Proactive Knowledge Management: Developing a Novel View on Manufacturing Flexibility

Prof. S. Wadhwa

Indian Institute of Technology,

New Delhi, INDIA.

(email: swadhwa@mech.iitd.ernet.in)

Mr K. S. Rao

Research Scientist, DRDO,

New Delhi, INDIA.

Abstract: This paper presents a novel view of flexibility to promote proactive knowledge management towards system performance improvement. We present a conceptual study enriched with simulation models aimed at understanding the role of flexibility in the manufacturing lead time reduction. We propose that flexibility may be viewed as a desired/achievable combination of concurrency and constraints. As a part of our research efforts on the proactive management of flexibility for the performance enhancement of the Manufacturing systems, we show how routing flexibility can be employed in a proactive manner to reduce the manufacturing lead-time. Towards this, we have developed simulation models of simple flexible manufacturing systems and studied the effect of routing flexibility on the lead time performance under different conditions of part load and machine (processor) load balancing. The studies indicate that routing flexibility has significant effect on the lead time performance of the manufacturing system and the effect of routing flexibility varies under different conditions of load balancing. Further studies indicate the existence of complex interactions between the routing flexibility, processor concurrency, processor load balancing, and the manufacturing lead-time. This paper intends to discuss some of the interesting results of these studies. In our opinion this novel way to view flexibility as a desirable combination of concurrency and constraints is important for industry practitioners. It will help towards proactive flexibility management by deploying the right type and level of flexibility to reduce the lead-times in complex entity flow systems. The management of flexibility must aim at increasing the concurrency and reducing the associated constraints, in order to achieve significant benefits.

Keywords:Routing Flexibility, Concurrency, Load Balancing, Manufacturing Lead Time, Knowledge Management.

1. Introduction

Manufacturing enterprises throughout the world are under great pressure to reduce time to market, reduce the cost, meet the global quality standards, while coping with variety or customisation pressures. The rapid advancement of technology is also resulting in shortened life cycles and putting great pressure on organisations to achieve shorter and shorter manufacturing lead time. Hence, one of the important focus of Manufacturing Enterprises is to find ways and means of reducing the manufacturing lead times to be able to respond quickly for changing market demands. Towards this, flexibility has emerged as a critical dimension of competition. Traditionally, flexibility is viewed as hedge against uncertainty. It is our research endeavour to promote the proactive application of flexibility for the performance enhancement of the Manufacturing systems. This paper is a step in this direction.

Flexibility is an inherent attribute and an intangible asset of a manufacturing enterprise. Flexibility is difficult to understand and quantify and is expensive to build. Knowledge about its own inherent flexibility helps an enterprise to manage it in a more effective manner towards the organizational performance improvement. In spite of considerable research and large number of publications on flexibility, it is our experience that, there is still a scarcity of knowledge on how flexibility should be viewed, deployed and exploited towards the performance enhancement. Effective knowledge management of flexibility helps in bridging this gap. Towards this, we propose a novel view of flexibility that will be useful especially for practitioners who need a simple, clear and concise understanding of flexibility. We describe flexibility as a desirable/achievable combination of concurrency and constraints. This knowledge will guide practitioners to increase flexibility by increasing concurrency and reducing and/or guiding the associated constrains in a desirable direction.

This paper addresses the issue in two parts, the first part focuses on developing a framework for the flexibility enabled concurrency and its measurement. This framework helps better understanding of knowledge by the practicing managers. The second part presents the results of the simulation experimentation aimed at understanding the lead time reduction through flexibility enabled concurrency. This knowledge helps the managers to deploy flexibility for the performance enhancement in a more appropriate manner.

2. Knowledge Management Context

The concept of Knowledge Management is becoming more popular as companies begin to recognise the need to more effectively leverage their intellectual assets in the information age (Laura LaMonica, 2001). Knowledge Management involves, identification and analysis of available and required knowledge assets and knowledge asset related processes, and the subsequent planning and control of actions to develop both the assets and processes so as to fulfil organizational objectives (found on internet). Knowledge Management caters to the critical issues of organizational adaptation, survival and competence in face of increasingly discontinuous environmental change. Essentially, it embodies organizational processes that seek synergistic combination of data and information processing capacity of information technologies, and the creative and innovative capacity of human beings. (Malhotra Yogesh). In the context of knowledge management what to know and when to know is a vital strategic issue (Rick Dove, 1999). Knowledge Management of flexibility requires understanding and identification of available and required flexibility, and planning and control actions to develop new knowledge about flexibility and its deployment for performance enhancement. Understanding flexibility requires a framework that can be easily understood by the practicing managers and application of flexibility requires knowledge generation about its usefulness under different conditions. This paper is an attempt in this direction. Wadhwa (2002) describes an overall architecture for proactive decision support using simulator-assisted models, which may be utilized for generating and using new knowledge in flexible systems more effectively.

Part-1: Framework for Flexibility Enabled Concurrency

What is Flexibility ?

