Supply Chain Flexibility and Knowledge Management: A Decision Knowledge Sharing Focus

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Abstract: Supply chains are increasingly required to work with core competencies of a flexible system, enriched with decision knowledge sharing. By effectively exploiting flexibility in supply chain structures, better and improved performance can be achieved. Similarly, by judiciously employing decision flexibility and the associated dynamic control amongst autonomous supply chain nodes, very many improvements are possible. Supply chains can have multiple-autonomous players with varying technical work ethics (affects knowledge mindsets), managerial background (affects decision knowledge) and SCM exposures (affects knowledge sharing attitudes). The key to great success lies in knowing which decision has more impact on the overall performance and this can be achieved by using effective and appropriate knowledge sharing. In this context, Knowledge Management (KM) can be used as an effective tool to achieve decision knowledge sharing (DKS), leading to improved SCM competence. Thus, there is a need to develop demo models which can encourage chain managers towards greater collaborative-knowledge sharing in the supply chains. This paper, thus presents a study on the role of different decision knowledge sharing options (i.e. no DKS, partial DKS and full DKS) with varying supply chain flexibility (i.e. no flexibility, partial flexibility and full flexibility) based on a dynamic control processes. A simulation model is herewith developed for a detailed study. The key results are highlighted along with their industry implications in the KM context.

Keywords: Supply Chains (SCs), Flexibility, Decision Knowledge Sharing (DKS), Knowledge Management (KM), Routing Flexibility.

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1. Introduction

Recent years have seen wide range of interest in field of Supply Chains (SCs), under conditions of flexibility, dynamic control and decision synchronization, utilizing the techniques of Information Sharing (IS), Decision sharing and Knowledge Management (KM) in supply chains. Supply chains are a network which is composed of many firms (i.e. nodes) in order to supply products responding to customer demands, where every individual node has an option (i.e. flexibility) to select subsequent nodes based on various alternatives. Supply chains are composed of many flows, which are guided by autonomous entities or nodes. Flexibility stands out as the most discussed and applied domain in manufacturing and supply chains (SC_s). Flexibility implications on the SCs performance need to be more closely studied, as most researchers have interpreted it differently. Wadhwa and Rao (2000) defined flexibility, as the ability to deal with change by judiciously providing and exploiting controllable options dynamically. We, define supply chain flexibility as the robustness of the buyer (nodes, SC member)–suppliers (nodes) relationship under varying supply conditions. The paper attempts to utilize the flexibility, from the stand point of a dynamic supply chain management, by using the routing flexibility or node based flexibility. Routing type flexibility refers to the availability of alternative resources of the same resource type, i.e., having more than one resource of the same type. This type of flexibility refers to situations where more than one type of resource (i.e. nodes or supply chain members or partners) of a given type exists. Recent trends show that competition has vastly increased which has resulted in reduced profit margins. This has led to the development of dynamic control in supply chains to reduce total cost, lead time, inventory, backorders etc, by selecting the best suppliers (e.g. for customer (buyer)-selection of best retailer (supplier), for retailer (buyer)-selection of best wholesaler (supplier) etc). This problem is relatively new, since many SC_s are integrated together and complexity is created to manage decisions at individual nodes. In this paper, dynamic control includes four dynamic parameters viz. inventory, lead time, ordering cost and distance. The dynamic selection of supplier, is based on overall least cost (i.e. cost, is our performance measure). One of the major problems faced by the SC members is the lack of proper vision and less knowledge about the uncertainty of end customer demands, adjacent node demand and trends of dynamic switching (i.e. dynamic suppliers' selection). Consequently, the apparent drawbacks that appear on SCs decision making also reflects the poor policies of enterprise management like ineffective sourcing, distribution, inventory, backorders decisions etc. Although, information sharing provides wide range of opportunities to overcome this problem but it is still difficult to understand the transformed demand pattern and effects of decision making flexibility. Knowledge and decision sharing is an alternate option which can be well facilitated by using knowledge management tools. Knowledge Management (KM) provides new opportunities to create and retain greater value from supply chains based on core business competencies (Tiwana, 2000). One way of looking at knowledge is that it facilitates in making predictions, casual associations, or predictive decisions about what to do, unlike, information that simply gives us the simple facts. This fact has enhanced the possibilities of developing knowledge shared supply chains. It is proposed that such SCs can significantly benefit from effective decision knowledge sharing strategies guided by KM initiatives across the entire chain. This has also enhanced the possibilities of developing knowledge shared supply chains. Considerable research efforts have been devoted to the development of Decision Knowledge Sharing (DKS) framework. DKS refers to the sharing of transformed decisions (i.e. based on demand and lead time trends) among supply chain members. As flexibility increases, transformation of decision increases due to dynamic behavior and increases importance of sharing decision trends with varying demand and lead time. We studied the performance of the supply chain under these conditions from the industry and practitioners point of view. To get wider industrial benefits from supply chain flexibility and decision knowledge sharing, we propose varying supply chain flexibility options (i.e. No Flexibility (NF), Partial Flexibility (PF), and Full Flexibility (FF)) and DKS options (i.e. No DKS, Partial DKS and Full DKS) . Keeping the above options in view, the paper proposes a framework for flexibility and DKS for supply chains that could help in understanding KM, dynamic control, and flexibility in supply chains. The objectives of this paper are: (a) To study the effects of flexibility (NF, PF and FF) in dynamic control environment (b)To observe the effects of decision knowledge sharing (i.e. no, partial and full DKS) (c) To capture and convey the idea of dynamic control in supply chains, (d) To study combined effects of flexibility, DKS and dynamic control (e) To identify various possible partial supply chain flexibility options, (f) To identify various possible partial DKS options, (g) To provide some useful directions for future research. The paper is organized as follows. In section two background and motivation is presented. Section three describes the flexibility constructs in supply chains. The role of decision knowledge sharing is discussed in section four. Section five result analysis is discussed followed by industrial and research implications in section six. Section seven presents the conclusions.

