Decision-Information Synchronization (DIS) in Flexible Systems: Knowledge Management (KM) Implications

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Abstract: This paper presents the results of a conceptual study and simulation experimentation aimed at understanding the impact of Decision-Information Synchronization (DIS) in Flexible Systems. The study shows that the flexibility enabled lead-time reduction in flexible systems is influenced by DIS of various types in various ways. It is thus important to appreciate the implications on knowledge management in flexibility driven enterprises. The knowledge of conventional FMS requires to be modified and managing the new knowledge is very important. In our view most flexible enterprises face DIS scenarios in real systems. For instance periodic decision-making is a common practice in many flexible systems. However, this leads to important DIS conditions. Hence it is important to develop new DIS based models of flexible systems and show the new knowledge explicitly to the managers. Towards this we propose a conceptual model for DIS scenario with period decision making policy operating in a period status-monitoring mode. Based on this we identify five important elements viz. decision delay, information period, decision period, information delay and decision information lag, that could influence decision information synchronization. The impact of these DIS elements on the routing flexibility based lead-time reduction are studied. The studies indicated that DIS has significant effect on the lead-time performance in the flexible system. In general, with the increasing levels of flexibility, the lead-time reduces and thereby the performance of the manufacturing system improves. The effect of DIS related delays, is to reduce the performance enhancement. Hence, for a given level of flexibility, the lead-time performance will be lower for a higher level of DIS delay. The studies further indicated that, beyond certain level of DIS delay, the use of flexibility becomes counter productive. Under these conditions, increase in flexibility levels may result in lower performance. Managing this new knowledge is very important. Typically managers invest in greater flexibility hoping that it will improve performance. The models of the nature discussed are needed by KM professionals to help change such mindsets. This paper aims to contribute in this direction.

Keywords: Decision-Information Synchronization, Decision Delay, Information Period, Decision Period, Decision Information Lag, Flexible System, Knowledge Management.

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1. Introduction:

With the growing competitive pressures on manufacturing enterprises to perform in global markets, flexibility has emerged as a critical dimension of competition. Traditionally flexibility is viewed as hedge against uncertainty. Our research indicated that flexibility could be employed in a pro-active manner to enhance the lead-time performance of the manufacturing system (for example, Jensen et al, 1996; Albino and Garavelli, 1998; Albino and Garavelli, 1999; Newman and Maffei, 1999; Tsubone and Horikawa, 1999; Borenstein, 2000; Garavelli, 2001; Seifert and Morito, 2001, Jack and Raturi, 2001). However, realising the complete benefits of the flexibility is closely linked to the levels of automation and integration. Since, flexibility, automation and integration require considerable IT investment many manufacturing enterprises operate in a semi-computerized flexible system environment (Wadhwa and Bhagwat (1998), Wadhwa and Aggarwal (2000)). Wadhwa and Rao (2003) extended these concepts for supply chains considered as flexible systems. The DIS problems in flexible systems are more prevelant for SMEs operating under partial information and decision system environments. Before embarking upon IT investment, there is a need for closer understanding of the requirements and use of judicious combination of flexibility, integration and automation. This motivated our research efforts in the area of semi-computerized flexible systems facing DIS delays. It is our research endeavor to develop an understanding of the impact of partial DIS automation levels and the consequent modes of DIS delays in semi-computerized flexible systems. There is need to develop and share new knowledge here.