Several attempts have been made in the literature to define, model, and measure the flexibility with a view to understanding its true nature and its effect on the performance of the manufacturing system. Some of the definitions of flexibility found in the literature include: ability to change (Slack (1993)), (Gustavsson (1994)), ability to cope with uncertainty of change (Tincknell, and Radcliffe, (1996)), ability of being usable for different production tasks, ability to reconfigure resources so as to produce efficiently different products of acceptable quality, ability to respond effectively to changing circumstances, ability to respond cost effectively and rapidly to changing production needs and requirements (Benjaafar, and Ramakrishnan, (1996)), an adaptive response to environmental uncertainty (Gerwin (1993)), a hedge against the diversity of the environment (Xavier de Groote (1994)). Wadhwa and Browne (1990) view flexibility as an option on possible state transitions whereby decision makers can exercise a control on flow of entities using three types of decision points. It offers an operational perspective wherein the decision-maker needs to exploit the available concurrent options in a flexible system at event focused decision points.

Based on the above definitions it can be summarised that the role of flexibility in a system is to enable the system to cope with change (certain or uncertain), in an effective and efficient manner. The change in the environment includes change in both the internal environment (resource bottlenecks etc.) and the external environment (customer preferences etc). Effective manner refers to the extent to which the effect of *change* has been successfully countered and efficiency refers to the time, cost and effort required to do this.

Our current research on flexibility indicates that flexibility can be used not only for effectively managing the changes but also for enhancing the performance of the manufacturing system. For instance, Wadhwa and Bhagwat (1998) indicate that manufacturing flexibility in the form of routing and machine flexibility can be judiciously exploited towards lead time reduction in multi-product manufacturing systems. It is shown that this is achievable through a dynamic control of the flow of products and resources. Wadhwa & Rao (2000) described flexibility as an emerging meta-competence for managing high technology and highlighted the potential for design flexibility and its judicious integration with manufacturing flexibility.

Types of Flexibility:

The literature on manufacturing flexibility discusses about several types of flexibility. The terms and definitions used by various authors are not always consistent; the same term often being used in different ways, and several different names being given to essentially the same type of flexibility. Browne et.al. (1984) proposed eight flexibility types to describe the nature of a manufacturing system which is still one of the most widely used classification of flexibility types. Gerwin (1993) explicitly ties the notion of manufacturing flexibility to the notion of environmental diversity. Benjaafar and Ramakrishnan (1996) describes 19 types of flexibility.

Routing Flexibility

Routing flexibility of a manufacturing system is its ability to produce a part by alternate routes through the system. Routing flexibility increases scheduling efficiency by allowing better balancing of machine loads. It also allows the system to continue to operate in case of machine breakdowns and other unanticipated events. However, proactive application of the routing flexibility enables performance improvement of manufacturing system. This paper examines this theme in detail with specific focus on routing flexibility enabled concurrency.

What is Concurrency ?

The term concurrency refers to acting or existing together simultaneously. In a manufacturing system concurrency refers to carrying out of multiple processes on multiple processors simultaneously and as more and more processes are carried out concurrently, the overall lead time will reduce as shown in Fig-1(a), (b) & (c).

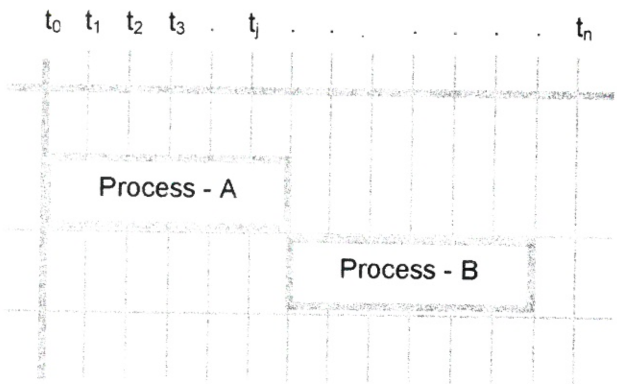

Figure1: (a): Sequential Processes (Concurrency = 0)

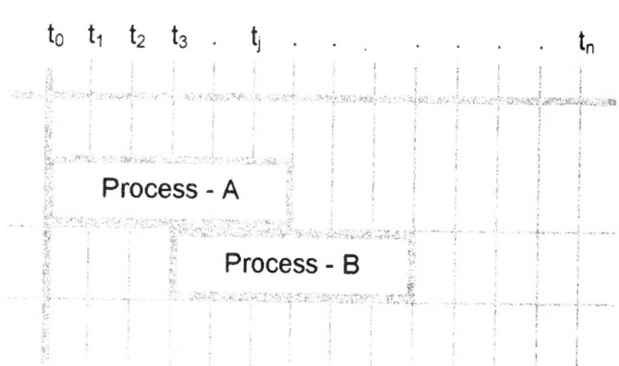

Figure1: (b) : Overlapped Processes (Concurrency)

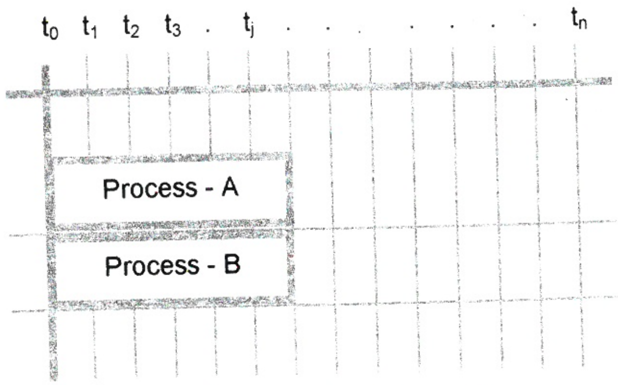

Figure1: (c) : Parallel Processes (Maximum Concurrency)

Constraints against Concurrency

Two processes 'A' & 'B' are carried out sequentially due to any of the following reasons:

(a) done as a matter of established practice, habit or for convenience
(b) due to functional boundaries
(c) 'B' requires certain information from 'A'
(d) 'B' requires certain decision from 'A'
(e) 'B' requires certain materials from 'A'
(f) 'B' requires certain resource which are currently being used by 'A'
(g) or there is a need for synchronization of certain events of 'A' & 'B', which may result in certain lead-lag precedence relationships between 'A' & 'B'

Lead time reduction efforts generally involve overcoming some or all of the above constraints. Proactive application of flexibility is an important step in this direction.

