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GUIDELINE FOR IMPROVING CAPACITY OF A JOB SHOP BASED ON SELECTED PERFORMANCE MEASURES

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Abstract. Manufacturing companies are required to fulfill customer's driven imperatives such as on time delivery as well its own requirements such as high machine utilisation and low work in process. In order to achieve these, manufacturers need to adopt the right manufacturing strategy. Selecting the right manufacturing strategies will improve its capability to meet its customers demand as well as its own limitations. This research identifies five strategies that a job shop may adopt to achieve flexibility in meeting demand. The five strategies ranges from the basic strategy of having a complete set of single-operation machines to flexible multi-operation machines. Each strategy is evaluated and a set of guideline is proposed. The results show that when job tardiness and work-in-process is the performance criteria, the duplication strategy is the best. However, if the performance criteria is machine utilisation, then the best strategy is the replacement strategy.

Keywords: Performance measures, job shop, manufacturing strategy

Abstrak. Syarikat pembuatan bukan sahaja perlu memenuhi keperluan pelanggan seperti penghantaran yang menepati masa tetapi juga perlu memenuhi keperluannya seperti penggunaan mesin yang tinggi dan tahap kerja separa siap yang minimum. Bagi mencapai matlamat ini, syarikat perlu menggunakan strategi yang sesuai. Penggunaan strategi yang sesuai dapat memperbaiki kemampuan syarikat pembuatan untuk memenuhi kehendak pelanggan dan juga kehendak syarikat pembuatan. Kajian ini mengenal pasti lima strategi yang membolehkan bengkel kerja menjadi fleksibel. Kelima-lima strategi ini merangkumi strategi asas yang melibatkan satu set lengkap mesin-mesin satu operasi hingga ke mesin-mesin berbilang operasi. Setiap strategi dinilai dan satu garis panduan dicadangkan. Hasil kajian menunjukkan bahawa strategi penduaan ialah yang terbaik jika kriteria prestasi yang dikehendaki ialah kelewatan dan kerja separa siap. Tetapi jika kriteria prestasi yang dikehendaki ialah tahap penggunaan mesin, maka strategi penggantian ialah yang terbaik.

Kata kunci: Ukuran prestasi, bengkel kerja, strategi pembuatan

1.0 INTRODUCTION

Manufacturing systems can be categorized into three major categories: flow shop, batch shop and job shop [1-4]. The job shop manufacturing system is considered to be unique because of its routing and processing time which are not identical for each product released [5].

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Job shop is usually practiced in manufacturing processes with high product variation and small number of product quantity. Each product will have its own process routing and each routing is rarely be exactly the same with the other. Other problems that might occur in job shop manufacturing are new order releases and revisions in due date, which can result in late product delivery, and thus losing customers' confidence. The capability of managing these uncertainties should be the main concern to manufacturers in selecting the right manufacturing strategies.

Management is therefore, faced with the problem in making decision in adding more capacity through increase flexibility of a manufacturing system. Different alternatives have different implications such as additional capital cost and increment number of manpower. Improvement on performance measure such as number of tardy jobs, job-in-process (WIP) and machine utilisation is usually used to measure the effectiveness of these strategies. Thus the effect of various strategies will need to be evaluated before a decision can be made as to which strategy is best for a manufacturing system. Failure to do this will cause an inappropriate strategy to be implemented, thus resulting in losses and inefficiencies. Therefore, it is important to be able to assess the effectiveness of various manufacturing strategies in coping with the randomness that occur in a job shop. Without proper planning and strategies, job shop manufacturing company will experience problems such as product due date cannot be met, large number of work in progress and underutilised machines.

The objective of this research is to identify the most appropriate strategy and provide guidelines that will assist management in deciding the most suitable strategy for their manufacturing system. These guidelines will assist manufacturers in selecting the appropriate strategy that best suit their manufacturing system.

2.0 PROBLEM DEFINITION

The flow shop and batch shop can be classified as manufacturing strategy, which are not usually subjected to random changes in demand and process flow. Therefore, the process of forecasting and manufacturing planning is relatively straight forward. Unlike the flow shop and batch shop, job shop manufacturing system involves random changes in demand, process flow and processing time. This environment contributes to difficulties in forecasting, planning, meeting due date and managing schedules and machine utilisation [6].

Selladurai [7] and Haupt [8] defined a job shop as a discrete parts manufacturing facility of fixed production capacity in which component (in low volume) for different orders frequently arrive at irregular intervals, and follow different sequence through the resource centers/machines. These machines are grouped by function in order to accommodate the variety in customer-specialised requirements and fluctuation in demand for product and/or service. The operations of a job have to follow the assigned processing route which is, specific for each job. Sometimes the routing will skip a process or machine while another machine and process may be visited more than once.

Drobouchevitch [9], Xu and Randhawa, [10], William and Roda[11], and, Watanabe *et al.* [12] identified the characteristics of a job shop manufacturing as:

(1) Experiencing random fluctuation in demand and order release.
(2) Producing medium to high variety of product type in very small volume.
(3) Having its own process routing and process time.
(4) Using a general-purpose machine.

Due to the characteristics of job shop, it is difficult to forecast information on future jobs such as the due date, processing time and routing. Thus many researchers have been trying to optimise the performance of job shop manufacturing.

Many researchers have studied problems related to job shop especially in the areas of scheduling, forecasting and meeting due date [13-19]. However, these researchers only emphasised on finding the right rules or combination of rules to optimise a shop floor with a certain set up [5]. Thus, the optimum rules that they have identified in their research are only valid for these configurations. However, non of these researchers have studied the performance of various types of set up used by a shop floor to increase its flexibility in coping with the randomness of job shop environment. This research fills this gap by evaluating the performance of several manufacturing configurations or strategies to increase the flexibility of a job shop.

3.0 CASE STUDY AND BASIC MODEL DEVELOPMENT

A mold and die manufacturing company is selected as the case study job shop. Details of the process, product and dispatching rules are given as follows:

(1) Types of processes
The facility involves a complete set of processes adequate in producing mold and die. The facilities consist of milling machine, lathe machine, drilling machine, grinding machine, Electrical Discharge Machining (EDM) machine and hardening work center.