This paper addresses the above issues in two parts, the first part provides a framework for understanding the Decision-Information Synchronization in a manufacturing environment, leading to the identification of five important elements, and the second part presents the results of simulation experimentation to study the impact of these five elements on the flexibility enabled lead time reduction. We refer to a semi-computerized system (i.e. with DIS implications) with a given level of flexibility as semi-computerized flexible system (SCFS). Such a system can be a supply chain, any enterprise or an operational system (manufacturing or service industry). A manufacturing system with flexibility and DIS is a subset, seen as a Semi-computerized flexible manufacturing (SCFM) system by Wadhwa and Bhagwat (1998). The KM implication is that we need to educate the managers about the difference between SCFS, SCFM and the conventional Flexible Manufacturing Systems (FMS). The latter are considered to face no DIS delays and the decisions are event driven that are considered to be real time. On the other hand SCFS exhibit DIS delays, can have on line but not necessarily real time decisions and decision-making can be periodic also. From KM point of view this explicit knowledge is to be shared. The tacit knowledge about the role of increasing flexibility on the flexible system performance needs to be revised. The models of the nature described here can help KM professionals to help evolve new mindsets for managers. Most mangers are aware of decision and information delays in their enterprises but seldom do they appreciate its impact on flexibility based performance in the system. We discuss important KM implications using KM concepts of Tiwana (2001) at the end.

Part-1: Framework for understanding Decision-Information Synchronization in a manufacturing environment

1.1 Modern manufacturing systems

Modern manufacturing systems are extremely complex and research efforts to understand these systems gave raise to several modeling formalisms like IDEF, Modeling methodologies like GRAI, and modeling frameworks like CIMOSA, GIM, PERA being used to understand the various aspects. Doumeingts et al (1995) gives a comprehensive survey of these modeling methodologies. Each of these methodologies view the manufacturing system from different perspectives, and thereby, provide different views of the same system. From the decision-information synchronization point of view, our research is motivated by (a) the GRAI reference model for the manufacturing system and (b) the concept of decision points, which are briefly described below.

1.1.2 The Decision Points View of the Manufacturing System

Similar to the idea of decision centers in the GRAI model is the concept of Decision Points. Decision Points are specific points in the manufacturing system responsible for a particular kind of decision-making. For instance, in a flexible manufacturing system, there could be a sequencing decision point attached with the input buffer of each machine, and a dispatching decision point attached with the output buffer of each machine. Similarly, in the case of a supply chain, each entity of the chain may have an order processing decision point and a stock replenishment decision point. Wadhwa (1988) suggested an explicit modeling of all entity flows (materials flow, resource flow, information flow, etc.) in the context of manufacturing systems with a focus on decision points. For instance, in flexible systems, the decision points control the flow of the entities in the interacting processes (Wadhwa and Browne, 1990)).

1.2 A view of the manufacturing system from DIS perspective:

Based on the GRAI model and the idea of decision points, we have evolved a view of the manufacturing system from the Decision-Information Synchronization point of view, as shown in Figure-1. The objective is to develop an easy understanding of Decision-Information Synchronization related issues in manufacturing systems.