How flexibility enables concurrency ?

It is our thesis that flexibility is a combination of concurrency and constraint. Every type of flexibility brings with it certain type of concurrency and associated constraints. Our research endeavor is to develop an understanding of the relationship between the various types of flexibility and concurrency. This paper specifically addresses the relationship between the routing flexibility and concurrency.

To enable understanding and measurement of concurrency we have evolved a method of measuring process concurrency as shown in Fig-2 below.

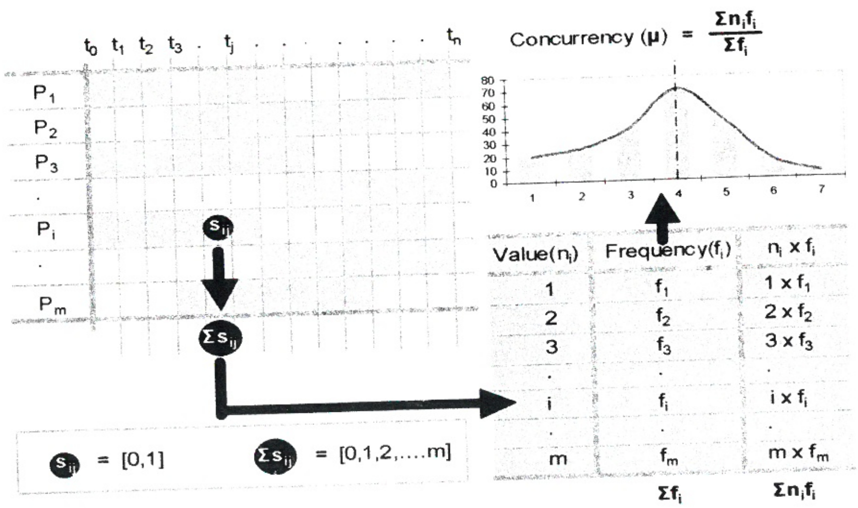

Figure 2

When certain jobs are to be processed on a given number of processors (machines), the jobs will be scheduled on the processors depending on the process plans and the routing flexibility available within the system. The resulting schedule is prepared in the form of a gantt chart as shown in Fig-2.

From the gantt chart we can identify the state (busy or idle) of each processor at any given instance of time. We denote these states as 1 or 0 respectively depending on whether the processor is busy or idle. Column sum of the gantt chart will give us how many machines are busy at any given point of time. This is used to build a frequency distribution table as shown in Fig-2. The mean of this frequency distribution indicates the level of concurrency existing within the system at that time. Based on this method we can compute the concurrency at different levels of flexibility as shown in Fig-3, 4 & 5.