2. Background and Motivation

Our primary and basic motivation in presenting this paper is to emphasize the importance of flexibility and DKS constructs in supply chains, while developing suitable dynamic control over the system. Literature, indicates the existence of several perceptions on supply chain flexibility, routing flexibility, dynamic control, information and knowledge sharing, decision information synchronization (DIS) etc. Realizing the importance of supply chains, recently a number of authors have started studying flexibility from a supply chain perspective. For example, Kosta and Malhotra (1999b), while presenting a perspective on research opportunities in manufacturing flexibility, emphasized that the presence or absence of flexibility in supply chains and its relationship with performance should be explored and the effect of supply chain integration on the development of flexibility in supply chains should be examined. Mello (2001) views supply chain flexibility as the ability to restructure the system quickly and inexpensively. He argues that the businesses must be bulletproof in their operations by having in built flexibility in supply chain. They view supply chain flexibility, as the ability to restructure the system quickly and inexpensively. Golden and Powell (1999) define flexibility as the capability to adapt across the four dimensions i.e.; temporal, range, intention and focus. Garavelli (2001) defines flexibility, as a hedge against the diversity of the environment. Garavelli (2003) views the supply chain flexibility and compares the results with NF, PF, and FF. Although the papers available on the specific subject of supply chain flexibility are not large in number, it is still possible to find some definitions for the various types of SC flexibility, usually associated with the top correspondent types of flexibility in manufacturing system and referred to the object of change. For instance, Vickery et al. (1999) proposes the following dimensions of SC flexibility: product, volume, access, target market, while Viswanadhan and Raghwan (1997) consider: volume, mix, routing, delivery time, and new product flexibility. Gunasekran (2001) cites the definition of flexibility as the ability to respond effectively to changing circumstances. The author specifies that, being flexible refers to making available the products/services to meet the individual demands of customers. Similarly, Gunasekran et al. (2004) views supply chain flexibility as a way of providing options to the customers. Rather than defining flexibility, Forrester Research summarizes the conditions that make global manufacturers inflexible (Radjou, 2000). The author states that the global manufacturers must be able to respond to "dynamic trade", which is defined as "the ability to satisfy current demand with customized response". Duclos et al., (2003) presents an integrated conceptual model of supply chain flexibility. They examine flexibility classification schemes and the commonalities of flexibility typologies published in the literature, to create a theoretical foundation for analyzing the components of supply chain flexibility. This helps us to create our simulation model to examine dynamic supply chain behavior or dynamic control in a flexibility based environment. Wadhwa and Rao (2004) have shown how improved decision knowledge can have significant impact on supply chain performance. In this paper, we have presented one such view, which shows the performance of dynamically controlled supply chains in a flexible environment. We are thus evaluating supply chain flexibility in a dynamic control environment. Understanding the dynamics of supply chains is important for a variety of reasons; to decrease inventory and back order cost (Bourland et al, 1996), the bullwhip effect (Lee et al, 1997), to enable smooth flow of materials, parts, etc. from start to finish without unnecessary wait (e.g. due to out of stock and backorders), to reduce overall cost by reducing inventory etc, and ultimately to increase customer satisfaction. Dynamic supply chain configuration is beneficial, when there are changes in cost of the products/services, resource availability, and customer demands. This assumes that for a given order there are several feasible supply chain configurations that can deliver the product. The number of such feasible configurations increases with the number of stages, products, suppliers, etc. (Baganha and Cohen, 1998). Wadhwa and Rao (2003) suggest the knowledge management (KM) concept in enterprise synchronization. They also discuss the decision information synchronization (DIS) for supply chains. They emphasis the information sharing needs to be fully synchronized with the decision making. At an enterprise level the role of DIS is more challenging to synchronize entity in the flow process. The main constraint to enriching the SC_s with information sharing is common attitude of the people that information is power and it is not to be provided free. As a consequence of the cutthroat culture, companies will deliberately distort order information to mask their intent not only to competitors but also to their own suppliers and customers, unbelievable though this may seem (Towill, 1997, Goggin and Browne, 2000). Information system managers today want flexible, adaptable and easily managed systems which do not require a lot of people and money to keep going (Chan et al., 2003; Gunasekaran et al., 2004). The importance of measuring the value of information, for a market player to exploit his best strategic advantage has been strongly advocated by Glazer (1993). Glazer states that "although through the implementation of IT many companies are swimming with information, very few have gained a competitive advantage via their improved dataflow". Implementation of IT is not enough if it only transfers the previous data pool faster, management of the information itself is the key variable. In any supply chain, the mode of knowledge sharing to be adopted is an important strategic issue, which may affect the overall performance of the system significantly. KM has immense potential to offer, expedient opportunities to create and thus retain greater value in this context. KM addresses several business problems whether it is creating and delivering innovative products and services or managing and enhancing relationship with existing and new customers, partners or suppliers (Handfield and Nichols, 1998, Tayur et al., 1999). KM provides processes to capture a part of tactic knowledge through informal methods and pointers and enhance fairly high percentage of explicit knowledge, without reducing the loss of organizational knowledge (Nonaka and Takeuchi, 1995). The KM driven SC_s hold future competitive potential for improved business performance in Industry. In the light of the above, there is a need to study the performance of decision knowledge sharing (DKS) in flexible supply chains (SCs) environment. However, most authors focused on reducing the information process times using the latest advances in IT and structured communication methodologies. These authors do not explicitly focus on decision systems. Some recent authors realized that information alone may not improve the performance, and started discussing the decision automation. However, in our view, both information (i.e. in our case actionable information or knowledge) as well as decision systems is important. Moreover, synchronization of decision and knowledge system with flexibility is more important. We identify this as an important research gap, and focus our research efforts in this direction. For this reason, we develop a simulation model to analyze the supply chains behavior in DKS and flexibility context. This motivates our current research to understand the impact of supply chains performance in flexibility, DKS and dynamically controlled environment.