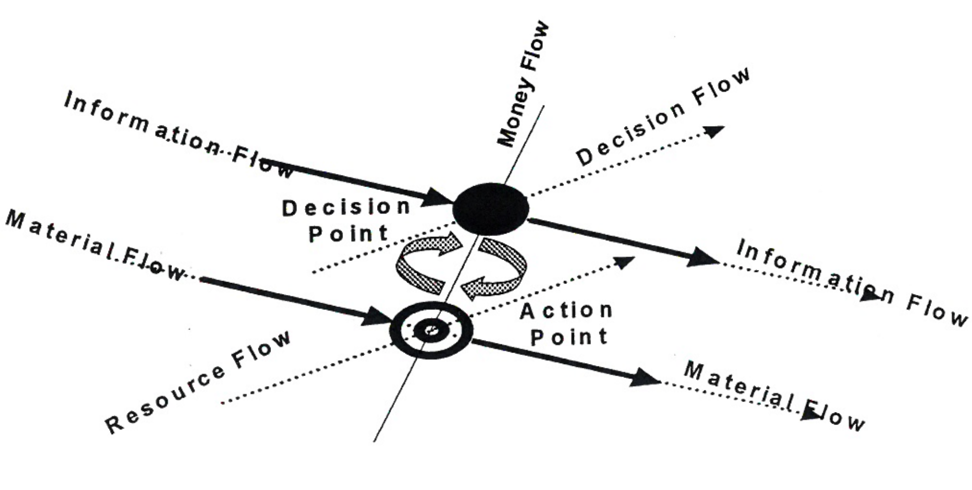

Figure 1: Various Entity Flows in a Flexible System

As shown in the figure, the manufacturing systems can be viewed in terms of five types of flows, namely, information flow, decision flow, materials flow, resource flow and money flow. The performance of the manufacturing system depends on the complex interaction of these five flows. In general, the information flow and decision flow constitute the control system, which controls the materials flow and resource flow. The information and decision flows meet at discrete points called the decision points, and similarly the materials and resource flow meet at discrete points called action points. The decision points and the action points interact with each other to ensure smooth functioning of the manufacturing system. The overall performance of the manufacturing system depends on the synchronization between all the five types of flows.

While the financial performance of the manufacturing system is reflected in the money flow in terms of the profit, return on investment, etc., the common method of measuring the manufacturing system performance is through the material flow out of the manufacturing system in terms of the quantity, quality, cost, timely availability, ability to respond to the market variations, etc. This output performance of the manufacturing system depends on the level of synchronization between the materials flow and resources flow, which in turn depends upon the quality of decision making by the control system. Hence our research explicitly focuses on this particular aspect.
Our research indicated that improving the quality of decision-making at various decision points is the key to the manufacturing system performance. However, the quality of decision-making at a decision point depends on several factors including the nature of information processing, the nature of decision processing, and the various control policies. In our view, for a given control system with specified control policy, the performance mainly depends upon the synchronization of information and decision flows. Hence, our current research specifically focuses on the information and decision processes and their synchronization. Our research endeavor is to characterize the various elements of a decision points and to develop a deeper understanding about their interactions. The motivated us to develop a simplified model of a decision point as presented below.

1.3 Elements of a Decision Point

Figure-2 presents a simplified model of a typical decision point in a manufacturing system.

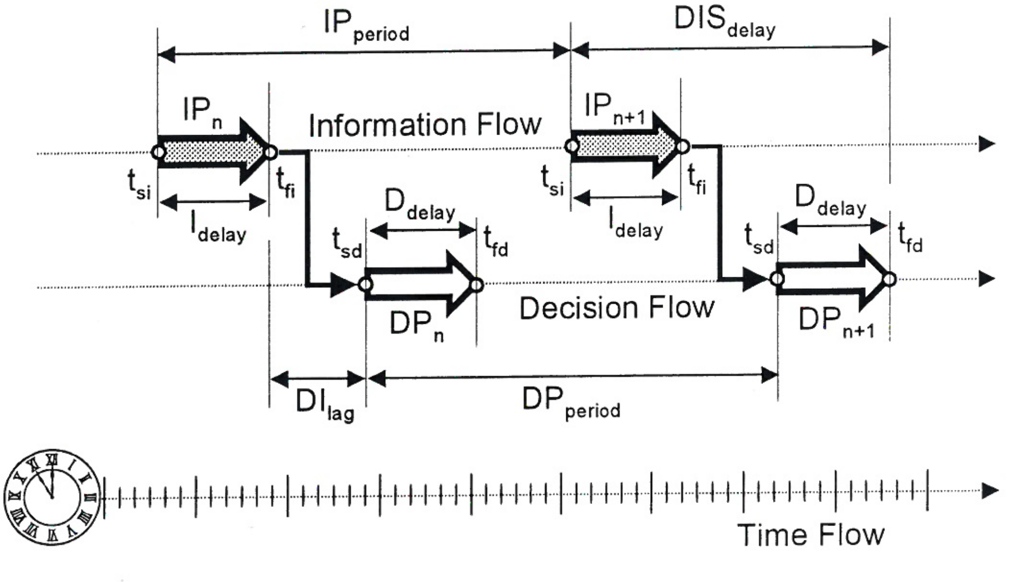

Figure 2: Conceptual Model of a Decision Point

As shown in the Figure-2, a decision point essentially comprises of two elements, namely an information process (IP) and a decision process (DP). A decision is made at time t_n by invoking the decision process DP_n. The decision process arrives at a decision by making use of information available to it at that point of time. However, the information is generated by the information process IP_n which is independent of the decision process. Hence the information available to the decision process may not correspond to the point of decision-making. Also both the information process as well as decision process takes finite amount of time to complete their respective processes. This gives raise to various kinds of delays, which we call as Decision-Information Synchronization Delays (DIS_{Delay}).