(2) Types of product
Mold and die consists of two parts; male and female. Each product is rarely identical to each other. However, from the observation and discussion with the management, the product type can be grouped into five categories which are based on routing. Tables 1 to 5 show the five product groups and the processing time for each process.

Table 1 Group 1 product

Product group	Part type	Route	Estimated processing time (hour)
1	Male	Mill Lathe Drill Hardening	15 6 8 7
	Female	Lathe Drill Mill Hardening	7 12 10 7

Table 2 Group 2 product

Product group	Part type	Route	Estimated processing time (hour)
2	Male	EDM Lathe Drill Hardening	3 4 7 2
	Female	Mill Drill Hardening	5 12 2

Table 3 Group 3 product

Product group	Part type	Route	Estimated processing time (hour)
3	Male	Grind Lathe Mill Hardening	3 7 9 3
	Female	Drill Lathe Hardening	8 4 3

Table 4 Group 4 product

Product group	Part type	Route	Estimated processing time (hour)
4	Male	Lathe	7
		Drill	16
		Hardening	5
	Female	EDM	4
		Grind	8
		Mill	13
		Hardening	5

Table 5 Group 5 product

Product group	Part type	Route	Estimated processing time (hour)
5	Male	Grind	3
		Mill	9
		Drill	8
		Mill	6
		Hardening	7
	Female	Mill	2
		Grind	7
		Lathe	8
		Drill	4
		Hardening	7

(3) Dispatching rules
The "First Come First Serve" rule is used by the job shop. Once adequate data has been collected a simulation model of the job shop is developed. A simulated model of the job shop is constructed based on the collected information. Test run are made and data is compared to verify and validate the model. The model is developed using WITNESS simulation software. Figure 1 shows the flow chart of the basic model (existing strategy).

When orders for parts are received, these are divided into male and female component. The routing for each component are determined. The components are then routed through the processes until the component is completed. The male and female components are then assembled.

4.0 EXPERIMENTATION DESIGN

4.1 Strategies Investigated

The manufacturing strategies that were tested and evaluated represents five choices of strategies that a job shop may adopt. These strategies range from not changing anything (using the existing facilities) to using all flexible machines. The five strategies are listed below:

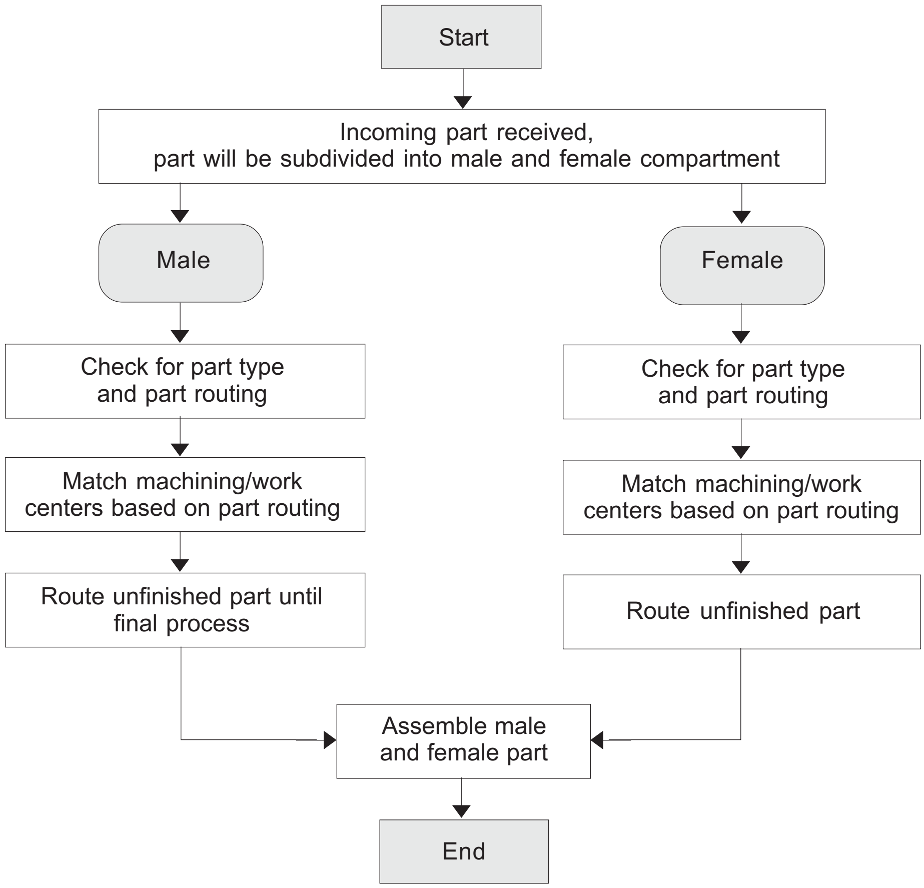


Figure 1 Flow chart for basic model

(1) Basic strategy (existing strategy)
This strategy represents the do nothing strategy, where the job shop is modeled to behave as the existing job shop. In this job shop, there are five general-purpose machine, each is capable of performing one type of process. These processes are milling, turning, drilling, grinding, Electro Discharge Machining (EDM) and hardening process. This set of processes are adequate in producing the product.

(2) Duplication strategy
In this strategy, the capacity of the job shop is increased by adding another identical general purpose machine to each process that experienced bottleneck.

(3) Basic and flexible strategy
In this strategy, the capacity of job shop is increased by adding two flexible machines in addition to the existing general purpose The system consists of existing plain system with two additional flexible machines. The first flexible machine can perform milling process and turning process while the other flexible machine is capable of performing drilling, grinding and EDM process.

(4) Replacement strategy
In this strategy, the machines in the job shop is replaced by three machines. Two of them are flexible machines. One of the flexible machines is capable of performing milling and turning process and the other is capable of drilling, grinding and EDM process. The third machine is for the hardening process only.