3. Flexibility Constructs in Supply Chains

Flexibility is an important factor in manufacturing and supply chains. This paper focus only SC flexibility constructs. Das and Malek (2003) define supply chain flexibility as the robustness of the buyer supplier relationship under changing supply condition. This flexibility provides an effective parameter for characterizing the behavior of asynchronous supply chain. A highly flexible relationship is one in which there is little deterioration in the procurement price under different supply conditions. They indicate that the order quantities and supply lead times are the two most common changes which occur in supply chains. Wadhwa and Rao (2004) propose a unified framework for understanding flexibility in manufacturing system as well as supply chains. The framework is based on the key elements and basic constructs for analyzing their interaction for possible flexibility type. In an ideal world, each SC member (i.e. node) at different stages in the SC_s has enough inventories to fulfill every order that comes in. Achieving this is rather straight forward when there is no variability in order type, quantity, as well as frequency. This assumes that there are no other effects due to incentives, lack of information, capacity constraints, demand forecasting errors, uncertainties in information flow, transportation scale economies, and setup costs (Garavelli, 2003). Now let us focus on the decisional knowledge and flexibility of each decision making member of the chain. The traditional supply chain does not offer the possibility of reviewing the end customer demand picture at various decisional stages. In practice each decisional stage has generally the possibility of accessing the end customer demand picture from its preceding stage during a mutually acceptable decision sharing period. We are therefore motivated to study such a decision knowledge shared focused supply chain in this paper. The practical difficulties in implementation of information sharing are shown in figure 1. We have considered flexible supply chains in which we elaborate the flexible decision stages and their implications in information and decision knowledge sharing.

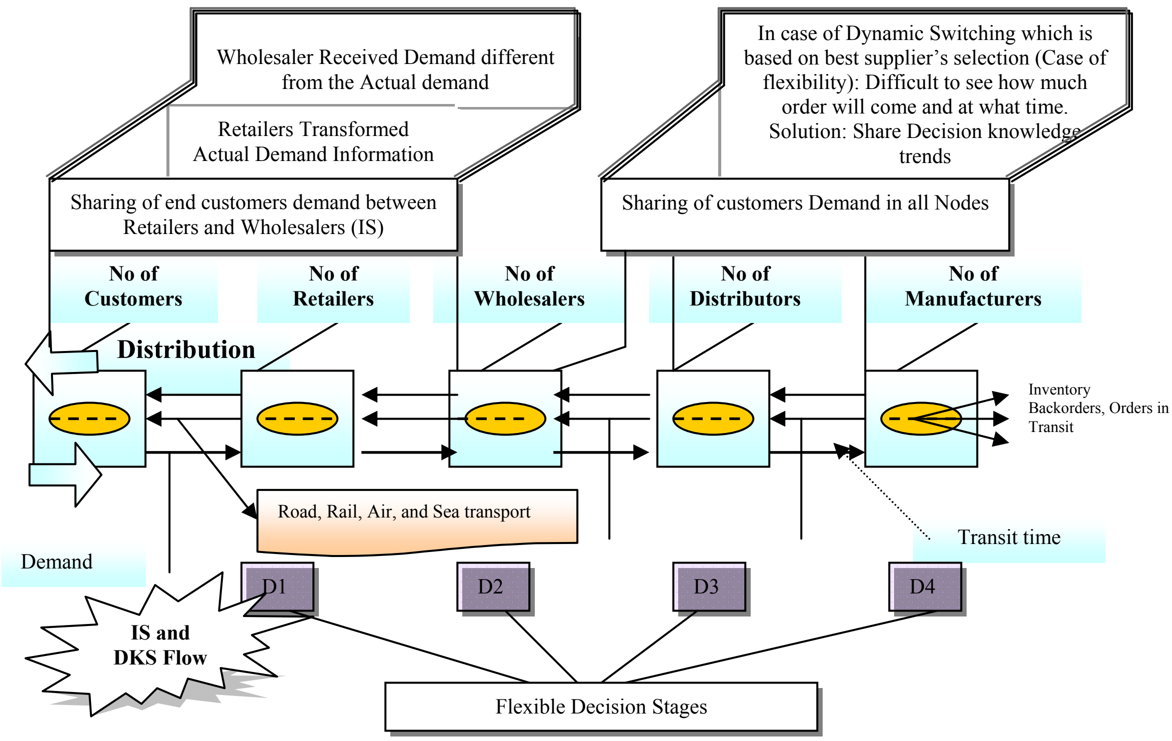

Figure 1: Role of Information Sharing (IS) and Direction towards Decision Knowledge Sharing

