Impact of Routing and Pallet Flexibility on Flexible Manufacturing System

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Abstract: *Flexibility in manufacturing operations is becoming increasingly important to industrial firms, due to demand volatility, globalization of markets, competition, and shorter product life cycles. This paper examines potential benefits of routing and pallet flexibility in flexible manufacturing systems. This paper focuses on flexibility's benefits exclusive of make-span. The contribution of this paper concerns first with the individual impact of routing flexibility and pallet flexibility and then their combined effect on the system performance. The results of the analysis show that (i) the value of make-span decreases with increase in routing flexibility, (ii) the value of make-span increases/decreases with change in pallet flexibility (iii) the combined effect of routing and pallet flexibility on make-span is substantial and (iv) there is some impact of variable number of pallets on system performance. This study will help the practitioners to have clear understanding of the impact of outing and pallet flexibility on the performance of flexible manufacturing system.*

Keywords: routing flexibility, pallet flexibility, flexible manufacturing system, simulation, make-span.

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1 Introduction

In the present day global competition, there is tremendous pressure on manufacturing unit to produce variety of products at low cost. The manufacturing unit thus has to simultaneously deal with product variety and costs. There are a few strategies available to achieve this dual target. Flexible manufacturing system performs variety of operations, and hence produces different variety of components and products. A flexible system is a system, which accommodates the ability to cope with changes. Upton (1994) defines manufacturing flexibility as the ability to respond to environmental changes with less time and cost. Browne et al. (1984) classified manufacturing flexibility into eight categories belonging to machine, process, product, routing, volume, expansion, operation and production flexibilities. Most of these categories are inter-dependent on each other. There are numerous studies published that have analyzed the impact of flexibility on manufacturing performance (for example, Sethi and Sethi, 1990, Beach et al. 1998, Koste and Malhotra, 1999, Narain et al. 2000, Garavelli, 2001, Ozer, 2002, Ali and Wadhwa, 2005, Wadhwa et al., 2009, Ali and Wadhwa, 2010 etc.). From the literature review it is seen that there are number of flexibility available to take care of uncertainties in the manufacturing system. From the web of manufacturing flexibility we have selected routing flexibility to study its impact on the performance of flexible manufacturing system. Browne et al. (1984), states routing flexibility is exhibited when machines break down i.e. potential flexibility occurs when the flexibility is present but is utilized only when needed, such as a part being re-routed when a machine breakdown occurs. Barad et al. (2003), states that routing flexibility is the capability of processing a part through varying routes, or in other words by using alternative machines. Hence we see that there has been lot of work on different perspectives of routing flexibility. As implementing routing flexibility involves substantial investment therefore many system designers have aimed at providing the optimum level of flexibility under the operating conditions (Chan, 2001). A key obstacle to the economic application of flexible automation is parts holding and feeding. Pallet is normally being used to hold parts. Usually pallets of an FMS are costly and therefore are not available in ample quantities. These pallets may be dedicated or flexible. Dedicated pallets are usually too inflexible. Flexible pallets are capable of holding different part types are commercially available but are invariably large and costly. Many authors have used dedicated pallets to study the performance of the flexible system (for example Danzler 1987, Morito et al. 1991, Chan 2001, Buitenhek et al. 2002). However Chan, (2003) used flexible pallets to study the performance of the system. Hence we see that researchers have studied the impact of dedicated pallets and flexible on the performance of the system. However they have not studied the impact of different level of flexibility associated with pallets. This is in contrast with routing flexibility, which has been studied at different levels. Further more the impact of routing flexibility and pallet flexibility has not been addressed by previous researchers. This paper proposes to undertake such a study. In this paper, different levels of routing flexibility are compared with the one without routing flexibility. Then different levels of pallet flexibility are studied. We define pallet flexibility as the ability of the pallets to hold and move efficiently several part types from one point to another. It can be measured by the part types the pallet can hold and move.