1.4 Elements of DIS Delays

The Decision-Information Synchronization Delays (DIS_{Delay}).at a decision point comprises of the following elements:

a) Information Delay (I_{Delay}) : This is the time taken by an information process to complete its process. It is measured as the time elapsed between the start of the information process (t_{si}) and the finish of the information process (t_{fi}). The magnitude of the Information Delay depends up on the level of Information Automation.

b) Decision Delay (D_{Delay}) : This is the time taken by an decision process to complete its process. It is measured as the time elapsed between the start of the decision process (t_{sd}) and the finish of the Decision process (t_{fd}). The magnitude of the decision Delay depends up on the level of decision Automation.

c) Period of Information Process Cycle (IP_{Period}) : In a periodic status monitoring kind of situation, the information process may be invoked in a cyclic manner with a specified periodicity. The period of such an information process cycle is the time elapsed between the start events of two consecutive information processes. The Period of Information Process Cycle is the reciprocal of the frequency of the information process cycle.

d) Period of Decision Process Cycle (DP_{Period}): In a periodic decision making kind of situation, the decision process may be invoked in a cyclic manner with a specified periodicity. The period of such a decision process cycle is the time elapsed between the start events of two consecutive decision processes. The Period of Decision Process Cycle is the reciprocal of the frequency of the decision process cycle.

e) Decision-Information Lag (DI_{Lag}): This is the time elapsed between the finish of the information process (t_{fi}) and the start of the corresponding Decision process (t_{sd}). When the information and decision flows are not synchronized, the Decision-Information Lag varies dynamically depending up on the relative frequency of the information and decision process cycles.

f) Decision-Information Synchronization Delay (DIS_{Delay}) : The Decision-Information Synchronization delay is the cumulative effect of all the above delays.

$$DIS_{Delay} = I_{Delay} + D_{Delay} + DI_{Lag}$$

In spite of large scale IT based automation, in our view, most of the real life manufacturing systems operate in semi-computerized environments. In such an environment, Decision-Information Synchronization Delays are important enablers for the success of IT based strategies. Hence our research focus is on understanding of these delays and the various modes in which they may manifest in a manufacturing environment.

1.5 Various Modes of DIS Delays: A Matrix as a KM Aid

It will help the knowledge management professionals to use a matrix that can display various modes of DIS delays caused by decision-information systems. Figure 3 shows this based on periodicity of decision-making and the periodicity of status monitoring.

Decision Process	Periodicity	Information Process: Continuous $I_{period} \simeq 0$		Information Process: Periodic $I_{period} > 0$	
	Speed	Real Time $I_{delay} \simeq 0$	Delayed $I_{delay} \geq 0$	Real Time $I_{delay} \simeq 0$	Delayed $I_{delay} \geq 0$
Continuous $D_{period} \simeq 0$	Real Time $D_{delay} \simeq 0$	$DIS_{delay} \simeq 0$	$DIS_{delay} > 0$	$DIS_{delay} > 0$	$DIS_{delay} > 0$
	Delayed $D_{delay} \geq 0$	$DIS_{delay} > 0$	$DIS_{delay} > 0$	$DIS_{delay} > 0$	$DIS_{delay} > 0$
Periodic $D_{period} > 0$	Real Time $D_{delay} \simeq 0$	$DIS_{delay} > 0$	$DIS_{delay} > 0$	$DIS_{delay} \simeq 0$ sometimes	$DIS_{delay} > 0$
	Delayed $D_{delay} \geq 0$	$DIS_{delay} > 0$	$DIS_{delay} > 0$	$DIS_{delay} > 0$	$DIS_{delay} > 0$