However, this combination of conditions is rarely satisfied in the most of the real world situations. Therefore, it is necessary to deal dynamically with variations in the environment (e.g. demand pattern, inventory, backorders, orders in transit, etc) to avoid problems in selection of subsequent node (immediate partners). This is a very important factor for SC_s to reduce overall cost. In this paper, we have presented one such view, which shows the performance of dynamically controlled supply chains in a flexible environment. In the process of SCs the nodes choose immediate suppliers based on the given data and rules set (Piramuthu, 2005). The nodes dynamically select the best immediate suppliers to improve performance measure (i.e. in our case total cost and fill rate). To cope with the uncertainty in SC_s, we suggest a different level of flexibility. In this context, flexibility helps in realizing the importance of performance measures and selection of an immediate business partner in dynamic fashion. To perform simulation experiment of SC_s, we select five cases and five different stages SC_s (i.e. 1-stage,2-stage,3-stage, 4-stage,and 5-stage; figure 2) along with the consideration of No Flexibility (NF), Partial Flexibility (PF) and Full Flexibility (FF) paradigm. Full flexible system refers where every supply chain member can buy or supply every other adjacent member and a non flexible system refers where every supply chain member is dedicated to one member only. Partial Flexibility (PF) refers to the limited availability of options where a buyer can communicate with some of the suppliers but not every one. Partial flexibility may be seen as a given level of flexibility in a system that is flexible to a certain extent but not to it's full potential (Wadhwa and Aggrawal, 2000). Garvalli (2003) study has then shown how the concept of limited i.e. (partial) flexibility can be usefully applied to the supply chain configuration. The author suggests that the way of defining suitable flexibility degrees for the different stages and nodes of the SC network appears very effective. Partial flexibility has the greatest benefits when configured to chain products and plants together to the greatest extent possible. Simulation study is carried out to measure supply chains performance in terms of cost for dynamically controlled scenario. The paper attempts to advance the flexibility from the point of view of SCs, by using the routing flexibility or node based flexibility. Routing type flexibility refers to the availability of alternative resources of the same resource type, i.e., having more than one resource of the same type. This type of flexibility refers in situations