The performance of the system is analyzed for the manufacturing system operating under different levels of routing and pallet flexibility. The advent of flexible manufacturing system also spurred a lot of work in manufacturing simulation. Since these manufacturing systems are more complex for developing mathematical models than conventional systems, simulation becomes very important as a modeling technique (for example Morito et al. 1991, Wadhwa and Rao, 2004, Wadhwa et al., 2009, Shafiq et al. 2010 etc.). The simulation software ARENA is used to run the models. The paper is organized as follows. In Section 2, a description of the existing system is discussed. Section 3, discusses the results followed by conclusion in Section 4.

2 Description of the existing system

The main objective of the study is to analyze the individual and combined impacts of routing and pallet flexibility on the performance of a manufacturing system. Though the routing flexibility aspect has been studied vis-à-vis its impact on manufacturing, the effect of pallet flexibility has not received much attention. This study carries out its objectives via simulation of the manufacturing system. The aim here was to see the extent of effects that would guide the decision makers in deciding about the proposed changes. For the routing flexibility it has been reported that there is maximum benefit when routing flexibility is increased from level 0 to level 1. Providing routing flexibility beyond this level is not found to be very beneficial. So the direction of the study was to find out the effects of the routing and pallet flexibility on the performance of flexible manufacturing system. Figure 1 shows the schematic diagram for illustrating routing flexibility.

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Under the conditions of RF=0 i.e., no-flexibility, each resource will be able to process only one type of product, whereas as the flexibility increases, the types of products that could be processed by each resource increases. Based on these logics, six levels of routing flexibility have been defined as shown in the Figure1. RF=0 corresponds to the condition of no flexibility and RF=1 corresponds to a condition where each product type can be handled by two resources, and so on. Under the conditions of PF=0 i.e., no flexibility, each part has got its own dedicated pallets. At this level of PF, parts are not allowed to move in the system, unless the dedicated pallets become empty. At PF=1, pallets have flexibility to hold two different parts one at a time and PF=2 indicates that each pallet can hold three different parts one at a time. PF=3 refers to highest level of pallet flexibility. At this level pallets are able to hold any part. Based on these logics four levels of pallet flexibility have been defined as shown in Figure 2.

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Some salient features of the existing system are that jobs do not recycle; one machine processes one part at a time; the buffers of raw materials are full, i.e., all the raw materials are available before starting the operation; operations once started cannot be interrupted before completion; all parts are processed as per a predetermined sequence. All the machines are 100% reliable and there is no breakdown of machines. The number of pallets is fixed at 12. We have selected 12 pallets because in one of our earlier study we have seen that system performs satisfactorily at this value of pallets. However in the later part of the study we vary the number of pallets and find out its effect on the system performance. The system operates under unbalanced load conditions. For the purpose of this study we focused on the relationship between routing flexibility and pallet flexibility and its impact on the system performance. The control strategy considered is Shortest Processing Time (SPT) and Minimum Number of Parts in Queue (MINQ) as the combination of sequencing and dispatching rules. In this work we consider make-span to study the performance of the system. Minimizing make-span is equivalent to minimizing the maximum completion time for all jobs.

3 Simulation Results

The simulation results are analyzed first for the impact of routing flexibility on the system performance. Then the impact of pallet flexibility is considered. This is followed by the combine impact of routing and pallet flexibility on the system performance.

3.1 Impact of routing flexibility at different level of pallet flexibility

Make-span performance of a flexible manufacturing system depends on the characteristics of the manufacturing system elements and many other operating conditions of the system. It is observed that, under certain conditions, the make-span reduces with the increase in manufacturing flexibility. This motivated us to study how the flexibility of a manufacturing system particularly routing flexibility may influence the make-span of a manufacturing system that encompasses it. The results of the simulation study are shown in Figure 3.

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From the results it is observed that the variation of make-span at different levels of routing flexibility is different at different level of pallet flexibility. At PF=0 there is decrease in make-span with the increase in the routing flexibility up to RF=3. Thereafter the increase in routing flexibility is counter-productive (Figure 3a). When the pallet flexibility is increased to 1 and 2 we observe that make-span decreases till RF=4. Further increase in routing flexibility is not beneficial (Figure 3b and 3c). At PF=3 there are monotonously decreases of make-span with increasing levels of routing flexibility (Figure 3d). Hence the influence of routing flexibility on the make-span appears to be different at different levels of pallet flexibility. It is also seen that the maximum reduction in make-span is obtained when routing flexibility is increased from level 0 to 1. This trend in make-span reduction is seen at all the level of pallet flexibility. Beyond routing flexibility of 1 there is marginal decrease in make-span. This indicates that routing flexibility negatively influences the make-span. The results indicate a make-span reduction of 26.17%, for a change in the routing flexibility level from a condition of no-flexibility (RF=0) to a condition of full-flexibility (RF=5), at PF=3 in a diminishing manner. The distribution of this make-span reduction among various flexibility levels is shown in the Table 1.