(5) Full flexible strategy
In this strategy, the system consists of six flexible machining work-centers. Each work center can perform all six processes, that is, milling, turning, drilling, grinding, EDM and hardening. This strategy represents the scenario where the job shop invested highly in the most flexible machineries, thus increasing its flexibility considerably.

4.2 Simulated Conditions

The simulation is based on terminating system. In terminating system, both the starting condition and terminating condition are defined by the nature of the system. In this study, the experiment is terminated after 500 parts entered the system. At the end of each run, the performance measure is observed based on the number of tardy jobs, machine utilisation and WIP.

The experimentation is designed to evaluate each strategy under various conditions. These conditions are:

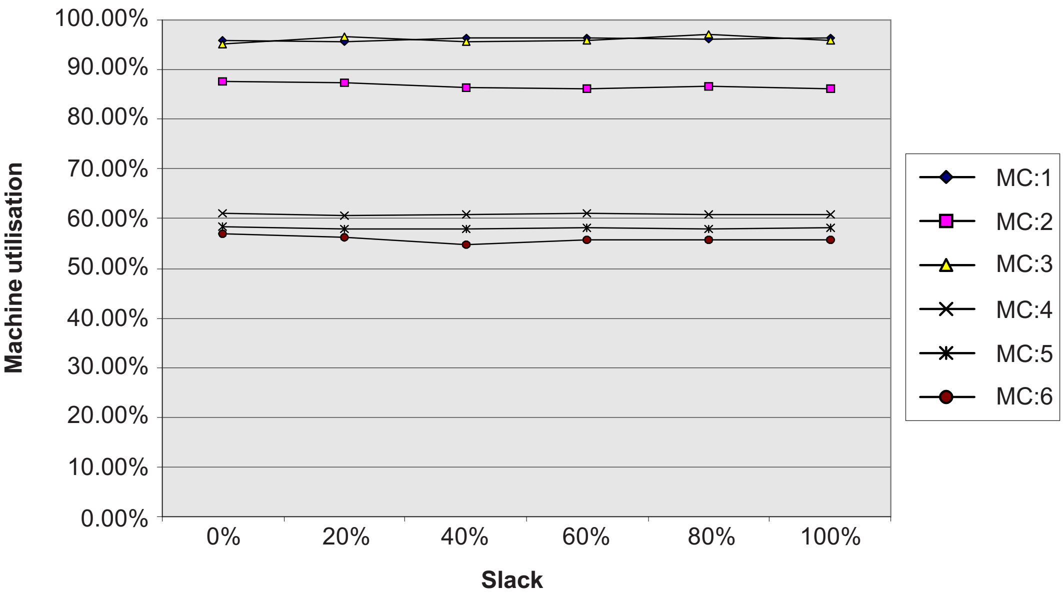
(1) Inter-arrival rate of jobs
To represent an environment of a busy job shop, the frequency of jobs coming into the system is set at 5 parts/50 unit hours (approximately 1 job every 10 hour shift)

(2) Slack (due date)
Due date is presented in the form of percentage slack. Zero percentage slack represents a very tight schedule where the due date for the job is equal to the total processing time for the job, that is, there is no slack. Meanwhile, 100% slack means that the due date of the job is equal to twice the total processing time of the job. That is the slack is equal to the total processing time.

5.0 PERFORMANCE MEASURES

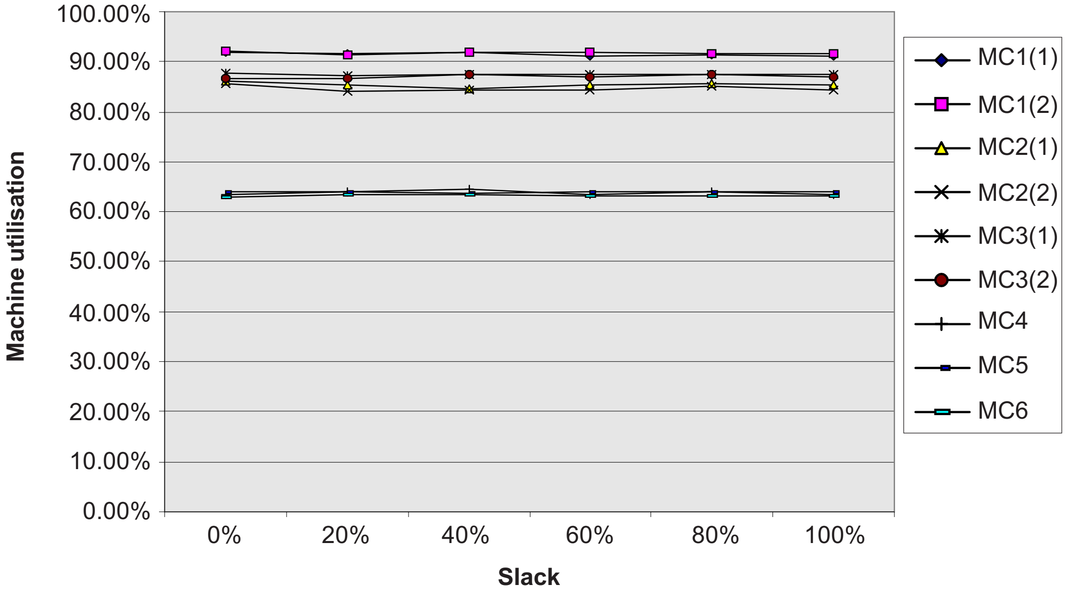
5.1 Effect of Slack on Machine Utilisation

Figures 2 to 6 show the graphs of machine utilisation versus slack for the respective strategies. All graphs show that there are no change in the percentage machine utilisation as slack is increased from 0 % to 100 %. This is because the amount of slack cannot influence the amount of time a job spent on a machine.