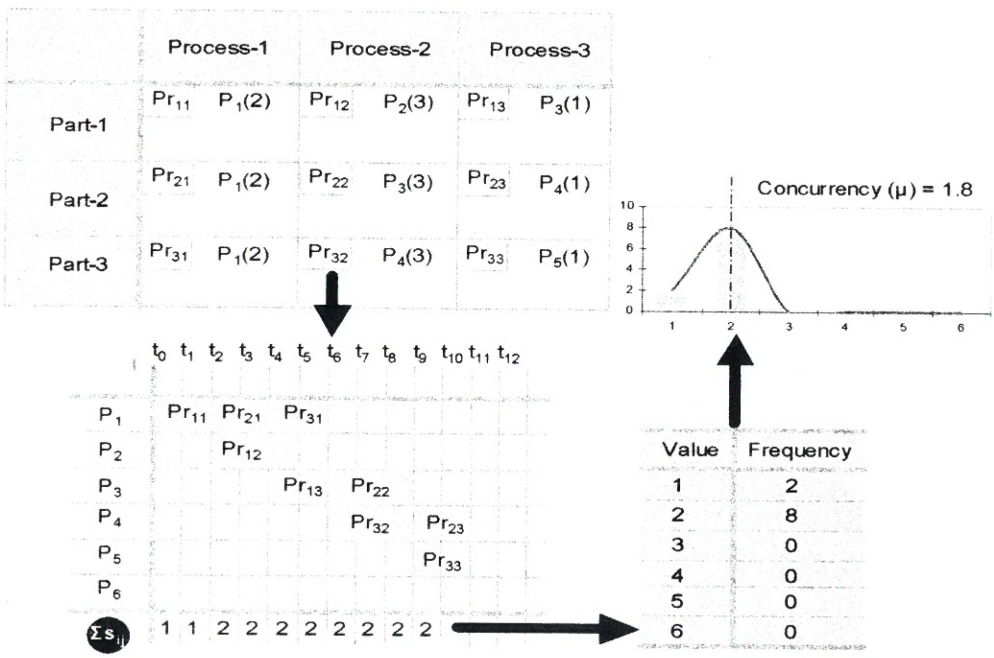

Fig. 3 : Computation of concurrency for rfl = 0

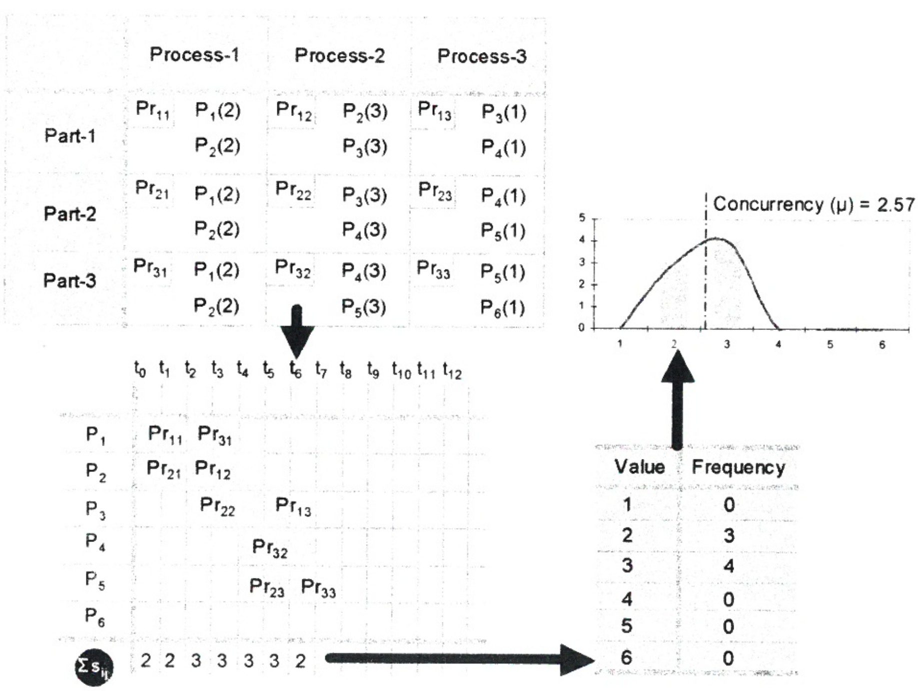

Fig. 4 : Computation of concurrency for rfl = 1

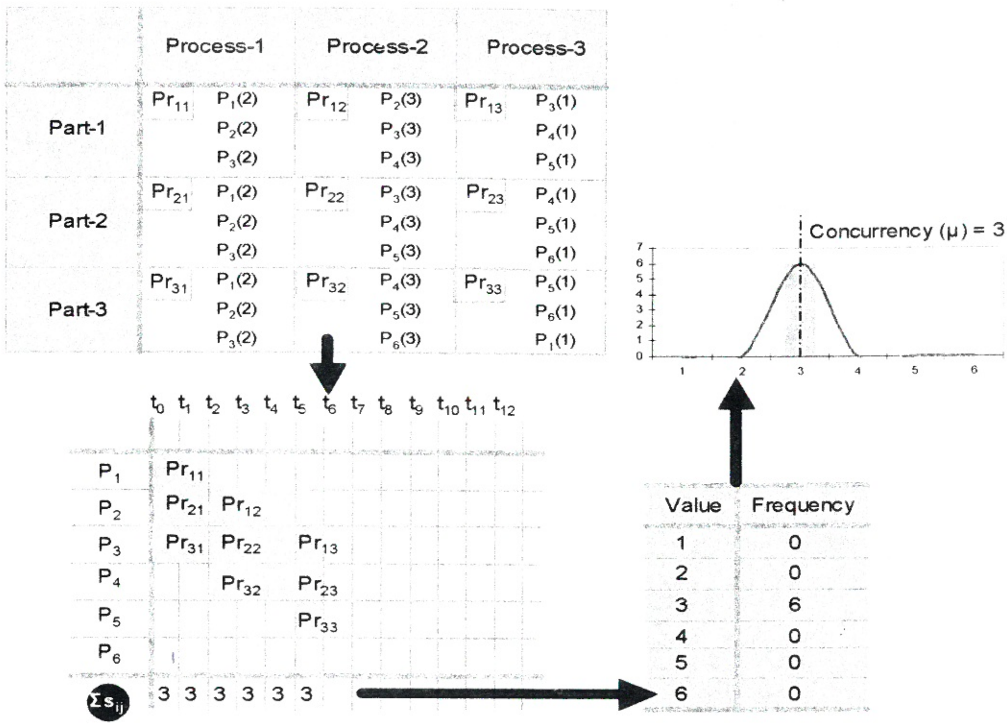

Fig. 5 : Computation of concurrency for rfl = 2

It can be seen that when the routing flexibility level is 0 (Fig-3), the concurrency is 1.8 and the lead time is 10 units of time. When the routing flexibility level is increased to 1 (Fig-4), the concurrency level has increased to 2.57 and the lead time is reduced to 7. As the routing flexibility level is further increased to 3 (Fig-5), the concurrency level has gone up to 3 and the lead time is reduced to 6. It is our research endeavor to develop an understanding of the underlying mechanisms of this flexibility enabled concurrency and its role in the reduction of the manufacturing lead time.

Part-2: Understanding the underlying mechanisms

Key Factors that influence the lead time:

Let a job "J" be performed by a set of processors (machines) $P_1..P_m$, while the completion of the job requires processes $Pr_1..Pr_n$ to be performed on the job. For the sake of simplicity, let us assume that we have enough flexibility to build the required concurrency among these processes. In such circumstances, among several factors that may influence the manufacturing lead time, in our opinion, two factors namely the level of concurrency among the processes and the load balancing among the processors will have much greater significance. It is our thesis that both concurrency as well as the load balancing must coexist for lead time reduction. To illustrate this point, we have presented a highly simplified model in Fig-6.