<<< Insert Table 1 here >>>

From the above results it is seen that the manufacturing system that use greater levels of routing flexibility are likely to achieve shorter make-span. This benefit diminishes with increasing levels of flexibility. It is also seen that the first level of routing flexibility (RF=1) provides the greatest benefit, followed by lesser and lesser benefits at subsequent levels.

Hence, there is a need to arrive at judicious levels of flexibility to balance the costs and benefits.

3.2 Impact of pallet flexibility at different level of RF

It is observed that, under certain conditions, the make-span reduces with the increase in pallet flexibility. This motivated us to study how pallet flexibility may influence make-span of the flexible manufacturing system. The results of the simulation study are shown in Figure 4. From the results it is observed that for flexible system i.e., RF>=1, the make-span gradually decreases with increasing levels of pallet flexibility. This indicates that pallet flexibility do influences make-span. At RF=0 the make-span decreases as the level of pallet flexibility is increased to 2. Thereafter the make-span increases with the increase of pallet flexibility. The results indicate a make-span reduction of 24.07%, for a change in the pallet flexibility levels from a condition of no-flexibility (PF=0) to a condition of full flexibility (PF=3), in a diminishing manner.

<<< Insert Figure 4 here >>>

<<< Insert table 2 here >>>

The distribution of this make-span-time reduction among the various flexibility levels is shown in Table 2. The above observations imply that flexible manufacturing system, which use pallet flexibility, are likely to achieve shorter make-span as compared to those that do not use it. Also greater levels of pallet flexibility are likely to achieve shorter make-span, and the benefit increases with increasing levels of routing flexibility. The results also indicate that the highest level of pallet flexibility (PF=3) provides the greatest benefit, followed by lesser and lesser benefits at lower levels.

3.3 Combined impact of routing and pallet flexibility on the make-span

As discussed above, it is important to understand the interactions between routing and pallet flexibility at different levels. This motivated us to study the combined effect of routing and pallet flexibility on the make-span performance of the FMS. The results of the simulation study are shown in Figure 5 and the corresponding reduction in make-span is summarized in Table 3. From Figure 5 we can see that there is maximum decrease in make-span when routing flexibility is increased from 0 to 1 at all the level of pallet flexibility. With the further increase in routing flexibility there is further reduction in the make-span till RF=3 at all the level of pallet flexibility. With further increase in routing flexibility different result are visible at different level of pallet flexibility. For instance at PF=0, if the routing flexibility is increased from 3 to 4 and then to 5 there is sharp rise and then gradual increase in make-span. At PF=1, there is further decrease in make-span when routing flexibility is increased from 3 to 4 and then it increases when the routing flexibility is increased from 4 to 5. Then at PF=2, we see slight decrease and increase in make-span with the increase in routing flexibility from 3 to 4 and 4 to 5 respectively. Finally when pallet flexibility is increased to 3 we see steady decrease in make-span with the increase in routing flexibility. The above results indicate that, while both the routing flexibility as well as the pallet flexibility is equally effective in improving the make-span performance of the FMS.