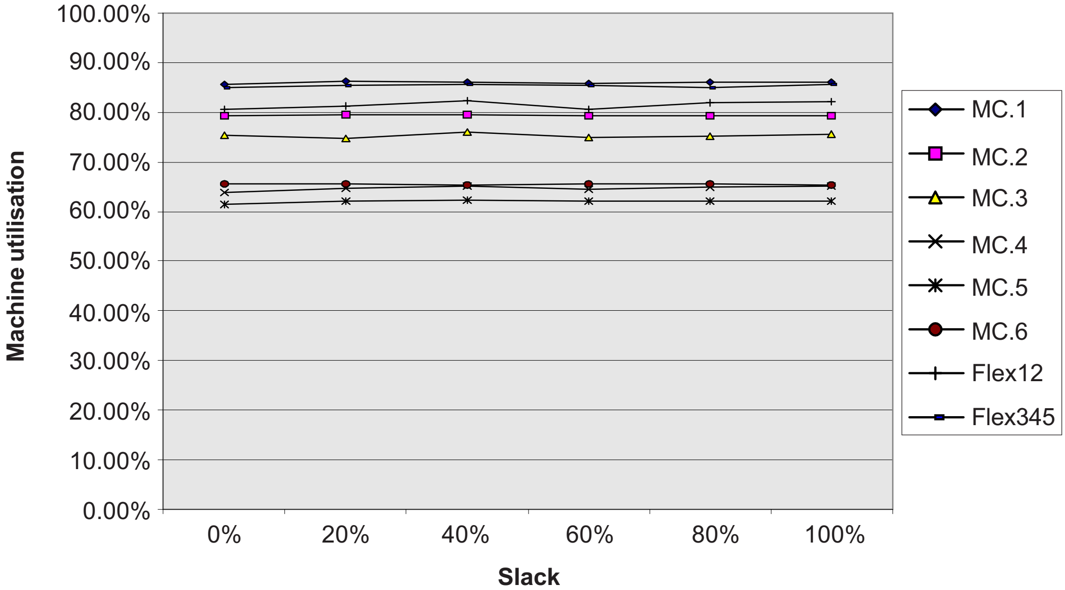
MC:1 to 6 are processes milling, turning, drilling, grinding, EDM and hardening respectively.

Figure 2 Machine utilisation versus slack (basic strategy)



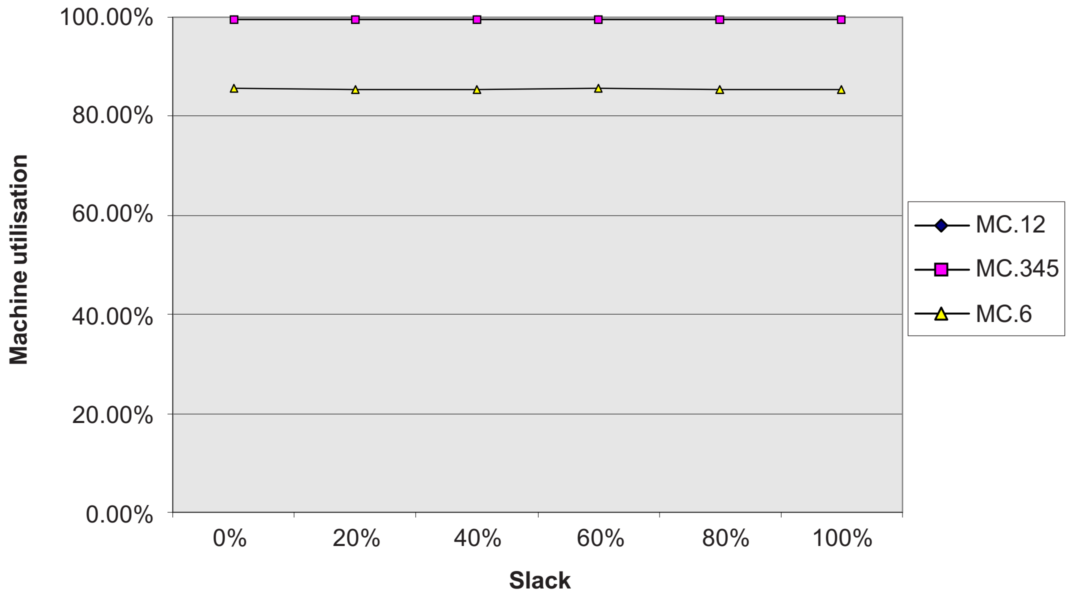
MC:1 to 6 are processes milling, turning, drilling, grinding, EDM and hardening respectively. The number in bracket is to indicate identical processes.

Figure 3 Machine utilisation versus slack (duplication strategy)



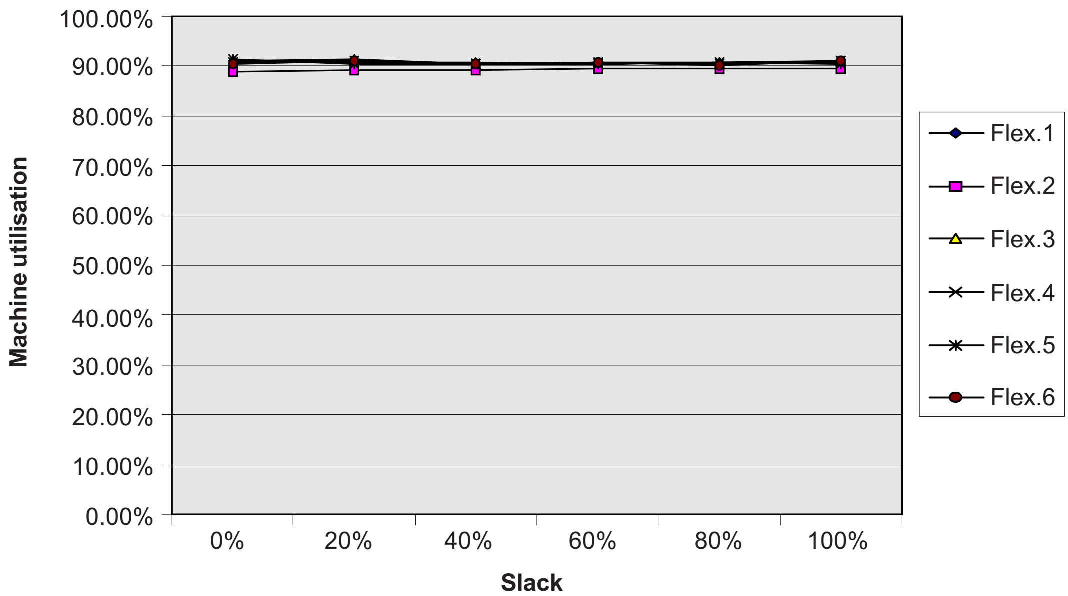
MC:1 to 6 are processess milling, turning, drilling, grinding, EDM, and hardening respectively.
Flex12 is a machine capable of processes milling and turning.
Flex345 is a machine capable of processes drilling, grinding and EDM.