Figure 3: Various Forms of DIS Delays Caused by Decision-Information Systems

As mentioned earlier, a decision is made by invoking the decision process which in turn makes use of the information generated by an information process. These two processes may flow independent of each other in a cyclic manner, with their own Delays & Process Cycle Periods. The magnitude of these Delays & Process Cycle Periods depends on the level of information & decision automation available in the system. This gives rise to various modes of DIS Delays as shown in the simple table in figure 3. This simple matrix can help KM professionals to share the DIS knowledge with many managers. It can also help to promote innovation of new DIS delay situations by the managers. The new DIS knowledge will get easily absorbed using such simple 2 dimensional KM aids. This can be further elaborated to link the DIS with real life. For instance, if the information automation is high enough to ensure that the information delay is insignificantly low, then the information process may be called as "Real time Information Process". Otherwise information delay will exist, resulting in DIS delays. Similarly, if the decision automation is fast enough to ensure nearly instantaneous decision making, we may call this as "Real time Decision Process". Otherwise decision delay will exist, resulting in DIS delays. If the Period of Information Process Cycle is insignificantly small, we may consider the information process as "Continuous Information Process". Otherwise it is called as "Periodic Information Process". Similarly, if the Period of Decision Process Cycle is insignificantly small, we may call this as "Continuous Decision Process". Otherwise it is called as "Periodic Decision Process". Thus, several possibilities exist for the magnitude of delays and periods, and their combinations will result in various modes of DIS delays as shown in Figure-3. Among these various modes of DIS delays, the mode corresponding to the continuous and real time execution of information as well as decision processes will result in Zero-DIS Delay situation. Another mode corresponding to both information as well as decision processes being periodic and real time may also result in Zero-DIS Delay situation when the periods of information and decision process cycles are exactly equal and both the cycles are perfectly synchronized to be in phase with each other. In all other cases, DIS Delays will exist. The magnitude of these DIS delays will depend upon the magnitude of the information and decision delays, periods of the information and decision process cycles and their level of synchronization.

The KM implication for the DIS discussion is easy to summarize. We can see that DIS Delays are a fact of life and they exist in almost all the systems. If we have to live with the DIS delays it is essential to understand their nature and how they influence the system performance. Since the investment in IT costs money, understanding of DIS Delays would help the designers to arrive at judicious levels of automation. This motivated us to carryout a series of simulation experiments to understand the effect of various types of DIS Delays on the lead time performance of different flexibility types. Part-2 of this paper presents the results of some of these studies pertaining to the DIS Delays originating from periodic status monitoring and periodic decision-making.

Part-2: Simulation to Study the Impact of DIS Delays on the Flexible Systems

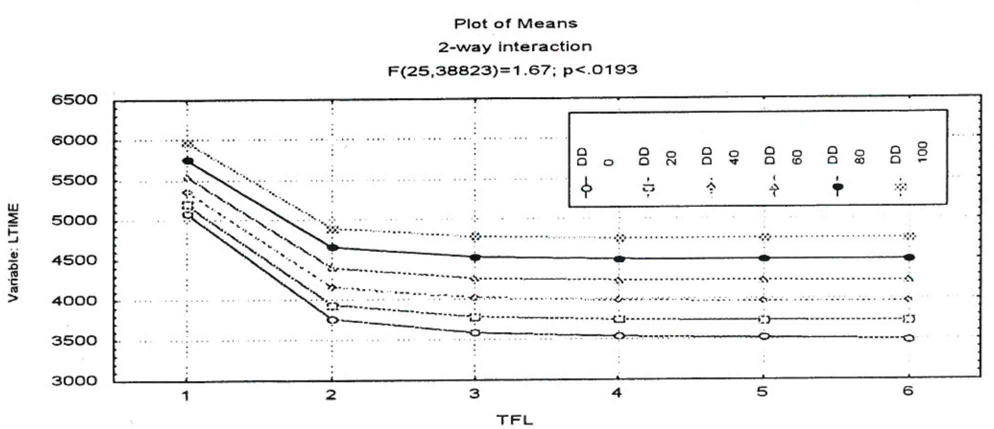

Figure 4: Flexibility Related Performance Benefits and Impact of Information Delay

Effect of Information Delay (ID).