<<< Insert Figure 5 here >>>

<<< Insert Table 3 here >>>

From Table 3 we see that with one level of increase in the pallet flexibility, at RF=0, the make-span is reduced by 6.85% whereas with one level of increase in the routing flexibility at PF=0, the make-span is reduced by 17.01%. With one level of increase in both flexibility types, the make-span is reduced by 28.84%. A similar trend could be observed in other flexibility levels also, but with a mixed diminishing and increasing benefit. We get the maximum benefit of the combined effect of routing and pallet flexibility when routing flexibility is increased from no flexibility level to total flexibility (i.e., from RF=0 to RF=5) and pallet flexibility increased from no flexibility level to total flexibility (i.e., from PF=0 to PF=3). These results indicate that the routing flexibility and pallet flexibility to some extent reinforce each other and at the same time can be substituted for one another. This observation is important from the fact that building and exploiting these flexibility types may require completely different approaches. Under certain conditions one may be more cost effective than the other. Thus, this would give an option to select a more appropriate type and level of flexibility. From the Table 3 we see that the maximum reduction in make-span occurs when pallet flexibility is increased from 0 to 3 and routing flexibility is increased from 0 to 5 i.e., 50.50 %. However 43.24 % reduction in make-span occurs when routing flexibility is increased from 0 to 1 and pallet flexibility is increased from 0 to 3.

3.4 Impact of number of pallets at different level of RF and PF

In this study we will see the impact of number of pallets at RF=0 and RF=1 with different level of pallet flexibility. The simulation result is shown in Figure 6 and Figure 7 respectively. Figure 6 shows the make-span reduction at RF=0 at different number of pallets for different level of pallet flexibility. From the figure we see that there is maximum reduction in the make-span when number of pallets is increased from 6 to 12. If number of pallets is increased beyond 12 the system starts blocking and it completely blocks at 18 pallets. This observation is true for both the level, of pallet flexibility. Moreover at RF=0 and PF=3 the make-span is less as compared to PF=0. Hence we can conclude that the system performs better if full flexible or universal pallet is used at RF=0. Figure 7 shows the make-span reduction at RF=1 at different number of pallets for different level of pallet flexibility. From the figure we see that there is maximum reduction in the make-span when number of pallets is increased from 6 to 12.

<<< Insert Figure 6 here>>

<<< Insert Figure 7 here>>

If number of pallets is increased beyond 12 there is gradual decrease in make-span till 24 pallets. If number of pallet are further increased then the system blocks. This observation is true for both the level of pallet flexibility. Moreover at RF=1 and PF=3 the make-span is less as compared to PF=0. Hence it can be concluded that the system performs better in this case also when full flexible pallet is used. With increase in routing flexibility the number of pallets increases in the system. The increase in number of pallets improves the system performance marginally.

4 Conclusions

The purpose of this study is to observe the effect of routing and pallet flexibility on the performance of flexible manufacturing system. The simulation models are developed and analyzed by ARENA simulation package. The study focused on two types of flexibility i.e., routing and pallet flexibility. The routing flexibility involves the ability of a processing a given operation by utilizing more than one route, whereas the pallet flexibility involves the ability of a given pallet to hold different part one at a time. From the analysis it is found that the make-span decreases with the increase of routing flexibility and pallet flexibility. The studies indicated that both types of flexibility are equally important and to some extent they can substitute for each other. However, the combined effect of these two flexibility types appears to be more beneficial than their individual effects. With increase in routing flexibility the number of pallets is increased in the system. However increase in number of pallets gives marginal improvement is system performance. These observations are important for the designers and managers of flexible manufacturing system to arrive at judicious types and levels of routing and pallet flexibility to attain a given make-span performance.