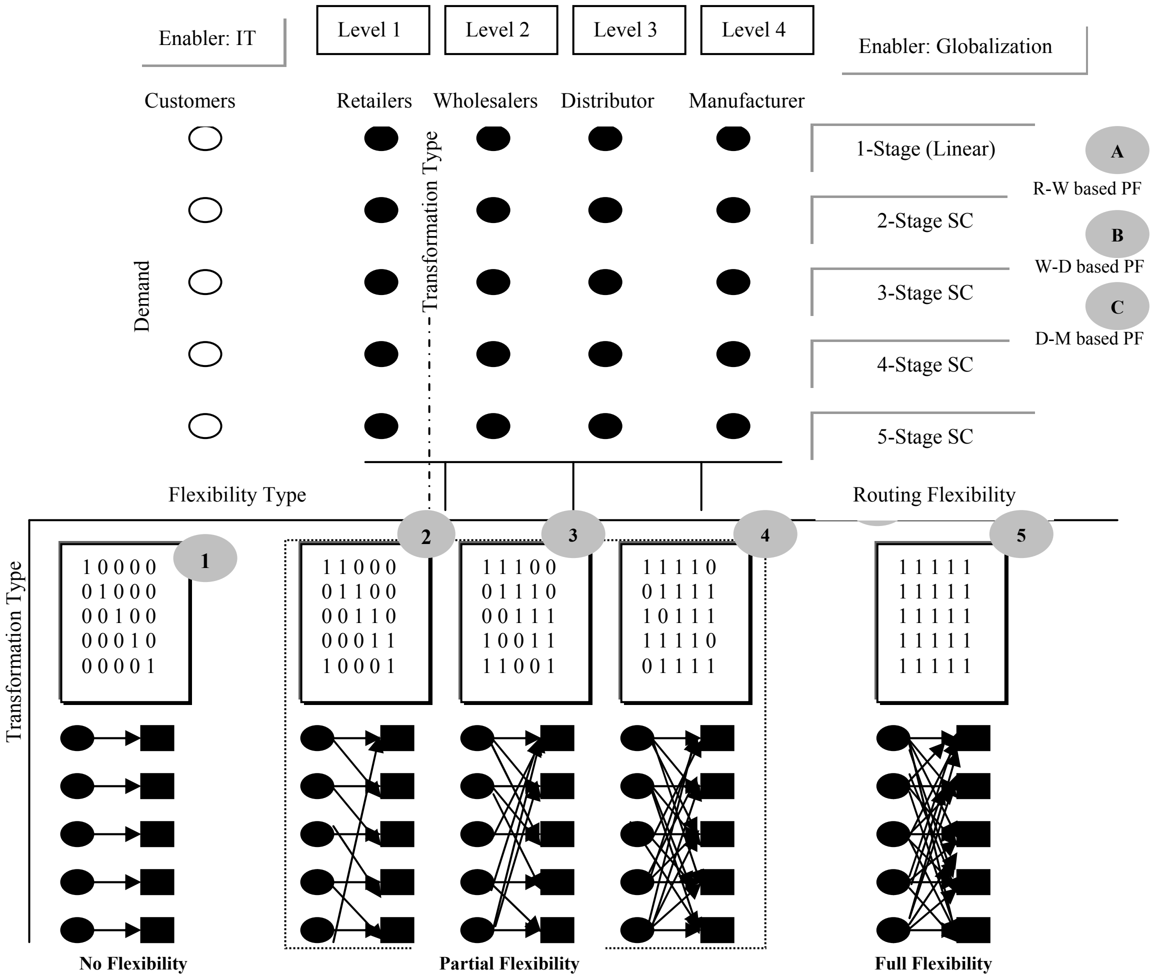

Figure 2: Supply Chains and Its Flexible Configuration based on Routing Flexibility

where more than one type of resource (i.e. nodes or supply chain members or partners) of a given type exists (Wadhwa and Rao, 2003; Wadhwa and Rao, 2004). We suggest the flexibility configuration for SCs using simulation for development of demo cases (i.e. cases based on NF, PF, and FF configuration). We proposed flexibility construct for 1,2,3,4, and 5 stage SCs. When we move from NF to PF or PF to FF, we have to be careful about the flexibility investments because flexibility has its own financial implications. More flexibility includes more cost investment which we call as penalty cost. We select, routing flexibility for our experimentation purpose and study its effects under varying stages with partial and full flexibility levels. Figure 2 shows the different level, and stages of flexibility configuration involved in supply chains. We have defined 5 different flexibility cases for simulation. Similarly we have proposed routing flexibility up to 5-stages. We study partial flexibility (PF) in supply chains in detail and propose partial flexibility for different stages viz. A (R-W based PF), B (W-D based PF) and C (D-M based PF).

Dynamic control in supply chains is beneficial when there are changes in cost of the products/services; resource availability, lead time, transport distances and customer demands (Piramuthu, 2005). It is assumed that for a given order there are several feasible SC_s configurations that can deliver the product. A major constraint is the willingness of these nodes in the chain, mostly because of mistrust. We assume that every node is willing and is fully able to communicate with other available nodes in the SC_s. Interaction is the other important facilitator in the SC_s basically; because it enables integrating knowledge that is spread across each of the nodes to facilitate smooth flow of material from start to finish. This also helps us to choose the best available option when involved in making upstream as well as downstream decisions. We assume that the products or parts that pass through each node in every stage are of the same quality. We also consider the single product supply chain. The proposed system picks the most appropriate supplier for any given combination of lead-time, ordering cost and transport distance while the demand pattern and inventory is dynamically changing. Each parameter is associated with some costs. The selection of the node is based on the least cost obtained from the dynamic parameters. Total cost is the performance measure to decide the performance of supply chains.