The study by Wadhwa and Bhagwat (1998) indicated that information delay reduces the influence of flexibility to reduce lead-time and beyond certain level of information delay the flexibility will become counterproductive. They carried out these studies in a simulation model of SCFM system with each machine having its own buffers. We developed models that could obviate the effect of ID with the help of a central buffer. The results of the study as shown in Figure-4 indicated that it may be possible to overcome the effect of information delays using methods similar to that of using a central buffer. From KM perspective this is an important result indicating that a better flexible system design can help to reduce the negative effects of Information delays.

Effect of decision delay

The study by Wadhwa and Bhagwat (1999) indicated that decision delay reduces the influence of flexibility to reduce lead-time and beyond certain level of decision delay the flexibility will become counterproductive. This motivated us to study how decision delays may behave with central buffer. The results on decision delay are given in Figure-5. The results indicate that in a central buffer environment, the effect of decision delay is to increase the overall lead-time as a whole but it may not interact with flexibility.

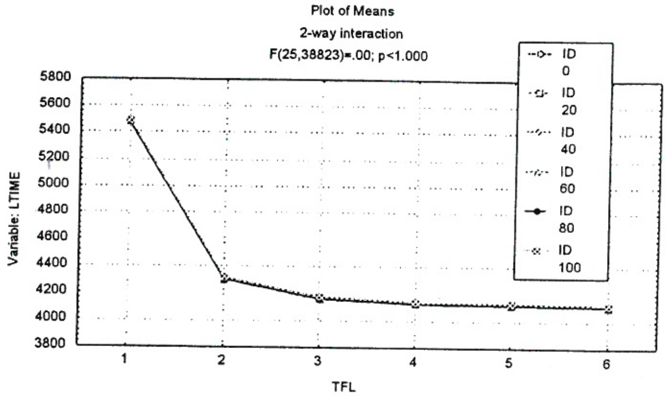

Figure 5: Role of Decision Delay in the Flexible System

The other three elements of decision information synchronization viz. the information cycle period, decision cycle period, and decision information lag did not receive adequate attention from researchers. The following are the results of the studies on these three elements.

Effect of information cycle period

Wadhwa et al (1997) studied the performance of a hysteresis Based Control Strategy for A Flexible Machine Operating Under A Periodic Status Monitoring. This motivated our studies on the effect of information cycle period. Figure-6 shows the interactions between varying levels of information period and the routing flexibility. It is observed that routing flexibility reduces lead-time at lower levels of information period. However when the information period is high, flexibility becomes counter productive and increase in the levels of flexibility will result in increase in lead-time. This observation has two implications, first is that to derive the benefit of flexibility we need adequate IT support which will ensure that DIS delays are within certain limit, the second is that, up to certain levels of DIS delays can be tolerated by flexibility without becoming counter productive.

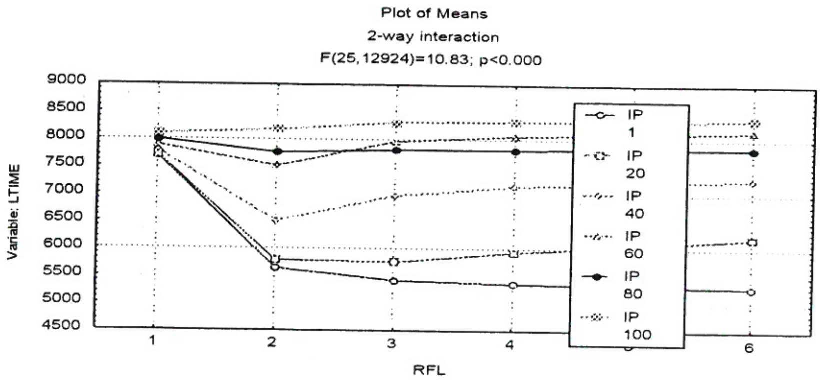

Figure-6: Interaction between varying levels of IP & RFL

This brings out the importance of using judicious combination of flexibility & IT levels.