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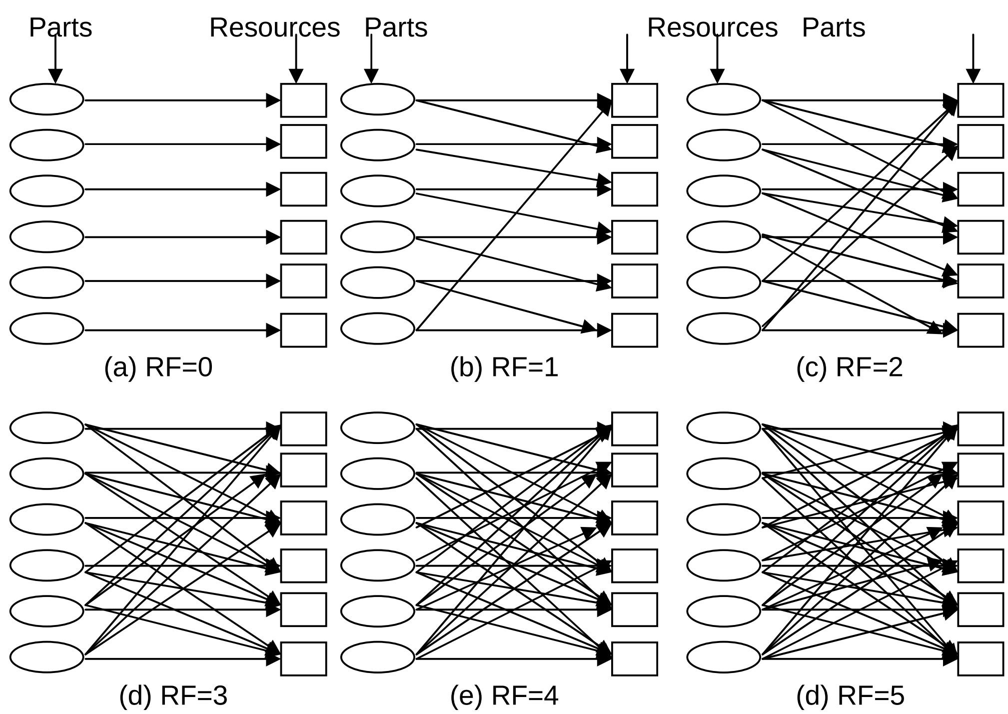


Figure 1 Different levels of routing flexibility (Wadhwa and Rao 2003)

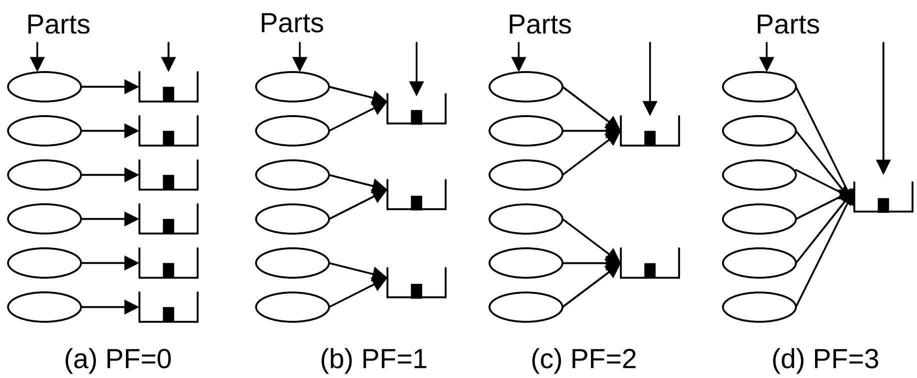
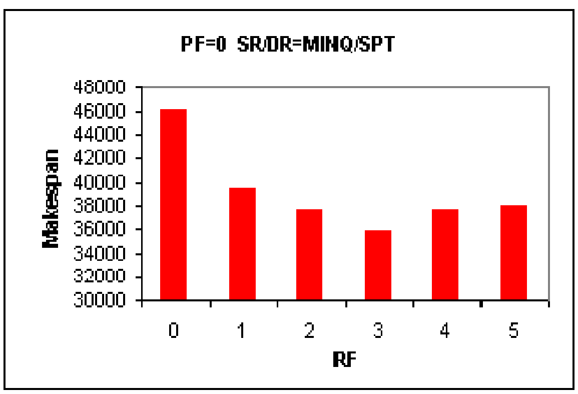


Figure 2 Different levels of pallet flexibility (Ali, 2007)



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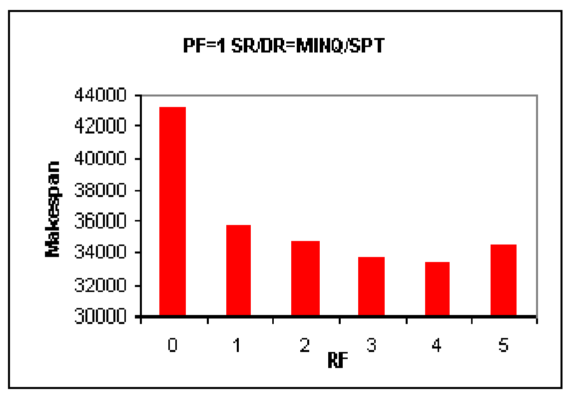