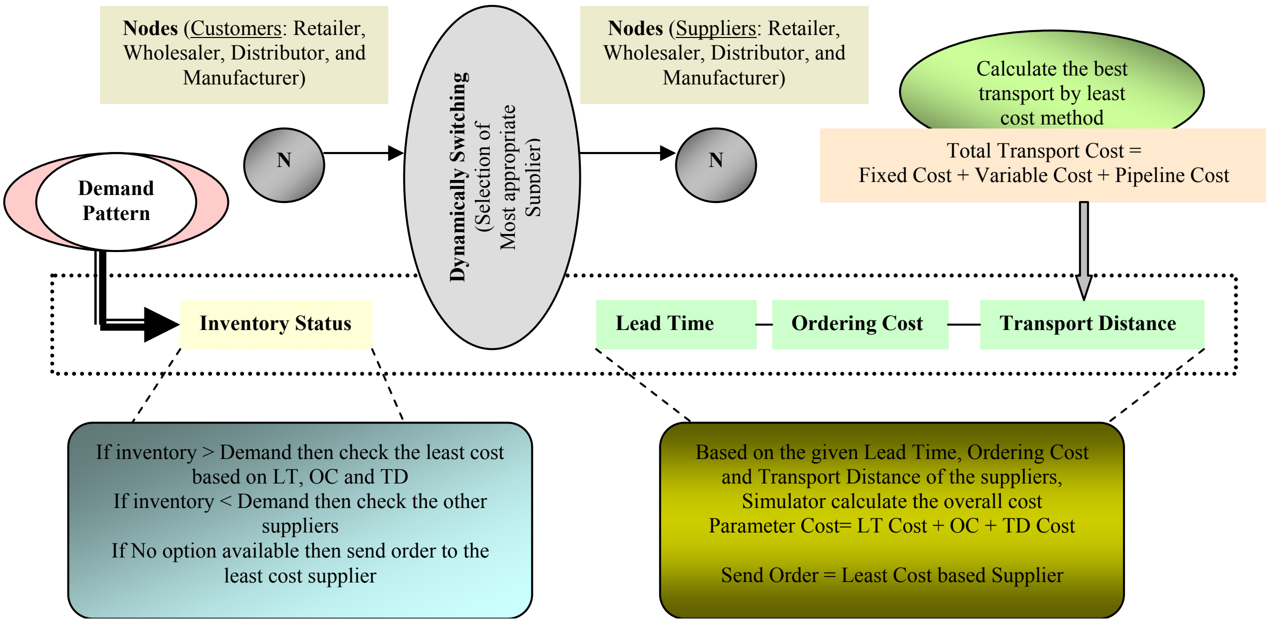

Figure 3: Framework for Dynamic Control in Supply Chains

Figure 3 explores the framework of dynamic supply chains. The selection is based on the static and dynamic parameters throughout the supply chains. The associated properties are held constant throughout the supply chains in all experiments. Inventory is the first check, which decides whether the supplier is having sufficient quantity as per the order or not. Then dynamic control parameters (i.e. least cost, ordering cost and distance) decide the selection based on the least cost. The dynamic control selects the cost that allows least cost for a product to be released, taking into account the current demand and inventory of the player (i.e. SC_s node). The heuristics then find the lowest expected cost at a given time $_t E(TC)$, expressed as the sum of lead time based cost $(LT_c)_s$, ordering cost $(OC_c)_s$ and transport distance cost $(TD_c)_s$ of the supplier μ_s and the product in process N, with queue NQ and path p of a given SC configuration:

Min. $_t E(TC) = (LT_c)_s + (OC_c)_s + (TD_c)_s$.

This dynamic control is addressed to select the best supplier based on the cost of all these three parameters and throughout the supply chain. Eventually, the selection procedure checks the inventory of the supplier. In case inventory of the selected supplier is not as per the demand then order will be supplied to next least cost based supplier. If in case no supplier is available, then order will be sent to the overall least cost based supplier.

Discrete event simulation models were developed for a typical flexibility and DKS constructs (e.g. no, partial, and full) focused supply chains (e.g. 1 to 5 stages) scenario. The various models have been developed for simulation. Logistics models deal primarily with material flows at the various levels. It is at these levels where the transfer of materials is accomplished using some sort of transportation such as trucks, rail, boat, or plane. The logistics model includes order planning, transportation planning, and inventory planning, among others. Material flows in the supply chain are handled by the transportation systems, which in turn are governed by some time-cost tradeoffs. Four main types of transportation modes are considered as 1) Road Transport 2) Rail Transport, 3) Air Transport and 4) Sea Transport. The total transport cost includes the fixed and variable cost. The total cost is the sum of transport cost, inventory cost, backorder cost, and orders in transit cost. Inventory cost refers to the no of items in the inventory and cost of keeping one item. Backorder cost is the cost of unfulfilled orders. An order in transit is a pipe line cost between two nodes (i.e. orders dispatched but not received in other end). The total cost of the system, is the sum of cost of all nodes and cost of each node (SC member). The decision makers at each of these stages had the flexibility to decide the inventory levels and reorder quantities. To achieve this common understanding, we have developed a collection of formal information model. Once the simulator has been made, it can be run in different scenarios with different conditions. Decision process models specify various management decisions that are made throughout the chain. Examples include: Location selection (Which supplier is best to produce and distribute?), Inventory planning (Where and how much inventory should be stored?), Load planning (How is the workload handled by each supplier?), Distribution planning (When and how much volume of end products or component parts should be transported and by what mode?). In our opinion all these problems entail decision flexibility. The model associates the basic component (i.e. Inventory, backorder, order in transit, etc) into the supply chains. The order policy is based on the forecasting which takes the average of initial demands. The simulation model is developed to show the dynamic behaviour of the SC_s and its importance in real cases. The model can deal with different SC_s configurations.

4. Decision Knowledge Sharing in Supply Chains

Decision Knowledge Sharing (DKS) refers the knowledge sharing (i.e. the trends of transformed decision, demand and lead time) among supply chain members. Decision knowledge is crucial for the performance of SC_s because it provides the platform for decisions in which knowledge enablers actively participate to make decisions. Walsh and Michael (1999) have discussed similar information and knowledge flow aspects. However, we propose a DKS framework that emphasizes greater focus on knowledge sharing. For instance, knowledge transfer is very important in supply chains simply because it enables integration of knowledge that is spread across each of the nodes, to facilitate smooth flow of entities leading to improved SCM synchronization. The DKS model allows various forms of flexibility and is motivated by Wadhwa and Rao (2000) and Wadhwa et al. (2005) that suggest manufacturing and supply chain flexibility to be seen as an ability to deal with change by judiciously providing and exploiting controllable options dynamically. The decision knowledge is embedded in various knowledge processes to enhance SC_s effectiveness. The KM takes the entire chain into account to minimize the cost of the supply chain, leading to reduced total costs for each individual member (company) within the supply chain. At each node, the process begins by collecting knowledge about the nodes in the next stage upstream. We use some of the concepts of proactive knowledge management proposed by Wadhwa et al. (2002) to evolve a novel framework supported by decision toolset to evolve KM guided SCM efforts in Industry. Figure 4 shows the DKS framework between two different nodes (i.e. for Retailer (R), Wholesaler (W), Distributor (D), and Manufacturer (M)). We propose Decision Knowledge Sharing (DKS) framework based on the decision sharing between two nodes (partial DKS) or whole chain (full DKS). We evaluate the trends of expected demands and dynamic switching of nodes and decide the policy of supplier node based on this pattern.

