

PART AND TOOL FLOW MANAGEMENT IN MULTI-CELL FLEXIBLE MANUFACTURING SYSTEM

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ABSTRACT

Simulation techniques have been proven as reliable and powerful tools in the design, development, evaluation and operation of manufacturing systems. The following paper presents a simulation-based work done for the part and tool flow management modeling in a multi-cell flexible manufacturing system (FMS). The objective of this research was to develop a simulation model which could analyze the system in detail, and provide a basis for analyzing the effects of part and tooling strategies on major cell performance measures. An overview of the system is given and an example application is presented to illustrate how the part and tool flow management simulation design system operates.

1 INTRODUCTION

Over the last two decades, there has been a steady increase in the number of installations in flexible machining systems. However, the trends in the design and management of such facilities have changed significantly since flexible manufacturing was introduced, from large scale systems to multiple machining cells which are integrated via an automated factory-level transport network. Although this has increased the flexibility and provided system users with a significant competitive edge, many systems have failed to take advantage because of increasing complexity in operation and control of machining cells.

Part and tool flows, two major dynamic entities, are the key factors for managing successful manufacturing. Stecke (1983) formulated the tool allocation problem as a non-linear programming model. Positioning of tools in the magazine and the magazine capacity were considered as primary constraints. Balancing the assigned machine processing times and maximizing the tool density of each magazine with the tool allocation are the objectives of the formulation. Coleman et al. (1996a) have studied tool management and job allocation in flexible machining cells using work-oriented strategies. This spreadsheet-based model presents and investigates strategies for tool

management and job allocations in a demand-driven system. The paper's major concern is to measure tool management strategy's effects on machining cells under the influence of job allocation rules. Coleman et al. (1996b) have developed a similar model of tool management and job allocation in machining cells using tool-oriented strategies. This paper presents a tool-oriented approach to provide further tooling economy. The model employs a cluster algorithm which identifies part and tool groups. These clustered groups are allocated to a particular machining cell configuration with respect to the additional constraints of balancing the overall work load per machine and managing tool kit exchange under limited tool magazine capacity.

Amoaka-Gyampah et al. (1992) have compared tool management strategies and part selection rules. They described four tool management strategies and three part selection rules of which two concentrated on tooling and the other on earliest due date (EDD). They developed a simulation model and used five performance measures. Although the paper primarily deals with tool management in FMS, all of the performance measures focus on the part and general system spectrum. Major tool management performance criteria such as tool requirements and tool inventory level have been omitted.

In this paper, we provide a simulation model considering several hardware configurations to investigate the effects of part and tooling strategies as well as of alternative cell hardware on the major system performance criteria. Some of the alternative cell operating strategies such as machine grouping, alternative part routing and tooling strategies have not been considered in this research and these issues have been left out for future research.

2 PART AND TOOL FLOW IN FMS

Part scheduling is one of the most important factors that affects cell performance. Since all the jobs use the same finite (limited) resources such as machines, materials, tools, time, etc., the competition for the same resources

make the part flow a vital function for successful manufacturing and requiring a particular attention (Unal and Kiran, 1992). Part flow function has been considered with an aim to examine the effects of part flow on tool flow in FMS. No attempt is made to develop optimal rules but part flow has been incorporated to maximize the efficiency of the modeling facility designed.

As pointed out by Ghosh et al. (1992), Amoako-Gyampah et al. (1992), and Graver and McGinnis (1989), tooling and tool magazine capacity have a significant impact and are the major constraints for part batching and scheduling.

2.1 Part Scheduling Under a Tooling Constraint

As indicated by several researchers (Carrie and Perera 1986, Ventura and Chen 1990, and Amoaka-Gyampah et al., 1992) the part allocation, machine balancing, production ratio, and tool allocation problems are closely related and unless they are considered simultaneously, the solution proposed would be insufficient. Part scheduling should satisfy timely assignment of manufacturing operations as well as determine what set of orders should be ready for processing at a particular station at a particular time, deciding on the sequence in which they will be run, and calculating the resulting start and finish times for each operation. On the other hand, the tool management aims at allocating the right tools for the right job at the right place, at the right time, and at the right quantity. Since manufacturing operations require a large number of tools on different work centers, it is vital to allocate the limited number of tools to the work centers with limited capacity magazines.