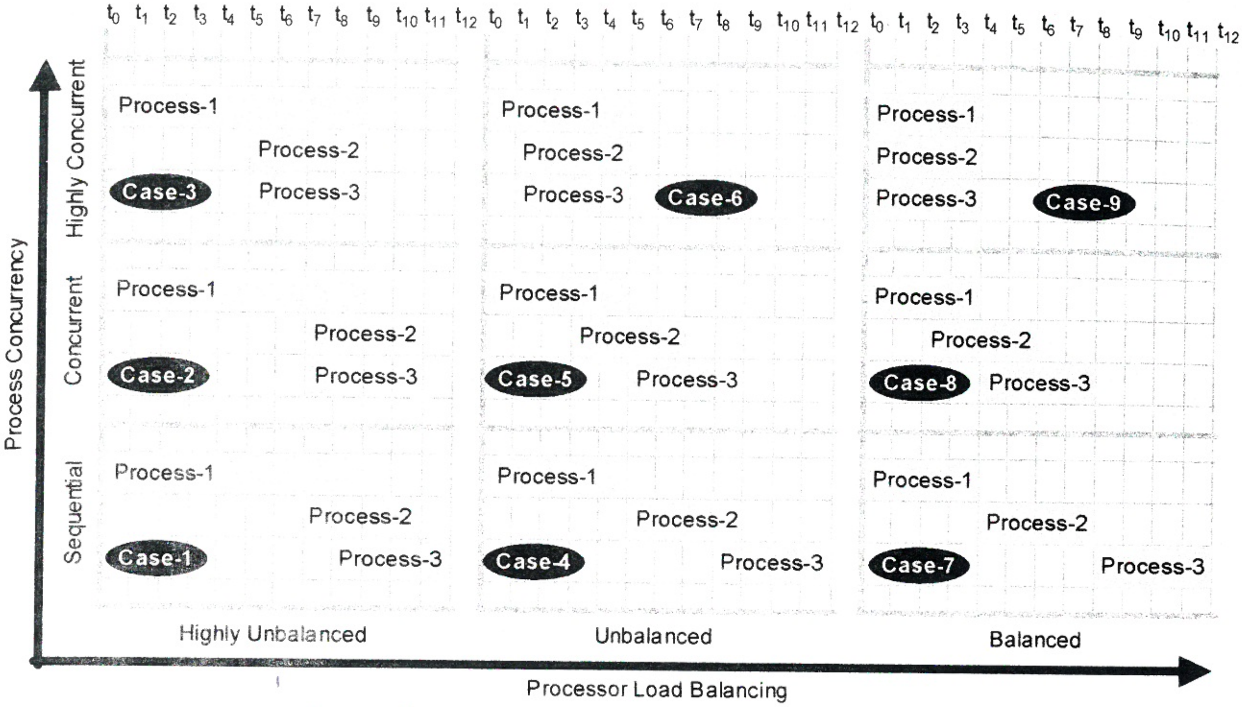

Fig.6 : Simple model to illustrate the relationship between concurrency, load balance, and lead time

In the above figure, Case-1 represents a condition of highly unbalanced processor loading and sequential execution of processes, with a lead time of 12 units of time. When we increase the process concurrency as shown in Case-2, the lead time comes down to 9 units. However, any amount of further increase in process concurrency may not result in further lead time reduction as shown in Case-3. Hence, for concurrency to be really effective, load balancing is essential. Case-7, Case-8 and Case-9 illustrates the effect of increasing concurrency under processor load balancing condition. It can be seen that simultaneous load balancing and concurrency help in minimizing the manufacturing lead time. While this model is highly simplified and too idealistic, it still reflects an important pattern in the complex behavior of the manufacturing systems. When we try to make use of the routing flexibility available within the system, either manually or through an automated control, what we are actually doing is to try and build concurrency among the processes. But in this process the processor load balancing alters resulting in a complex interaction among the various key factors namely routing flexibility, process concurrency, processor load balancing and the manufacturing lead time. The possible interactions between these factors can be modeled as shown in Fig-7.

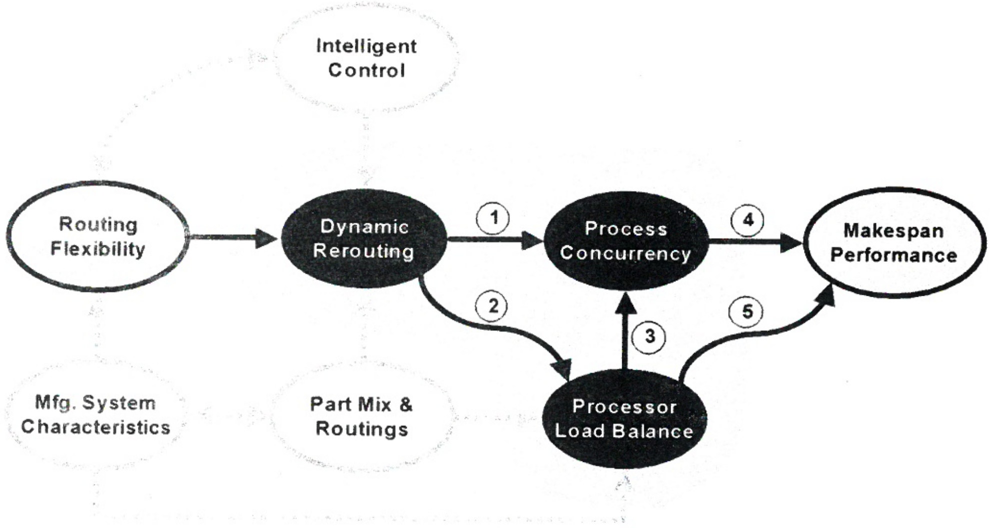

Fig. 7 : Possible Interactions between Routing Flexibility, Process Concurrency, Processor Load Balancing and Manufacturing Lead Time.