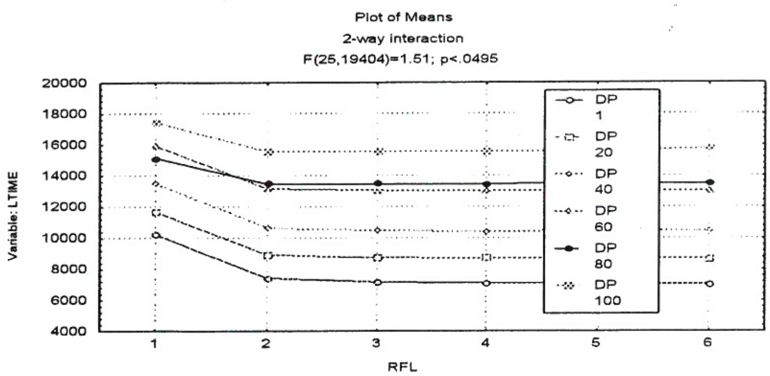

Figure 7: The Role of Decision Period on the Performance of Flexibility.

Effect of decision cycle period

The results of the simulation studies on the effect of decision cycle period indicates that, while the effect of decision period is to increase the lead-time as a whole it may not interact with flexibility. Thus the results indicate uniform performance degradation at all the levels of flexibility with the increasing decision periods. The results are shown in Figure-7.

Effect of Decision Information Lag

Figure-8 shows the effect of decision information lag on the flexibility enabled lead-time reduction. The results indicate that the effect is similar to that of information period. At lower levels of decision information lag the flexibility is effective in reducing the lead-time however as the decision information lag increases the flexibility will become less effective and beyond certain level of decision information lag the flexibility becomes counterproductive.

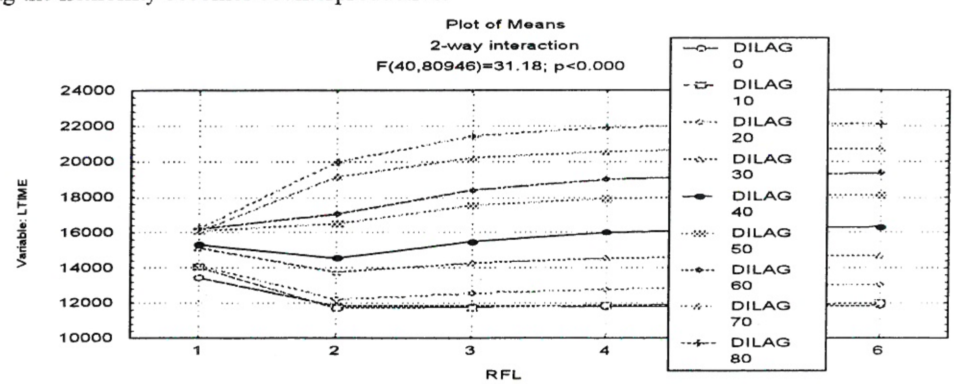

Figure 8: The role of DIS based Decision Information Lag in Flexible System

Knowledge Management (KM) Implications

From KM perspective it may be summarized that the impact of information period and decision information lag are very important for flexibility as they have a potential to make the flexibility counterproductive. The reason for this behavior is understandable because, under the conditions of information period and DI lag, there will be mismatch between the information and decision flows resulting in corresponding mismatch between material and resource flows. As a result, with increasing levels of information periods and DI lag, the decision-making becomes less effective initially and eventually lead to wrong decision making. This degeneration process will be faster under the conditions of higher levels of flexibility as more number of alternatives are involved. As regards the decision delay and decision period, the main impact is to increase the lead-time at all the flexibility levels. This is understandable because the decision-making drives the actions and when the decision making is delayed the flow of materials and resources are effected.