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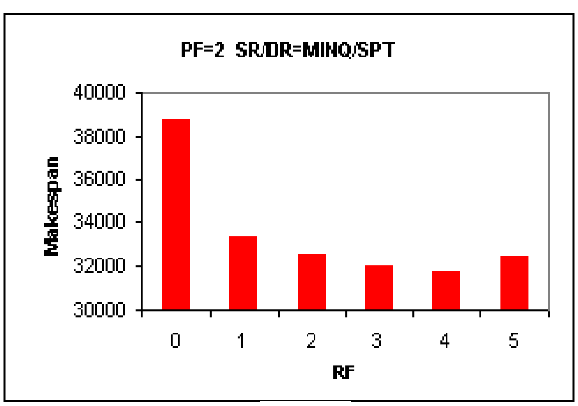

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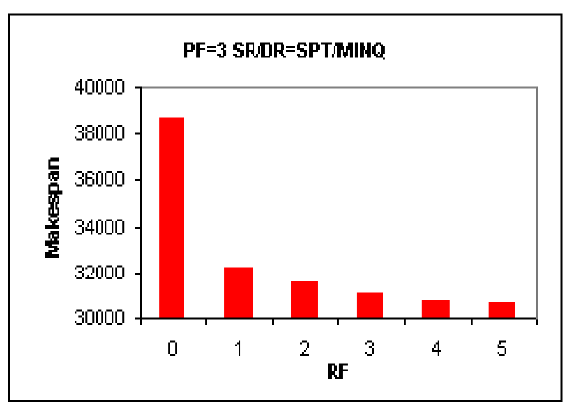

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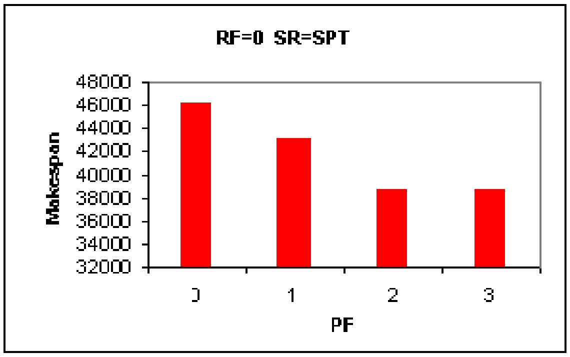
Figure 3 Impact of routing flexibility at different level of pallet flexibility



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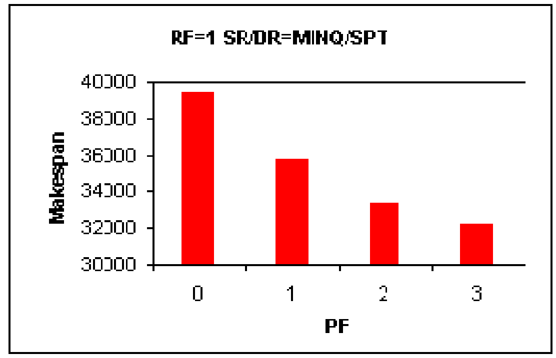

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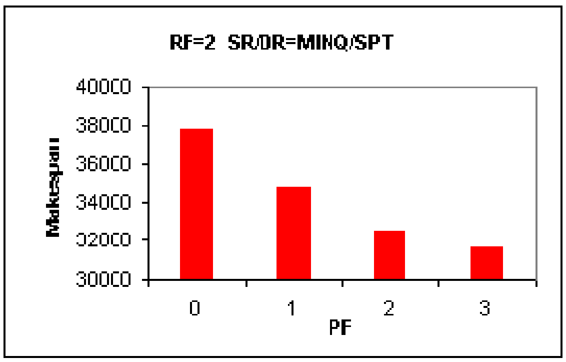