Figure 4 Machine utilisation versus slack (basic + flexible strategy)



Mc.12 is a machine capable of milling and turning.
Mc.345 is a machine capable of drilling, grinding and EDM.
Mc.6 is the hardening process.

Figure 5 Machine utilisation versus slack (replacement strategy)



Flex.1 to 6 are identical machines, each capable of all 6 processess (milling, turning, drilling, grinding, EDM and hardening)

Figure 6 Machine utilisation versus slack (fully flexible strategy)

5.2 Effect of Slack on the Number of Tardy Jobs

Another simulation run is made to identify the effect of slack on the number of tardy jobs. Figures 7 to 11 show the effect of slack on the number of tardy jobs.

Figures 7 to 9 and 11 show that the number of tardy jobs is influenced by variation in the percentage of slack. The number of tardy jobs gradually reduces as percentage

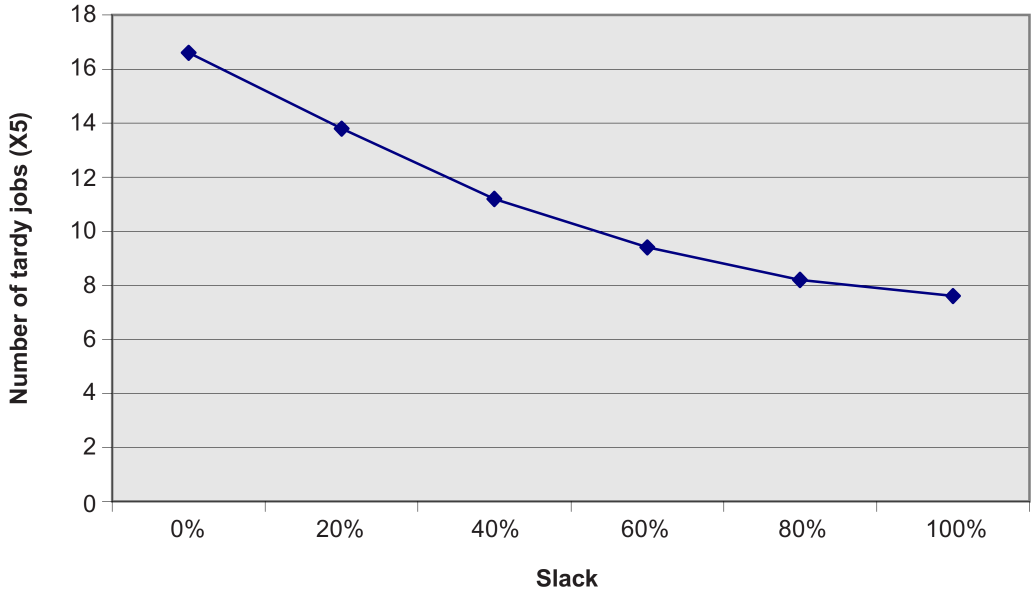


Figure 7 Number of tardy jobs versus slack (basic strategy)

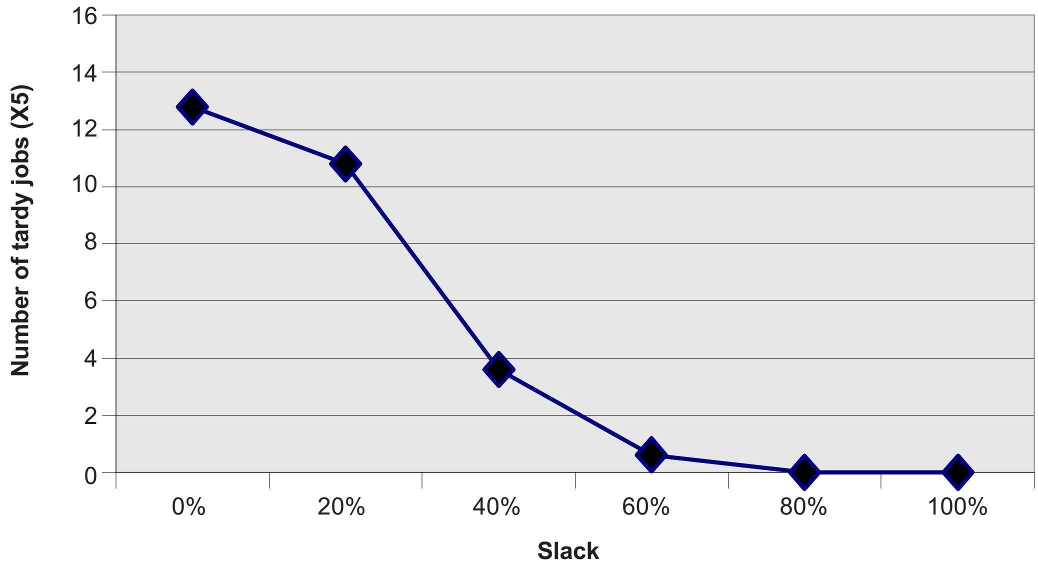


Figure 8 Number of tardy jobs versus slack (duplication strategy)