Possible Interactions between Routing Flexibility, Process Concurrency, Processor Load Balancing and Manufacturing Lead Time.

Manufacturing system characteristics give rise to certain amount of routing flexibility which when used with the help of an intelligent control will enable dynamic re-routing of the parts within the manufacturing system. The part mix to be manufactured and the corresponding process plans together determine the static load balance among the processors. However, during the dynamic re-routing of the parts the processor load balance gets altered. The dynamic re-routing effects the process concurrency, which together with the load balance effects the manufacturing lead-time. In addition there may be a relation between the processor load balance and process concurrency. As a whole five kinds of interactions may be identified as shown in Fig-7.

We have carried out extensive simulation experimentation to understand these five types of interactions. Simulation experiments are carried out under four conditions of static load balancing namely, "both part load as well as machine load balanced", "part load balanced but machine load unbalanced", "machine load balanced but part load unbalanced", and "both part load as well as machine load unbalanced". The results of the experimentation are shown in Fig. 8, 9, 10, 11, below.

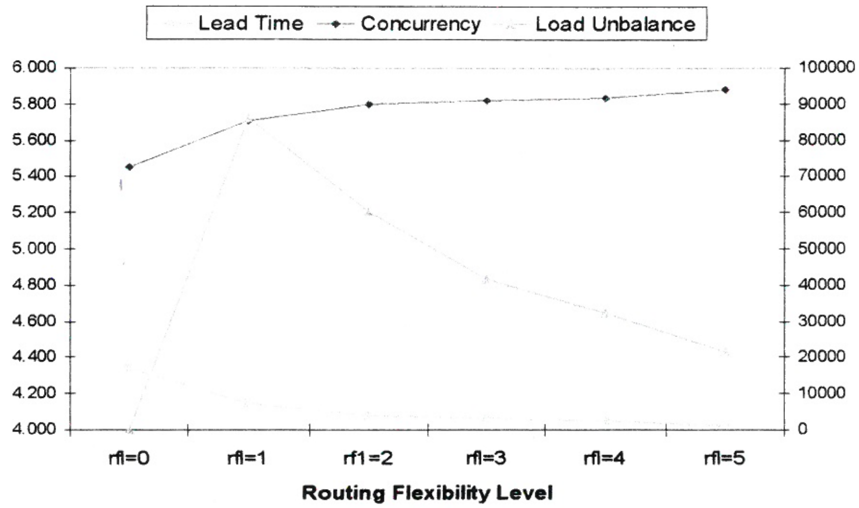

Fig.8 : Relationship between routing flexibility, concurrency, load balancing and lead time, when part load as well as machine load are balanced

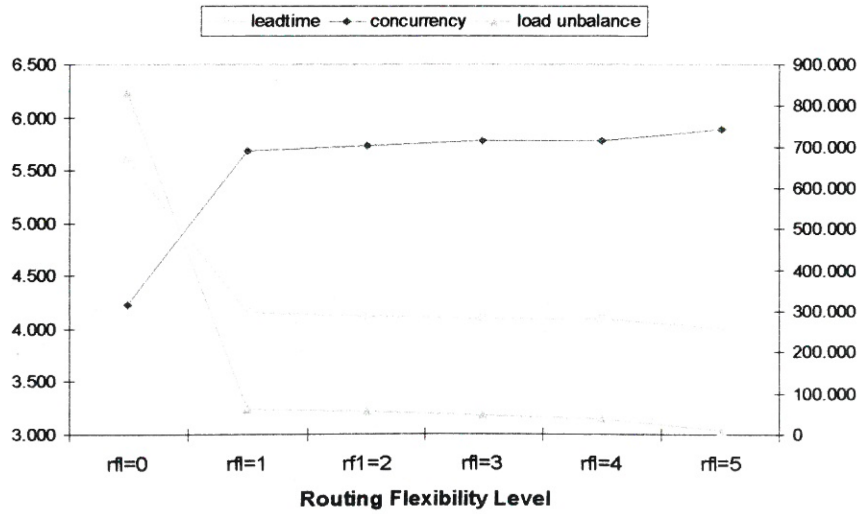

Fig.9 : Relationship between routing flexibility, concurrency, load balancing and lead time, when part load is balanced and machine load is unbalanced