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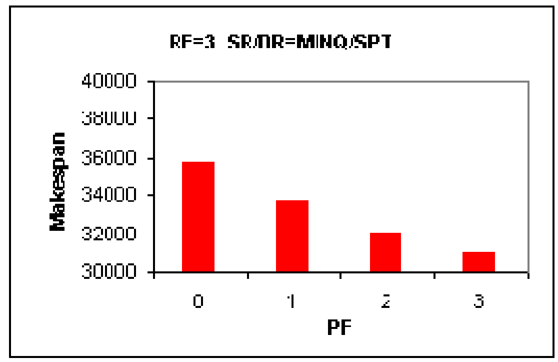

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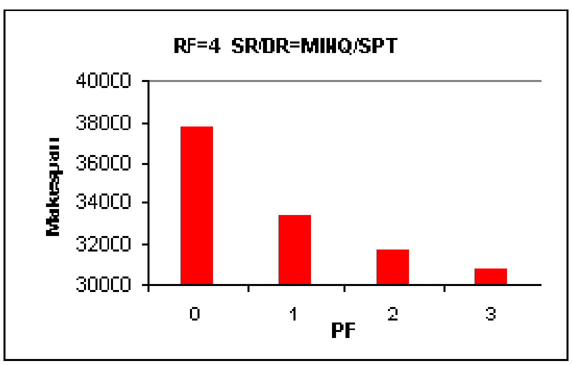

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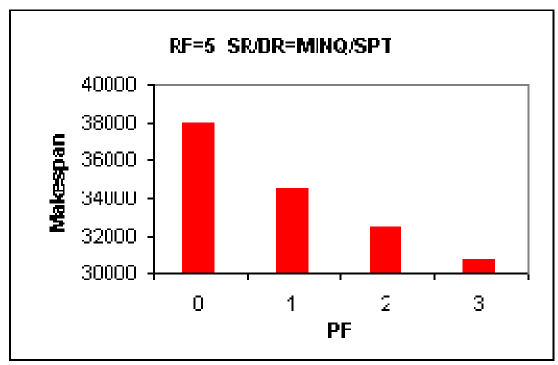

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Figure 4 Impact of pallet flexibility at different level of routing flexibility