Sometimes some of the criteria considered by the different scheduling programs may conflict and may cause substantial manufacturing chaos. It is thus necessary to consider solution procedures for the part scheduling and tool allocation problems simultaneously. However, it is often very difficult to determine the best part and tool schedule combination relative to all these criteria.

In this study, four scheduling rules, which are shortest processing time (SPT), longest processing time (LPT), earliest due date (EDD), and first come first served (FCFS), are used to schedule the parts to a multi-cell flexible manufacturing system, and four different part-oriented tooling strategies, which are full kitting, differential kitting, single tools kitting, and resident kitting strategies, are used to allocate the tools to the limited capacity-work centers. Tool magazine capacity (in this study 20 and 40 pockets), pallet capacity (10 each, 20 each and 40 each), and the automated guided vehicle (AGV) (1 and 2-vehicle system) are the finite resources in the system. The major research focus of this

study is on investigating the parts scheduling effects on tool requirements and on major cell performance criteria. In addressing the part and tool flow problem in multi-cell FMS, the paper reports the results of an experiment based on a computer simulation model by considering different combinations of cell operating rules.

2.2 Tool Management - An Overview

The essential role of tool management is the timely scheduling of tools to satisfy a short to medium term manufacturing task. The heart of a typical tool management system is the tool list which is derived from the machining schedule, the starting point and controlling factor of all the cells' activities and events. The machining schedule or list, at the highest level, consists of order numbers, due dates, priorities and required quantities. The machining list may be subdivided into partial orders (individual workpieces) and stored in the form of order waiting queues or work schedules. These schedules exist for every machine in the cell, and specify the sequence of operations for a particular workpiece, and the required tool sequence (the tool list). The tool lists not only determine the schedules for tool transfer and tool changing but also the gross tool requirement. A net tool requirement is established by examining tool store contents for the appropriate tools which have adequate residual tool life, and introducing new tools where necessary, to service the machining schedule. The generated tooling requirement is placed in the tool room, which is responsible for supplying the required tools. The organization of the tool room to manage these required tools depends upon the facilities supplied and the manpower used. As orders are being processed, the currently completed number of workpieces is recorded and updated. The consequences of these completed workpieces on the lists is an indication of which tools are no longer required or can no longer be used due to reaching their life limit. This in turn activates the tool transfer schedule and new tools may be introduced into the system.

A tool management system thus typically concentrates on maintaining a dynamic inventory of all tools in the cell, their size, type, number and location; and on improving tool forecasts and warnings of tool changes, reducing delays in the system and improving the reliability of tool information. The number of captive tools at cell level particularly within the cell secondary tool store (STS) is the major factor in determining the total tool inventory and the cost of the solution.

The pattern of supply and return of tools is of particular importance. A number of solutions exist resulting in either irregular, periodic or regular patterns of supply. The solutions adopted range from

kitting through to the issue of single tools under the workpiece-oriented strategy and from the issue of tool cluster sets to tool packages under the tool-oriented strategy. The selection of a tool flow solution bears a direct relationship to the pattern of supply and return of tools within a cell and thus on the selection of a strategy within either of the two tool management categories.

2.2.1 Workpiece-Oriented Tool Management

The workpiece-oriented tool management categorizes those cases where the machines are supported with tools related to the actual orders, i.e. the manufacturing system is said to be demand-driven. A tool rationalization algorithm is applied to reduce duplication of the tools not only within the primary or machine-based store, but also within the overall manufacturing system. Tool disposition using this approach requires greater planning to determine tool demands, but guarantees maximum availability and flexibility of tools in the system.

2.2.1.1 Full Kitting Strategy

Basically, a kit of tools is allocated with every job to be processed at a machine. The kit is usually returned to the secondary tool stores when the particular job to which it is assigned has been finished. The strategy is highly flexible and ensures tool availability. However, a large number of basic and sister tools are unavoidably required. Since there is no life sharing across the production period there is no need to trace the available tool life. Therefore, it is easy to operate and control.

2.2.1.2 Differential Tool Kitting Strategy

The differential kitting strategy is an improved form of the kitting strategy and its basic principle is that it allows tool life sharing. The rule for issuing tools according to the differential kitting strategy is: If any tools used by the existing job are common with tools required by the new job and if the common tools have enough life to carry on the operations required for the new job, then keep these common tools on the machine. Then remove the remainder of the existing tool kit and assign the new tools which are required by the new job to the machine. Repeat for successive jobs. Since the strategy allows for tool life sharing across kits, tool life may be used more effectively and tool inventory may be reduced.