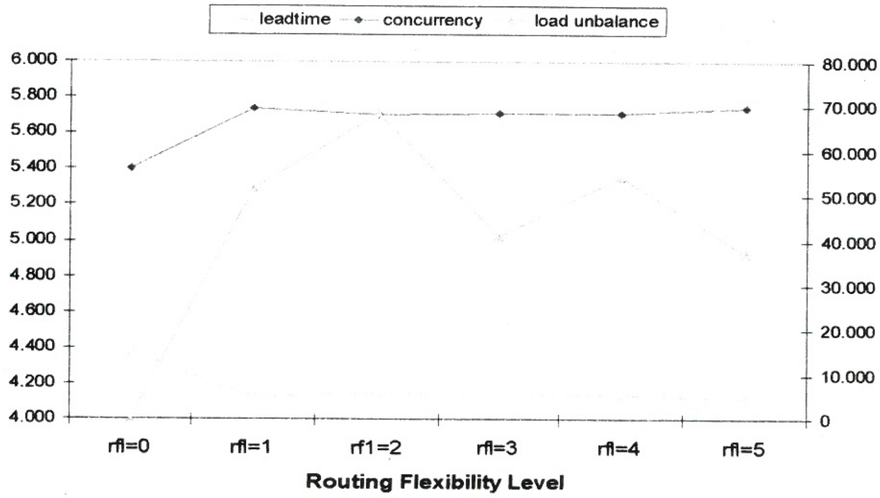

Fig.10 : Relationship between routing flexibility, concurrency, load balancing and lead time, when part load is unbalanced and machine load is balanced

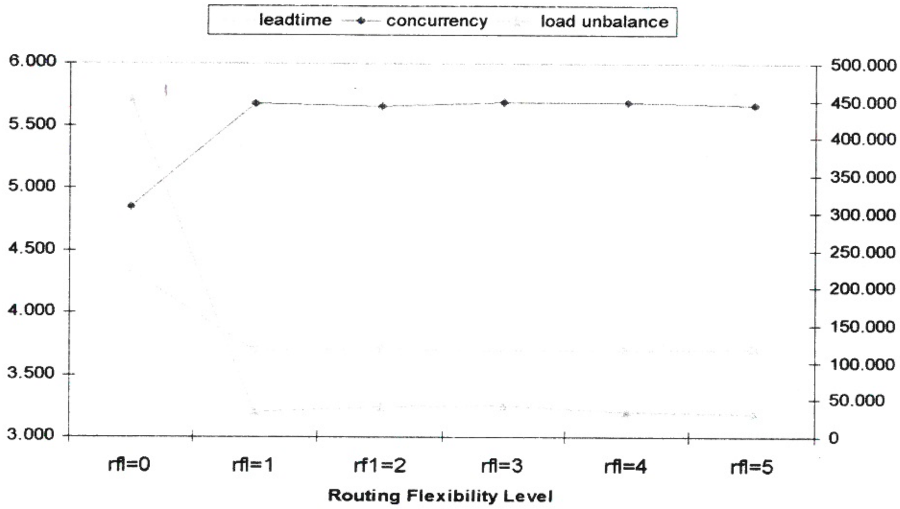

Fig.11 : Relationship between routing flexibility, concurrency, load balancing and lead time, when part load as well as machine load are unbalanced

Based on the simulation experimentation we have analysed the five types of possible interactions. The following is a brief summary of our findings.

Interaction between routing flexibility & process concurrency

It can be seen that as routing flexibility increases the process concurrency increases. However, the rate of increase decreases with increase in the flexibility level. Hence, for the first level of flexibility there will be a substantial increase in concurrency and thereafter the effect diminishes.

Interaction between routing flexibility and load balancing

The relationship between routing flexibility and the load balancing has been observed to be very complex. From the results of experiments it has been observed that the change in routing flexibility has significant effect on the load balance. However, the variation of load balancing with change in the level of routing flexibility depends on the initial condition of the load balancing. If under no flexibility condition the load is balanced, then the effect of increasing routing flexibility will be to initially disturb the load balancing. Thereafter subsequent increase in routing flexibility will restore the load balancing. If under no flexibility condition the machine load is unbalanced, then increasing routing flexibility will improve the load balancing.

Interaction between Concurrency and the Lead Time

It has been observed that there is a perfect negative correlation between concurrency and lead time under all conditions of load balancing. This strengthens our thesis that flexibility can be viewed as a combination of concurrency and constraint. In this case the constraint happens to be the disturbance of load balance. The implication of this observation is that if we can improve the concurrency by any means then we will be able to reduce the lead time. The means could be various types of flexibility. Towards this, this paper presents the routing flexibility enabled concurrency and the resulting reduction in the manufacturing lead time. This can be extended to other types of flexibility.

Interaction between Load balance and Lead Time

As seen from the model presented in Fig-6, load balancing plays an important role in lead time reduction. However, the interaction between the load balancing and the lead-time appear to be too complex. In the case of the unbalanced loading conditions, there is a certain amount of correlation observed between the load balance and the lead-time. However in the case of balanced loading conditions, no such correlation could be observed.

Interaction between Load balance and Process Concurrency

In our experience, certain interactions exist between the processor load balance and process concurrency. However more research would be required to establish this relationship. Simulation models may offer an expedient tool to study these relationships under a wide variety of scenarios.

Implications for the Knowledge Management

In this paper we have attempted to provide a novel view of flexibility from the perspective of a proactive knowledge management. Based on a realization that the knowledge about flexibility enables its effective application, we have presented a simple framework of flexibility that can be easily understood by the practicing managers as well as the knowledge generated through simulation experimentation about usefulness of flexibility under different conditions. Thus, this work demonstrates the usefulness of knowledge management perspective for the effective exploitation of flexibility. Since flexibility is expensive and is often needed in the evolving dynamic demand environments, the decision-makers need proactive knowledge about the available flexibility and how it may be utilized. Wadhwa (2002) describes an overall architecture for proactive decision support using simulator-assisted models, which may be utilized for generating and using new knowledge in flexible systems.