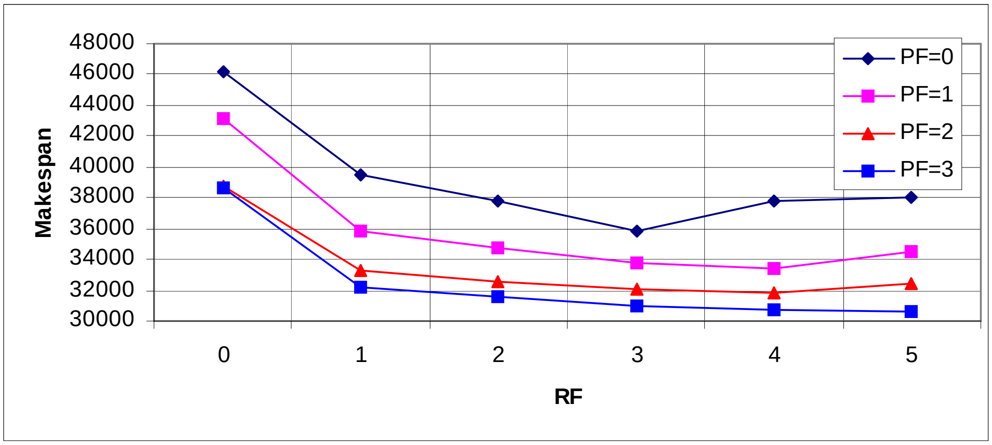

Figure 5 Combined Impact of Routing and Pallet Flexibility on the make-span

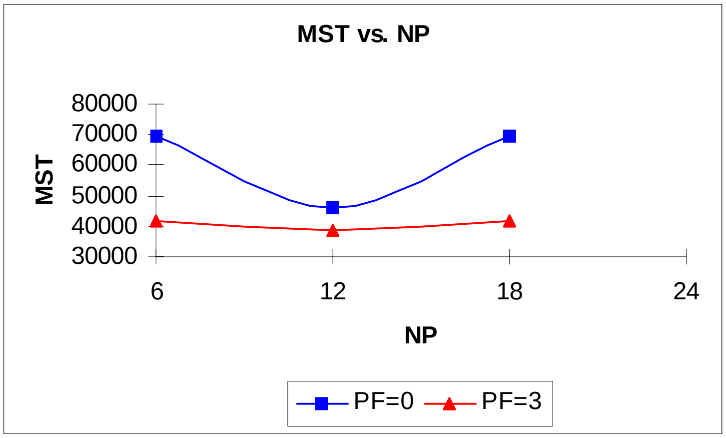

Figure 6 Impact of number of pallets at RF=0

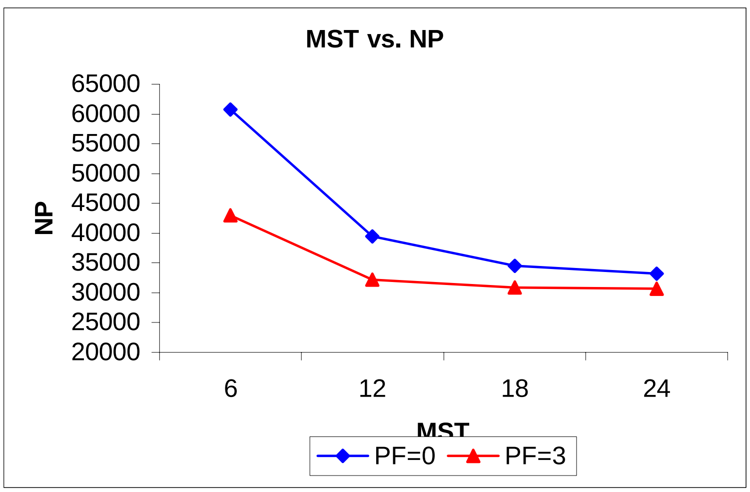

Figure 7 Impact of number of pallets at RF=1

Table 1 Pattern of make-span variation with the Increasing levels of RF at PF=3

Make-span Variation		**To (Flexibility Level)**				
		1	2	3	4	5
From (Flexibility (Level)	0	- 76.77%	- 85.60%	- 95.34%	- 98.79%	100%
	1		- 7.33%			
	2			- 7.95%		
	3				- 2.79%	
	4					- 0.96%

Table 2 Pattern of make-span variation with the increasing levels of PF at RF=5

Make-span Variation		**To (Flexibility Level)**		
		1	2	3
From (Flexibility (Level)	0	- 42.12%	- 70.96%	- 100%
	1		- 26.17%	
	2			- 24.80%

Table 3 Make-span reduction due to combined impact of RF and PF

% of Make-span Reduction		**Pallet Flexibility**						
		PF=0	PF=0 to PF= 1	PF=0 to PF=2	PF=0 to PF=3	PF=1 to PF=2	PF=1 to PF=3	PF=2 to PF=3
Routing Flexibility	RF=0		6.85	19.06	19.28	11.43	11.64	0.19
	RF=0 to RF=1	17.01	28.84	38.41	**43.24**	29.54	34.07	20.31
	RF=0 to RF=2	22.29	32.63	41.87	46.00	32.78	36.65	22.63
	RF=0 to RF=3	28.77	36.76	43.96	48.37	34.74	38.86	24.62
	RF=0 to RF=4	22.11	38.15	45.18	50.12	35.88	40.50	26.09
	RF=0 to RF=5	21.30	36.60	42.02	**50.50**	32.92	40.85	26.40
	RF=1 to RF=2	4.51	13.35	21.24	24.77	10.11	13.32	5.49
	RF=1 to RF=3	10.15	16.88	23.03	26.80	11.74	15.16	7.20
	RF=1 to RF=4	4.36	10.07	24.07	28.29	12.68	16.52	8.46
	RF=1 to RF=5	3.67	14.18	21.37	28.62	10.23	16.81	8.74
	RF=2 to RF=3	5.29	11.83	17.72	21.32	8.54	11.86	4.58
	RF=2 to RF=4	-0.15	12.97	18.71	22.75	9.46	13.18	5.81
	RF=2 to RF=5	-0.81	9.25	16.13	23.06	7.08	13.47	6.08
	RF=3 to RF=4	-5.17	7.29	12.74	16.58	6.15	9.77	4.28
	RF=4 to RF=5	-0.66	9.41	16.30	23.24	2.80	8.93	3.66