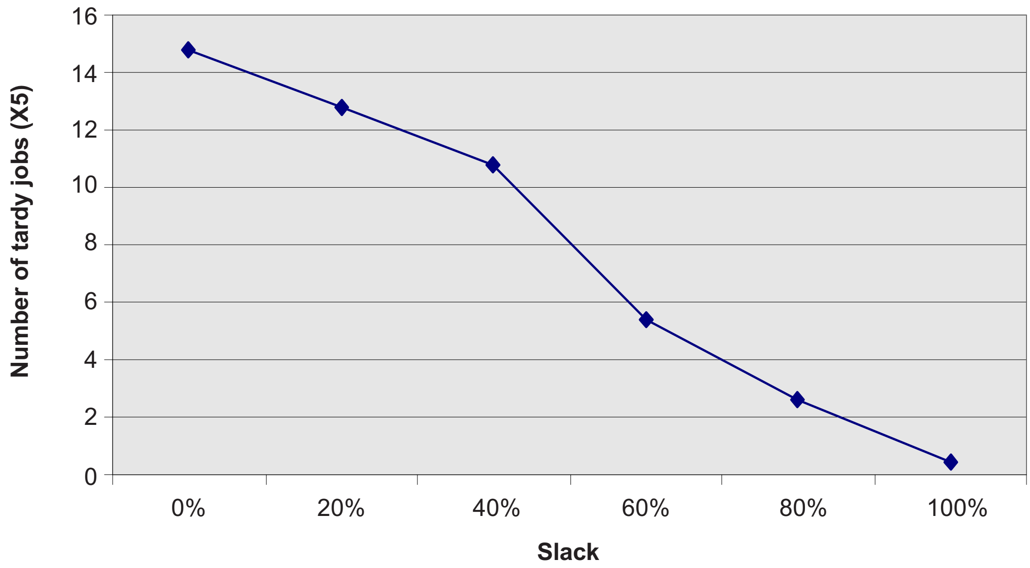


Figure 9 Number of tardy jobs versus slack (basic with flexible strategy)

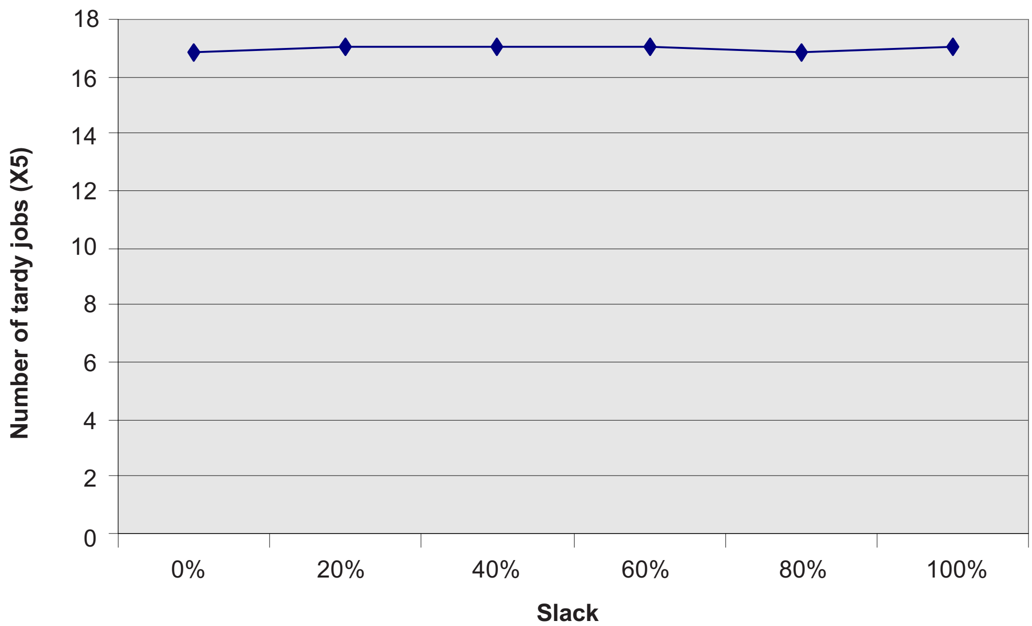


Figure 10 Number of tardy jobs versus slack (replacement strategy)

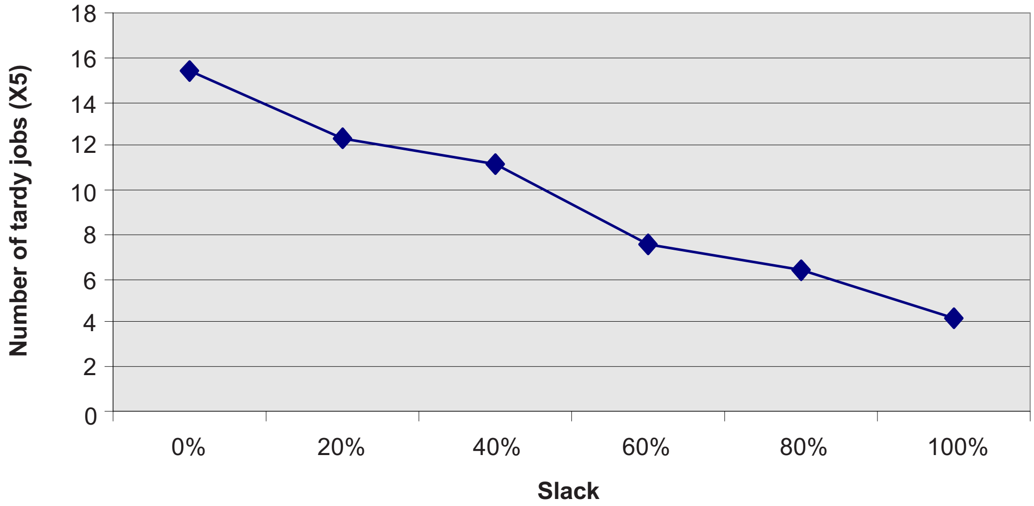


Figure 11 Number of tardy jobs versus slack (fully flexible strategy)

slack increases. This is because, as due date becomes more relaxed, more jobs can be completed on time. However, Figure 10 shows that for the replacement strategy, the number of tardy jobs are not influenced by variation in percentage slack. This is because the amount of slack is still not adequate to allow for reduction in tardy jobs.

