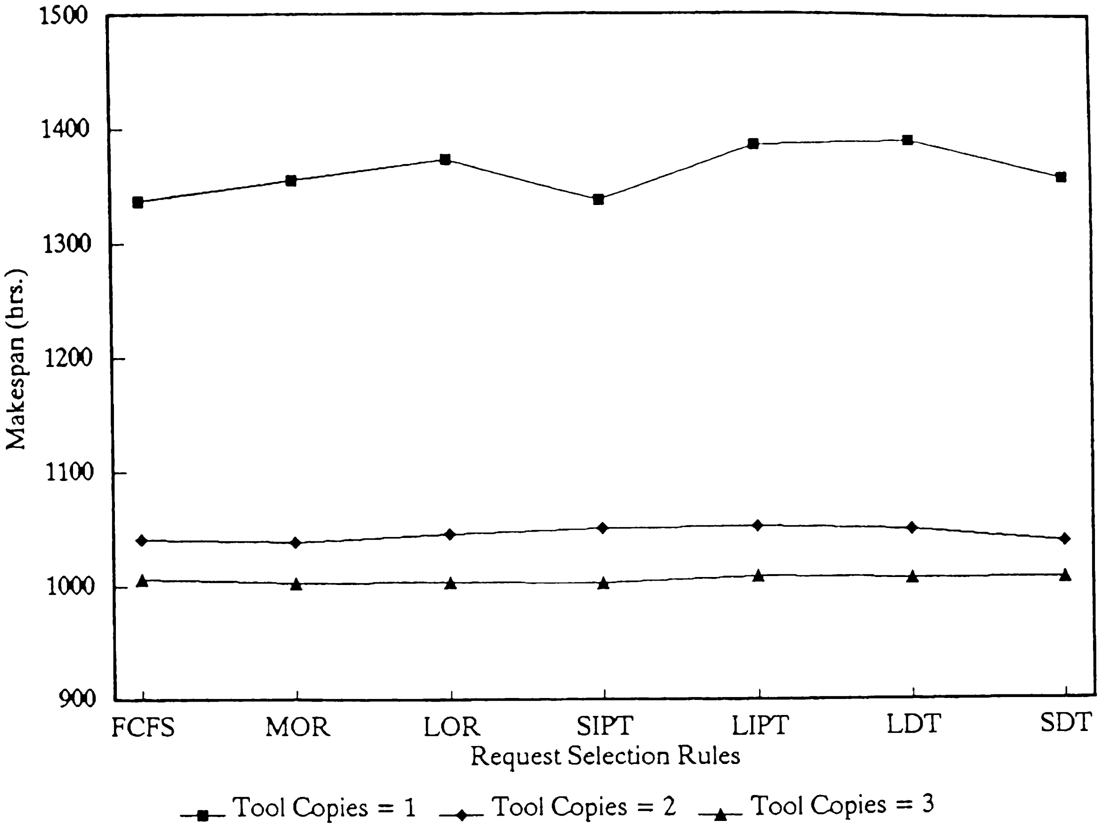


Figure 3: Request Selection Rules Vs. Makespan

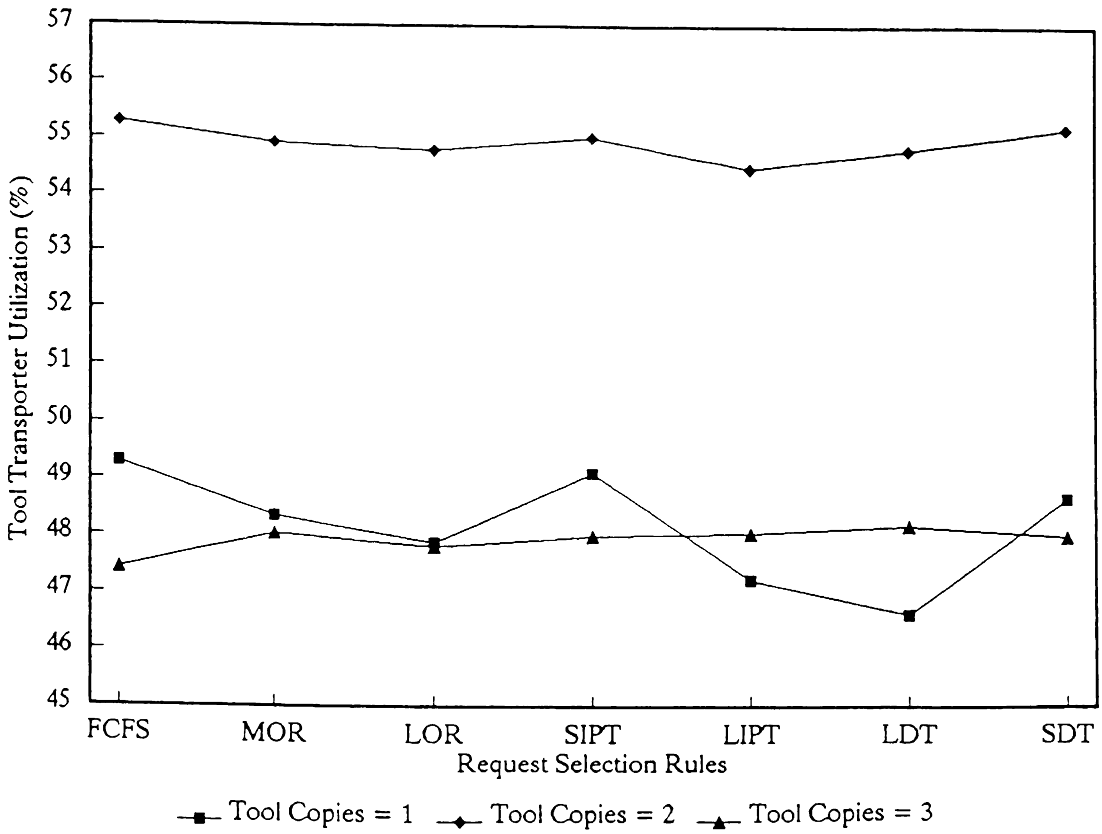


Figure 4: Request Selection Rules Vs. Tool Transporter Utilization

study was conducted. Among the various request selection rules Shortest Imminent Processing Time and First Come First Served rules seemed to perform best. Among the worst performers were LIPT and LDT rules.

The study can be further enhanced by studying other performance measure criteria such as flowtime. The initial work release rules may have a greater influence on the system performance if the jobs arrived in the system based on certain arrival patterns.

The above results are specific for the configuration of the system modeled and assumptions made. Simulation provides results which are highly system oriented, but the model logic was not dependent on the physical parameters of the system. The proposed model, can hence be adapted to different FMS environments with modifications pertinent to that system.

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