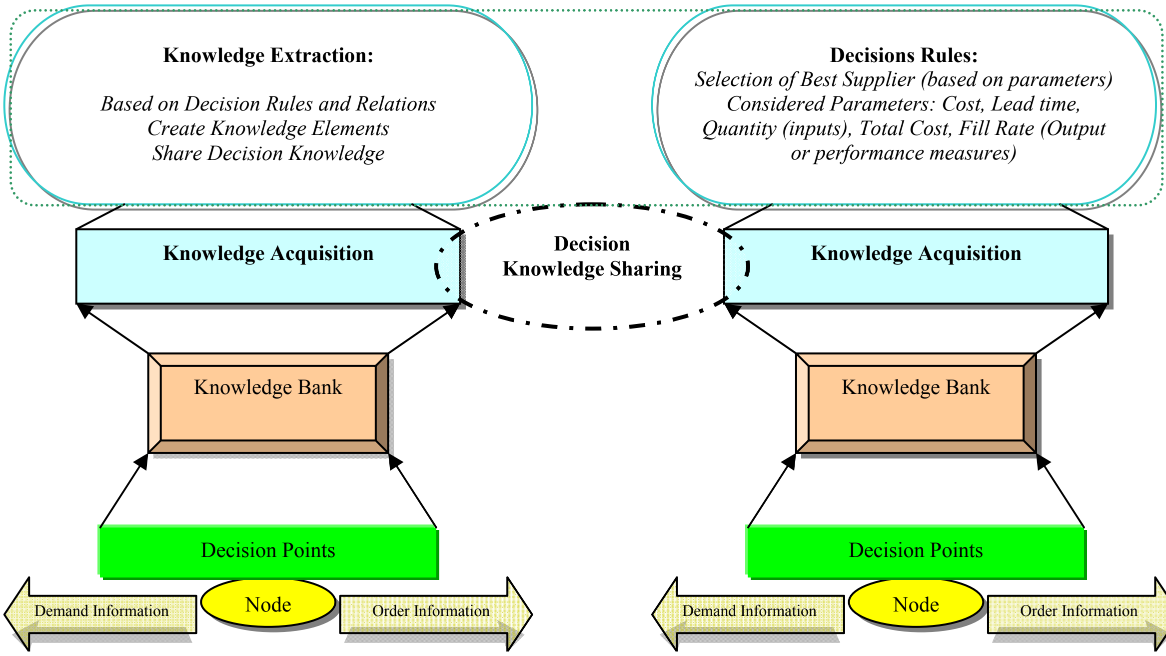

Figure 4: Decision Knowledge Sharing Framework between two Different Nodes

The conceptual framework for Decision Knowledge Sharing (DKS) highlights the importance of decision flexibility (i.e. in our case we use routing flexibility in each decisional node) in enterprise wide integration (figure 5). The concept of DKS is suggested as KM-Flexibility-Dynamics switching integration approach to manage supply chains effectively.

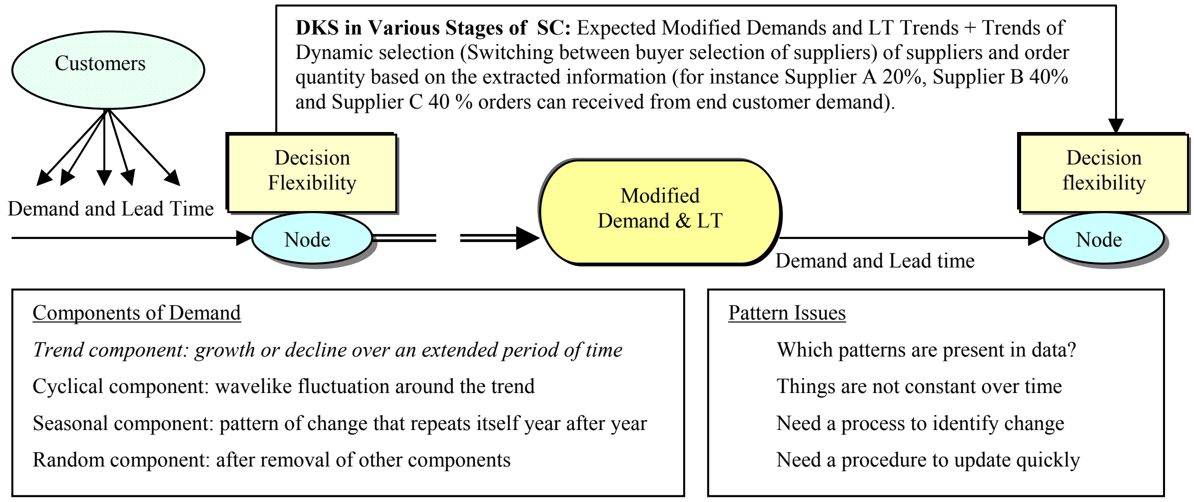

Figure 5: Conceptual Framework for Decision Knowledge Sharing (DKS) between two different Nodes

DKS framework helps to overcome the limitation of information sharing and shows better cost based performance. DKS is also helpful in enterprise synchronization which facilitates in effective decision making. This is possible by increasing flexibility and dynamics of supply chains. DKS evaluates the dynamic switching based on the trends, the formula for forecasting and trends equation with a smoothing constant δ (delta) is

FITt = Forecast including trend

$$FITt = Ft + Tt$$

$$Ft = FITt\text{-}1 + \alpha(At\text{-}1 - FITt\text{-}1)$$

$$Tt\ (Trends) = Tt\text{-}1 + \delta(At\text{-}1 - FITt\text{-}1)$$

Where…

F_t = forecast demand

A_t = actual demand shared

Tt = Trends

The modified trends calculation is

Let Modified Trend 'x'

If Trend >0

X= (Trend * Backorder) / (Backorder + Inventory)