2.2.1.3 Single Tools Strategy

The single tools strategy is more progressive in the sharing of available tool life across batches in

comparison with the differential kitting strategy. The logic is based on group technology principles. At the beginning of the manufacturing period, a rationalized set of all tools required are loaded into the magazine of the each machine, according to the job list to be processed. New tools are required when they are not already available on a machine or when the available tools become worn. Tools are unloaded when a magazine is full and they are no longer required or worn.

2.2.1.4 Resident Kitting Strategy

The strategy uses an external scheduling system to assign jobs and then assigns the tool kits. However, in contrast to the differential kitting strategy it does not remove the tools from the magazine as long as there is sufficient space in the magazine. The magazine is gradually filled to capacity loading only unavailable tools in the magazine. The strategy only exchanges tools if they become worn and they are still needed for the current operation. Since the strategy keeps the previously assigned tools in the magazine, there is always a good possibility to meet the requirement with one of the tools which is already in the magazine.

2.2.2 Tool-Oriented Tool Management

The tool-oriented strategies are targeted to respond to the need for workpiece processing and routing flexibility and in situations where there are many diverse workpieces produced, unlike the workpiece-oriented strategies, where the number and type of tools is determined from the machining requirements of a workpiece spectrum introduced over a given scheduling period. This is in contrast to the workpiece-oriented strategy where there is an assumption that a set of workpiece types will visit particular machines with a high degree of certainty.

In this paper, only workpiece-oriented tool management strategies have been considered and tool oriented tool management strategies are subjects of a separate paper.

3 THE SIMULATION MODEL

In this study, an FMS with six cells which contains 14 machines altogether, is considered. Every machine has one-component input and output buffer and each cell has a queue holding a maximum of 6 components, an inspection station, an automated storage and retrieval system (AS/RS), up to two-vehicle automated transporter systems (AGV) to move parts to and from machines, and a robotic material handling system that loads and unloads parts from the machine tool. The layout of the system is shown in Fig. 1. At the

beginning of the planning horizon, the system is assumed to be empty. It is also assumed that operation times, transportation times and the part routes are known either with certainty or by calculation. Moreover, basic tool requirements for each job are known beforehand, but the tool kit size is calculated by the tool issue strategy adopted. Parts are sequenced and scheduled according to one of the four scheduling rules adopted and are transferred on pallets of variable sizes which forms the transferred batches. Since the lot sizes are variable, a variable quantity of parts is introduced into the system every day. In total, 30 different parts-types are processed using 80 different tool types in FMS. Also five different pallet types are used to transfer parts. The setup time for each batch is deterministic and known previously. The simulation was coded in SIMAN IV (Peden et al., 1990). Simulation has been run for three shifts in a day and 30 days, altogether 43200 minutes. The performance criteria were first classified into two groups as performance measures for cell performance consisting of the mean flow time, mean tardiness of parts, production rate, machine utilization, robot utilization, and AGV utilization, and for tool management system performance consisting of tool requirement planning and worn tool quantity.

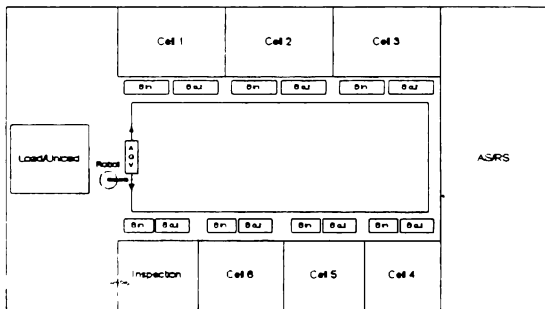


Figure 1: The Layout of the System

4 EXPERIMENTAL RESULTS AND DISCUSSION

The scenarios designed and run are as follows:

- Scenario 1: 14 Machines, 30 Part Types, 79 Tool Types, 1 AGV, 40-Magazine Capacity, 5 Pallet Types each has 40 pallets,
- Scenario 2: 14 Machines, 30 Part Types, 79 Tool Types, 2 AGV, 40-Magazine Capacity, 5 Pallet Types each has 40 pallets,
- Scenario 3: 14 Machines, 30 Part Types, 79 Tool Types, 2 AGV, 20-Magazine Capacity, 5 Pallet Types each has 40 pallets,
- Scenario 4: 14 Machines, 30 Part Types, 79 Tool Types, 2 AGV, 40-Magazine Capacity, 5 Pallet Types each has 10 pallets,

- Scenario 5: 14 Machines, 30 Part Types, 79 Tool Types, 2 AGV, 40-Magazine Capacity, 5 Pallet Types each has 20 pallets,

Each of the results will now be discussed in turn according to the performance criteria listed above.

4.1 Mean Flowtime

A graphical comparison of the four tooling strategies with four scheduling rules for 5 scenarios for the mean flowtime measure is shown in Fig. 2. As shown in the figure, there is no exact best solution for a specific tooling strategy. However, while the single tools and the resident kitting strategies with the EDD scheduling rule for scenario 1 has given the best result, the single tools and the resident kitting strategies, this time with SPT for scenarios 2, 3, 4, and 5, have given the best result. Since there is less tool changing in the single tools and the resident kitting strategies, operation times have decreased considerably and this has affected the mean flow time of the parts. On the other hand, since the full kitting strategy requires a great number of tools and tool changes which causes frequent machine downtime, it increases the part flow time. Also, the system that works with a single AGV has given the worst flow time performance. The only reason for this result is that long part queues were created by the insufficient material handling system. The most remarkable conclusion is that the single tools and the resident kitting strategies have given almost the same results for all part scheduling rules and for all scenarios. The only explanation for this result is that both strategies' working logic becomes almost the same after a while. The only difference is that the single tools strategy starts manufacturing with a full magazine, and the resident kitting strategy starts with an empty magazine. Therefore, in the long term, both strategies give very similar performance.

4.2 Mean Tardiness

The graphical comparison of the four tooling strategies for each part scheduling rule for 5 scenarios is shown in Fig. 3. Similar results to the mean flow time results are also obtained for the mean tardiness. As it happened for the mean tardiness, there is no exact emerging best result for all strategies and rules for all scenarios. However, for Scenario 1, the single tools and the resident kitting strategies with EDD have given the best result.

For scenarios 2, 3 and 5, the single tools and the resident kitting strategies with LPT have given better results in comparison with other scheduling rules. However, for scenario 4, again the single tools and the resident kitting strategies this time with EDD have given better results in comparison with other scheduling

rules. The LPT and EDD rules have emerged as the better working rules with the single tools and the resident kitting strategies in terms of mean tardiness.

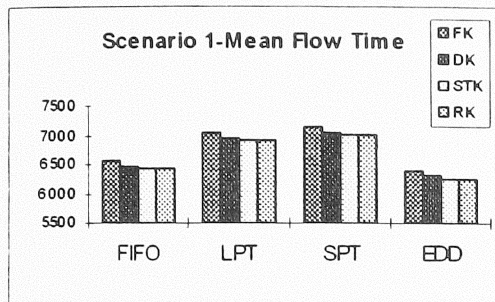


Figure 2: Mean Flow Time for Scenario 1

The LPT rule should not be a surprising rule since when jobs with longer operation times are released first, the average job numbers available in the system will be less than for the other scheduling rules, which decreases the average waiting times in the queues. This can also be seen from the production rate, in Fig. 7, which is relatively less than for the other three rules. However, this does not mean that the LPT rule is a superior scheduling rule to the other scheduling rules and this situation could be different for different FMS simulations (Amoaka-Gyampah, 1992).

4.3 Average Machine Utilization

The graphical comparison of the four tooling strategies under four scheduling rules for five scenarios is shown in Fig. 4. There is no outperforming strategy and scheduling rule combination for any scenario and almost all the scenarios with different tooling strategy and part scheduling rule pair have given very close performance. The full kitting strategy has given poorer performance in comparison with the other tooling strategies because of frequent tool exchange and machine down time.

4.4 Average AGV Utilization

As it happened in machine utilization performance, there is no single outperforming tooling strategy-scheduling rule combination for the better AGV utilization, see Fig. 5a and 5b. Almost all the strategies have given similar results to each other. The only difference is that, since there is one AGV car in scenario 1, the material handling system is busier than in the other scenarios. Again, parallel to jobs produced in the system, the AGV utilization is either increased or decreased.