5.3 Effect of Slack on WIP

Figures 12 to 15 shows that changes in percentage slack have only a slight effect on WIP. Slack represents due date of jobs , however, there is no change to the processing time. Thus, WIP level remains constant.

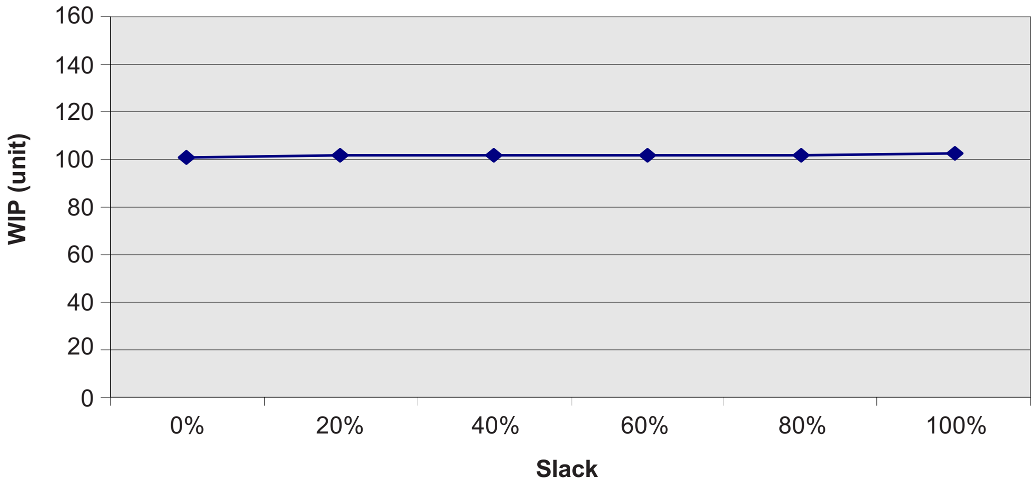


Figure 12 WIP versus slack (duplication strategy)

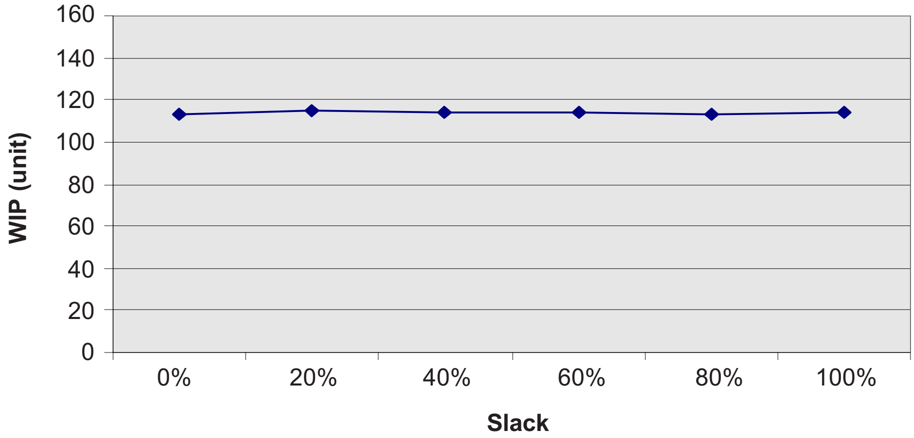


Figure 13 WIP versus slack (basic with flexible strategy)

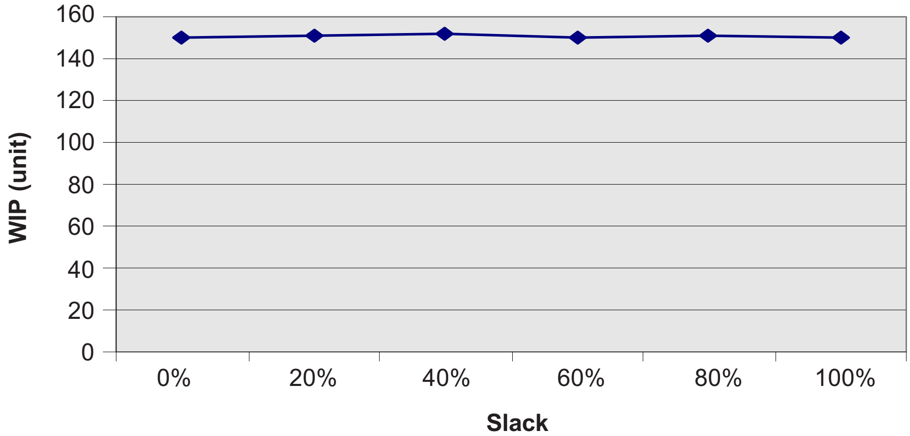


Figure 14 WIP versus slack (replacement strategy)

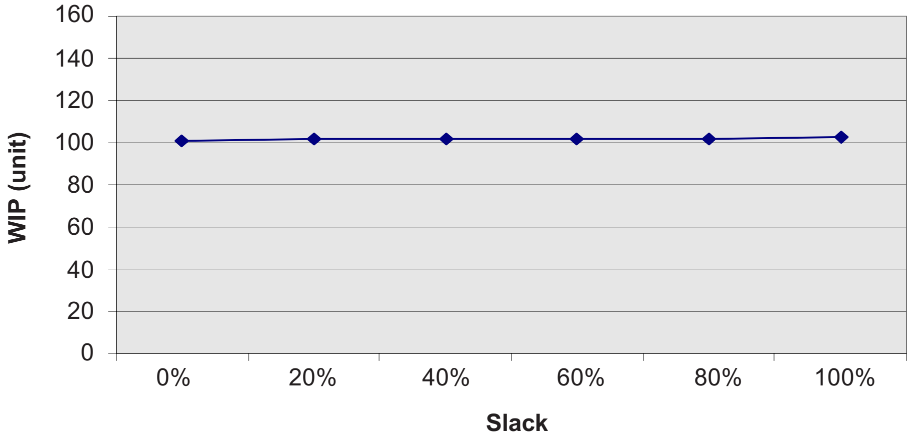


Figure 15 WIP versus slack (fully flexible strategy)

5.4 Comparison Between Strategies

This section discusses the performance of the five strategies in comparison to each other based on the performance measure of the number of tardy jobs, machine utilisation and WIP. The performance of each strategy is ranked as first, second, third, fourth and fifth from the best to the worst, according to their performance measure.