The Knowledge management implications for these studies are important. We are motivated by the works of Tiwana (2000), Davenport et al (1998), Grundstein, (2000) and Nietok(2003) and thus discuss both the

Explicit knowledge and Tacit Knowledge. Explicit knowledge needs to be shared for two important results in flexible systems operating under DIS scenarios. (i) The potential of higher levels of flexibility can be realized only through appropriate levels of information automation. In fact, beyond certain level of DIS delays there is no point in investing in flexible technologies, without the matching automation. (ii) There is a level of DIS delays, which can be tolerated by the flexibility. This means we do not really need very high levels of automation with huge investment. As we move closer to the real time applications, the cost will increase exponentially. We need to strike a balance. For instance, Internet based technologies offer a cost effective solutions, but they entail significant DIS Delays. Hence a judicious level of DIS automation needs to be decided for each specific flexible system application.

Conceptual models such as Figure 2 and 3 help to develop an explicit knowledge about the DIS delays and its manifestations. Here what is important is to appreciate that the DIS delays are prevalent in various forms in the flexible systems. Further its is important to consider them explicitly while investing in IT based flexibility, integration and automation (Wadhwa and Agarwal (2000)). The tacit knowledge that has to be promoted is the knowledge and experience of various managers in dealing with the DIS delays. Often investment in IT is seen as the only way out. But as shown in figure 4, the change in the flexible system configuration i.e. the use of a central buffer may obviate the negative effects of information delays. Such experiences need to be promoted through the use of simulation models within the organization. Often it will be difficult to develop such knowledge by managerial intuition alone. In order to effectively promote the benefits of Knowledge Management, it is suggested that simulation models can play a very significant role. As discussed in one of our earlier papers on simulation based models for intelligent manufacturing systems using the SAMIN architecture, the KM implication for complex flexible systems is important to study. We need to provide tools to managers to innovate new knowledge more effectively and then share the same inside the flexible enterprise. In this paper we outlined that DIS domain and Flexible Systems require similar KM focus of exposing to the need for new knowledge, facilitating models for basic explicit knowledge, dynamic simulation models for helping to build tacit knowledge, optimization tools to advance the knowledge towards improved performance and finally to share the advanced knowledge. This paper has outlined this entire approach for the flexible enterprises. Our future work focuses on applying these ideas to supply chains and virtual enterprises. The latter poses an additional challenge of dynamic structural changes in the chain with new partners. This being a short time strategy, it poses new KM challenge of how to develop and deploy new knowledge in short duration opportunistic projects.

2. Conclusions

This paper presented the Knowledge management implications for the flexible systems operating under DIS scenarios. The results of a conceptual study and simulation aimed at understanding the impact of Decision-Information Synchronization (DIS) on the flexibility enabled lead-time reduction was studied. For the purpose a Semi-Computerized Flexible System (SCFS) model was used. The paper presented a conceptual framework for understanding of DIS in a semi-computerized manufacturing environment. This framework includes a manufacturing system view from DIS perspective, a model for decision points and a methodology to identify different modes of DIS Delays. Based on this framework five important elements of decision information synchronization have been identified and their impact on flexibility enabled lead-time reduction has been studied through simulation experimentation. The simulation studies indicated that the effect of all the elements is to increase the lead-time in general. However, under the conditions of study, the Information period and decision information lag appear to have more interaction with flexibility. As the level of information period and DI lag increases the flexibility becomes less effective and beyond certain level the flexibility becomes counter productive. The effect of decision delays and decision periods appear to be same at all the levels of flexibility. These observations are important for the designers and managers of semi-computerized flexible manufacturing (SCFM) systems to arrive at judicious levels flexibility and automation, while dealing with various DIS delays. The knowledge management implications were discussed along with future challenges.

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