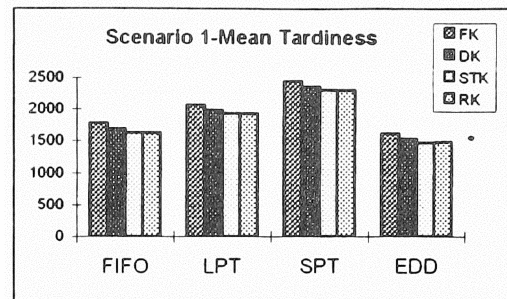


Figure 3: Mean Tardiness for Scenario 1

4.5 Robot Utilization

Robot is used for part loading, unloading and tool exchanging activities. Fig. 6a and 6b show the graphical comparison of robot utilization for all scenarios. The figures clearly show that the full kitting and the differential kitting strategies keep the robot busier than the other strategies for all part scheduling rules because of relatively more tool exchanging activities.

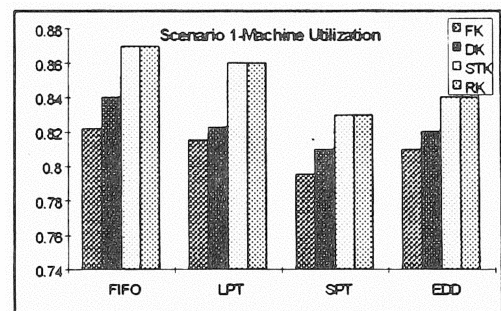


Figure 4: Average Machine Utilization for Scenario 1

4.6 Production Rate

Figure 7 shows the graphical comparison of the production rate for the tooling strategies and part scheduling rules for scenarios 1. The graph shows that there is no significant production rate difference between tooling strategies-part scheduling rules pairs. For scenario 1, since there is one AGV, relatively less material is transferred than the material transferred in the other scenarios. Therefore the production rate is less in comparison to the other scenarios. Also, for scenario 4, since the pallet number is smaller than the pallet numbers in scenarios 2, 3 and 5, the part transfer and therefore production rate is less when they are compared with the other three scenarios. For pallet number 20, scenario 5 and pallet number 40, scenarios 2 and 3, the production rate is almost the same. This means that 20 and more pallets are enough to run the system smoothly. Therefore, there is almost no

difference between 20 and 40-pallet systems in terms of production rate.