Referring to Table 6 in terms of the number of tardy jobs, duplication strategy rank first as being the strategy with the lowest number of tardy jobs, followed by basic+flexible strategy, basic strategy, fully flexible strategy and the worst performance is by the replacement strategy.

In the case of WIP, duplication strategy still rank first followed by basic+flexible strategy, basic strategy, fully flexible and the strategy with the highest WIP is replacement strategy. For machine utilisation, replacement strategy perform best with the highest machine utilisation followed by basic strategy, duplication strategy, fully flexible strategy and finally basic+flexible strategy.

Table 6 Comparison of performances measure under high percentage of slack (low demand job shop)

Ranking	**Performance measures**		
	Number of tardy jobs	**WIP**	**Machine utilisation**
1st	Duplication	Duplication	Replacement
2nd	Basic+Flexible	Basic+Flexible	Basic
3rd	Basic	Basic	Duplication
4th	Fully flexible	Fully flexible	Fully flexible
5th	Replacement	Replacement	Basic+Flexible

Table 7 Comparison of performances measure comparison under low percentage of slack (demanding job shop)

Ranking	**Performance measures**		
	Number of tardy jobs	**WIP**	**Machine utilisation**
1st	Duplication	Duplication	Replacement
2nd	Basic+Flexible	Basic+Flexible	Basic
3rd	Basic	Basic	Duplication
4th	Fully flexible	Fully flexible	Fully flexible
5th	Replacement	Replacement	Basic+Flexible

6.0 PROPOSED GUIDELINE

The ranking of each strategy against each other can be presented in a web graph as illustrated in Figure 16. It shows the most appropriate strategy for a particular performance measure:

(1) Number of tardy jobs
If the priority of a job shop is to achieve the lowest number of tardy jobs, then the best strategy in increasing the job shop's capacity is the duplication strategy. This strategy involves adding another identical single operation machine to the bottleneck process. However, in this strategy the low number of tardy jobs is achieved at the cost of a much lower machine utilisation.

The worst strategy a job shop may adopt under this performance measure is the replacement strategy. This strategy involves replacing a few machine with one that is capable of the same number of processes that the machine replaces.

(2) Work In Process (WIP)
If the priority of a job shop is to achieve the lowest level of WIP in the system, then the best strategy in increasing the job shop's capacity is the duplication strategy, followed by basic+flexible, basic, fully flexible and replacement strategies.

(3) Machine utilisation
If the priority of a job shop is to maximise machine utilisation, then the best strategy is the replacement strategy, that is, replacing all the single operation

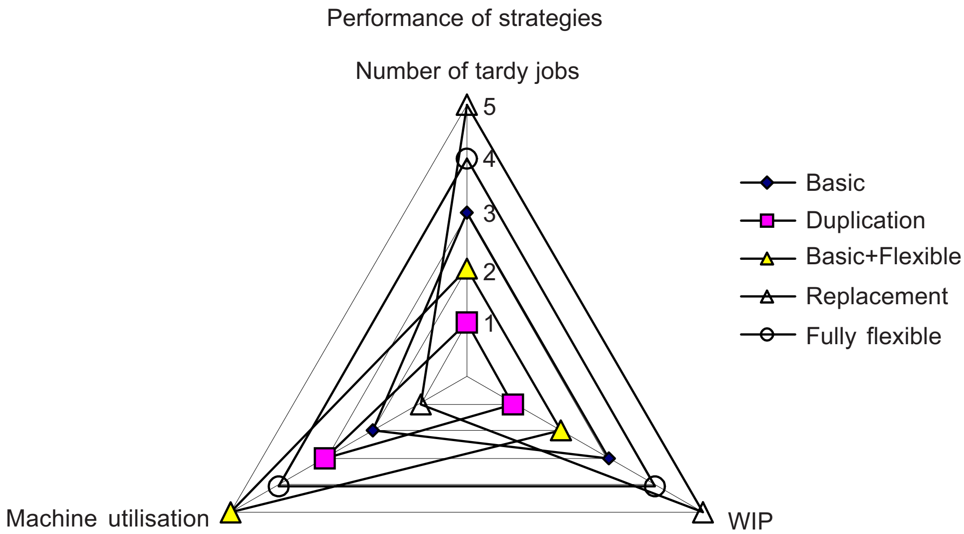


Figure 16 Guideline for the selection of strategies

machines with a few multi-operation machines but together they are capable of performing all the required operations to complete a product. This is followed by the basic, duplication, fully flexible and basic+flexible strategies.

There is no one strategy that yielded the best in all three performance measures. The duplication strategy that resulted in the best number of tardy jobs and WIP ranked third in machine utilisation. On the other hand, the replacement strategy that resulted with the best machine utilisation ranked the worst with the number of tardy jobs and WIP. Thus management needs to identify its priority such as minimise the number of tardy jobs, minimise WIP or maximise machine utilisation.

The existing strategy (basic) is not the worst nor the best strategy. However, should the company decide to increase its capacity, the best strategy would be the duplication strategy, that is to add identical machine to the bottleneck machine. Investing in advanced or high tech flexible or multi operation machines does not seem to yield the desired performance. This is probably due to the random nature of a job shop.

7.0 CONCLUSION

The results indicate that there is no one strategy that ranked the best for all three performance measures. Decision on the best strategy depends on the performance measure that a company chooses. However, the guideline proposed will assist management in making these decisions.

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