Conclusions

This paper presented the results of a conceptual study and simulation experimentation carried out to develop an understanding of manufacturing lead-time reduction through routing flexibility enabled concurrency. The study proposes that flexibility may be viewed as a combination of concurrency and constraints in any manufacturing system. It is the interaction between flexibility, system configuration and the operation control logic that determines the system performance in flexible systems. This study presents some of the industrially important interactions with a focus on manufacturing lead-time. These involve interactions between routing flexibility and process concurrency, interaction between routing flexibility and processor load balancing, interaction between process concurrency and manufacturing lead time, interaction between processor load balancing and manufacturing lead time and interaction between processor load balancing and process concurrency. Among these interactions, process concurrency and manufacturing lead-time were found to be having significantly useful benefits. Thus increased flexibility involving greater concurrency and/or fewer constraints appear to be a good strategy towards manufacturing lead-time reductions. As compared with similar results obtained during our study of the sequencing flexibility, it has been observed that the effect of routing flexibility in reducing the manufacturing lead time is better than that of sequencing flexibility. This is because the sequencing flexibility makes use of options available to interchange the sequence of processes, and as more and more processes are completed, these options will gradually reduce. Another important observation is that, unlike the routing flexibility, sequencing flexibility does not alter the static load balance, and hence sequencing flexibility may be more suitable to the balanced loading conditions as compared to the routing flexibility. These studies demonstrate the importance of flexibility knowledge management for the performance enhancement of manufacturing enterprises.

REFERENCES

1. ***Knowledge Management, found on Internet at http://www.aiai.ed.ac.uk/~alm/ kamlnks.html
2. BENJAAFAR, S, & RAMAKRISHNAN, R. (1996) **Modeling, measurement and evaluation of sequencing flexibility in manufacturing system,** International Journal of Production Research, Vol. 34, pp. 1195-1220.
3. BROWNE, J., DUBOIS, D., RATHMILL, K., SETHI, P. & STEKE, K, E. (1984) **Classification of Flexible Manufacturing Systems,** The FMS Magazine, April 1984, pp. 114-117.
4. GERWIN, D., **Manufacturing Flexibility: a strategic perspective**, Management Science Vol. 39, No. 4, 1993, pp. 395-410.
5. GUPTA, Y.P., & S. GOYAL 1989, **Flexibility of manufacturing systems: concepts and measurements,** European Journal of Operational Research Vol. 43, pp. 119-135.
6. GUPTA, Y.P., & T.M. SOMERS, (1992), **The measurement of manufacturing flexibility,** European Journal of Operational Research Vol. 60, pp. 166-182.
7. GUSTAVSSON,S., (1984), **Flexibility and productivity in complex prosuction processes,** International Journal of Production Research, 22 (5), pp. 801-808.
8. LAURA LAMONICA, **The Case for Knowledge Management at DPA: Is What We Don't Know Hurting Us?,** Journal of Systemic Knowledge Management, May 2001.
9. MALHOTRA, YOGESH **Knowledge Management for the New World of Business** Brint Institute at www.brint.com.
10. RICK DOVE, (1999), **Knowledge Management, Response Ability, and the Agile Enterprise,** Journal of Knowledge Management, March 1999, found on Internet at www,parshift.com.
11. SETHI, K.S., & SETHI S.P. (1990), **Flexibility in Manufacturing: A Survey,** The International Journal of Flexible Manufacturing Systems Vol. 2, pp. 289-328.
12. SLACK, N., (1983). **Flexibility as a manufacturing Objective**, International Journal of Production Management , Vol. 3, No. 3, pp. 4-13.
13. SON, Y.K & PARK, C.S., (1987), **Economic Measure of Productivity, Quality and Flexibility in Advanced manufacturing Systems**, Journal of Manufacturing Systems, Vol. 6, No. 3, pp. 193-207.
14. STECKE, K.E. & BROWNE, J., (1985) **Variations in Flexible Manufacturing Systems According to the Relevant Types of Automated Materials Handling**, Material Flow, No.2, pp. 179-185.
15. TINCKNELL, D.J. & RADCLIFFE, D.F. (1996) **A generic model of manufacturing flexibility based on system control hierarchies**, International Journal of Production Research, Vol. 34, pp. 19-22.
16. WADHWA, S. & BHAGWAT, R. (1998) **Judicious Increase in Flexibility and Decision Automation in Semi-Computerised Flexible Manufacturing (SCFM) Systems**, International Journal, Studies in Informatics and Control.
17. WADHWA, S. & BROWNE, J. (1990) **Modeling FMS with Decision Petri Nets**, International Journal of Flexible Manufacturing Systems, No.1, pp. 253-280.
18. WADHWA, S. (2002), **Simulation Assisted Models for Proactive Decision Support in Intelligent manufacturing Systems'**, IMLF-2002, Feb 8-11, Adelaide, Australia.
19. WADHWA, S., RAO, K. S. **Flexibility: An Emerging Meta-Competence for Managing High Technology**, International Journal of Technology Management, Vol 19, no. 7/8, 2000.
20. XAVIER DE GROOTE (1994) **The flexibility of production process: a general frame work,** Management Science, Vol. 40, pp. 933-945.