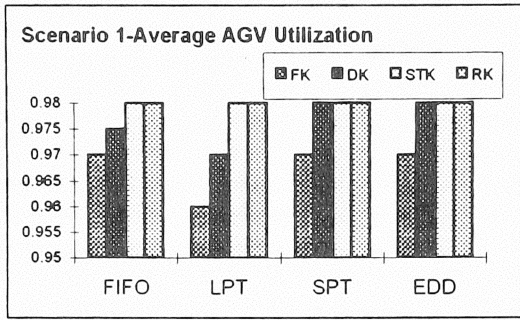


Figure 5a: Average AGV Utilization for Scenario 1

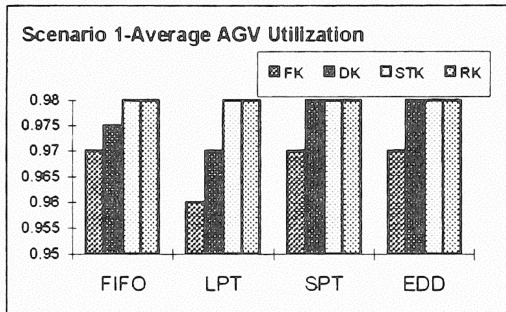


Figure 5b: Average AGV Utilization for Scenarios 2 and 3

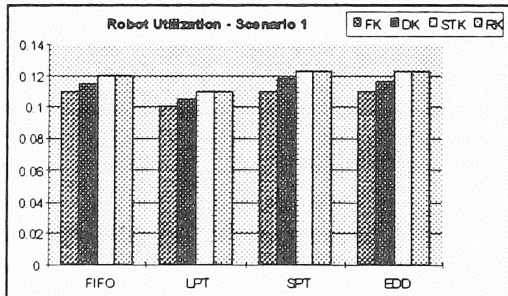


Figure 6a: Robot Utilization for Scenario 1

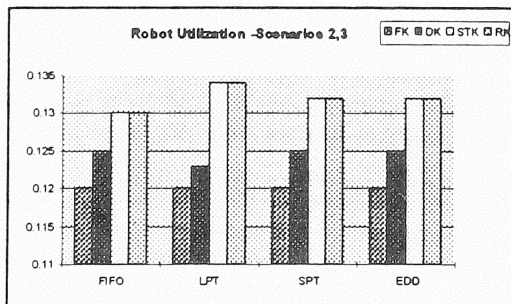


Figure 6b: Robot Utilization for Scenarios 2 and 3

4.7 Tool Requirements Planning

As shown in Table 1, due to the nature of the full kitting strategy, which involves a complete tool exchange for each job, a large number of tools are required. This creates extensive tool traffic between cell based secondary tool stores (STS) and the machine based primary tool stores (PTS) unnecessarily with too many sister tools involved in the tool traffic the majority of which are used very lightly, see Fig. 8. Since a tool kit is assigned to each job, the part scheduling rule has no effect on the tool requirements at all. As indicated in Table 1, the differential kitting strategy's primary characteristic, tool sharing between successive jobs, leads to substantial savings in tool requirements. The strategy largely depends on part scheduling rules. If a scheduling rule assigns a very diverse list of jobs to the same machine in terms of tool commonality, then the differential kitting strategy may perform poorly. A scheduling rule involving part-tool clustering can lead to substantial tool savings when it is coupled with differential kitting strategy.

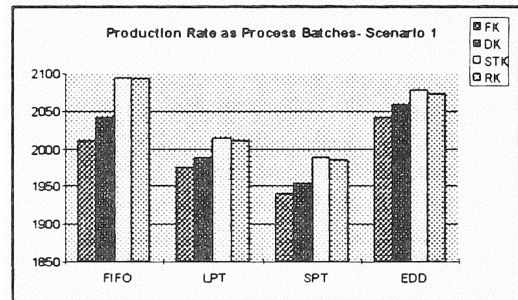


Figure 7: Production Rate for Scenario 1

The single tools kitting strategy concerns the assignment of all tool types at the beginning of the manufacturing period, therefore, the strategy guarantees tool availability. The strategy uses tool life effectively and works very efficiently, especially with a large magazine capacity. As seen in Table 1, with a smaller magazine capacity, Scenario 3, because of relatively frequent tool exchange which results in inefficient tool life utilization, the tool requirement has increased in comparison to other single tools kitting strategy applications with the larger magazine capacity, Scenarios 2, 4, and 5. Since the strategy aims to guarantee the tool availability at each machine, the part scheduling rules have no significant effect on the strategy's tool requirement. The resident kitting strategy gives a similar performance to the single tools kitting strategy, see Table 1 and Fig. 8. Especially in long term manufacturing, which has happened here, the strategy turns to be a single tools kitting strategy and works in a similar way. Therefore, the strategy's performance

follows almost the same pattern with the single tools strategy. However, the strategy works better with lean magazine capacity, Scenario 3. The reason for this, is that the strategy does not require whole tool types at the beginning and only requires succeeding tool kit difference. Therefore the tool life is used in a more efficient way which pulls gross tool requirement down.

4.8 Worn Tool Quantity

The worn tool quantity is a result of efficient tool life utilization. As shown in Fig. 9 and Table 1, the strategies which are more effective in tool life utilization have produced more worn tools. Since the worn tool quantity is a derivation of tooling strategies, the same comment can be made for the tooling strategies in terms of worn tools. The part scheduling rules have almost no effect on the worn tool quantity.

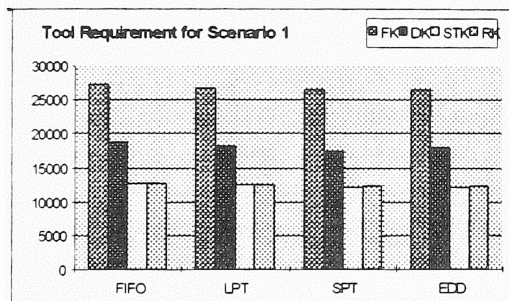


Figure 8: Tool Requirement for Scenario 1

5 CONCLUSION

Part and tool flow management play important roles in the operation of a flexible manufacturing system. Most of the researches done in this field consider part and tool flow as separate issues and often, the effects of one of the pair on the other is neglected.

In this paper, dual flow of parts and tools have been considered, taking into account four popular part scheduling and four tool assignment strategies. A simulation model has been designed for different cell configurations which has led to a study of the different aspects of the system. The effects of the different part scheduling rules on the tooling requirements are not very significant and there is no part scheduling-tool assignment strategy pair available that is consistently superior. However, the full kitting strategy, because of a great number of tool exchanges, always gives the worst performance and the single tools kitting and the resident kitting strategies, because of extensive tool life sharing, have given relatively better performance in terms of tool requirements, worn tools, mean tardiness, mean flow time, and average machine utilization for almost all cases.

Our future research will focus on tool re-cycling for the low tool life sharing strategies and building a tool refurbishment facility in the cell for the resharpenable tools for further tooling economy.

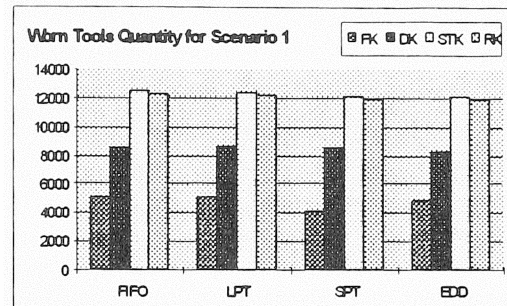


Figure 9: Worn Tools Quantity for Scenario 1

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Table 1: Tool Requirement and Worn Tools Quantity for all Scenarios

| | | Tool Requirement Planning | | | | Worn Tools Quantity | | | |
|------------|-----|---------------------------|-------|-------|-------|---------------------|-------|-------|-------|
| | | FIFO | LPT | SPT | EDD | FIFO | LPT | SPT | EDD |
| Scenario 1 | FK | 27146 | 26690 | 26462 | 26366 | 5068 | 5069 | 4757 | 4895 |
| | DK | 18564 | 18148 | 17384 | 17991 | 8549 | 8654 | 8521 | 8216 |
| | STK | 12571 | 12440 | 12127 | 12130 | 12488 | 12377 | 12060 | 12054 |
| | RK | 12625 | 12488 | 12177 | 12195 | 12296 | 12176 | 11932 | 11843 |
| Scenario 2 | FK | 29108 | 29078 | 29002 | 29068 | 5265 | 5324 | 5185 | 5264 |
| | DK | 18794 | 18642 | 18642 | 18793 | 9370 | 9437 | 9378 | 9365 |
| | STK | 13294 | 13330 | 13206 | 13279 | 13208 | 13265 | 13133 | 13206 |
| | RK | 13355 | 13394 | 13279 | 13339 | 13006 | 13054 | 12937 | 13003 |
| Scenario 3 | FK | 29108 | 29078 | 29002 | 29068 | 5265 | 5324 | 5185 | 5264 |
| | DK | 18794 | 18642 | 18642 | 18793 | 9370 | 9437 | 9378 | 9365 |
| | STK | 14439 | 14518 | 14320 | 14466 | 11212 | 11208 | 11160 | 11244 |
| | RK | 13809 | 13840 | 13726 | 13770 | 11686 | 11727 | 11665 | 11672 |
| Scenario 4 | FK | 27530 | 27501 | 27909 | 27375 | 5228 | 5322 | 5142 | 5194 |
| | DK | 18243 | 18309 | 18048 | 18034 | 8945 | 8988 | 9064 | 8783 |
| | STK | 12808 | 12867 | 12839 | 12673 | 12732 | 12793 | 12763 | 12619 |
| | RK | 12876 | 12922 | 12898 | 12734 | 12545 | 12606 | 12590 | 12418 |
| Scenario 5 | FK | 29109 | 29070 | 29000 | 29133 | 5267 | 5319 | 5185 | 5259 |
| | DK | 18826 | 18871 | 18623 | 18976 | 9327 | 9307 | 9271 | 9250 |
| | STK | 13289 | 13327 | 13205 | 13279 | 13203 | 13262 | 13132 | 13206 |
| | RK | 13349 | 13393 | 13266 | 13335 | 13007 | 13043 | 12958 | 13016 |