If Trend <0

X= (Trend * Inventory Rate)/ (Inventory Rate+ Backorder)

In short we can explore DKS is

Decision Knowledge Sharing = Collaborative Modified Information Sharing (i.e. Decisions Knowledge) + Dynamic Switching Trends

Furthermore, since suppliers are distributed across the globe, communicating information and transporting material can be costly and time consuming. Therefore, the proposed architecture must support communication protocols to allow worldwide knowledge transfer. The parameter selection module in the simulator in DKS framework filters the information to extract necessary actionable information that is used as input in the next module (Called as knowledge learning). The outputs are the knowledge patterns that are extracted from corresponding node. These patterns (decision rules in this study) are then stored in a knowledge base. DKS is instantiated when the new order information arrives from a downstream stage. As soon as this happens, appropriate knowledge from the knowledge base is gathered and the dispatcher identifies the best choice of node(s) among those in the previous (upstream) stage. The order is then dispatched to the identified node(s). This process repeats itself continually until all orders are dispatched. The entire process can be flexible enough to receive and dispatch orders, information and decisions from lower order nodes to higher order nodes.

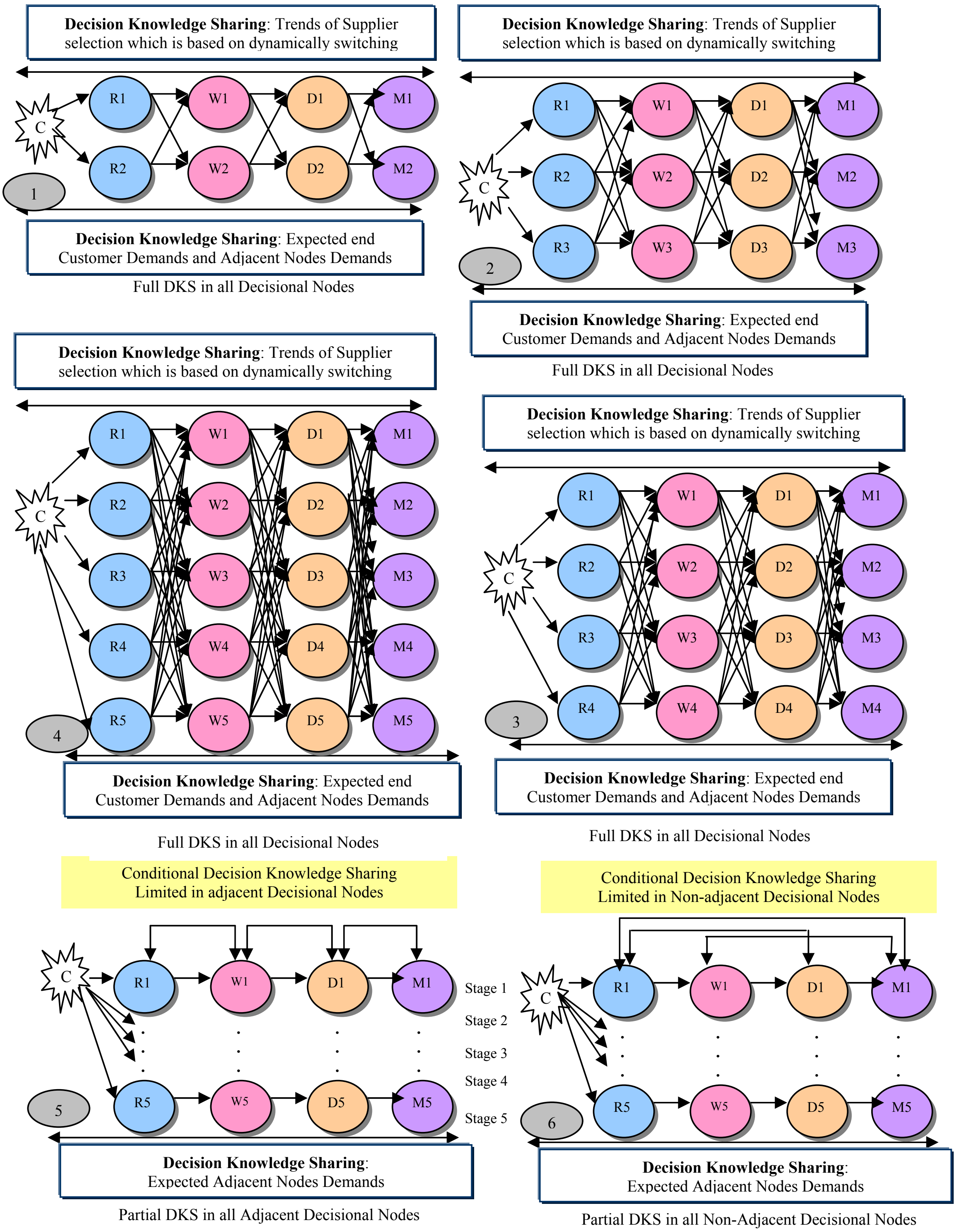

Figure 6: Full and Partial Decision Knowledge Sharing Configurations in Supply Chains

The DKS framework incorporated for the retailer, wholesaler, distributor, and manufacturer were similar. The decision makers at each of these stages had the flexibility to decide the inventory levels and reorder quantities to work under the DKS framework. The overall decision logic deals with stocking, ordering, and shortages. The decision maker exercises his flexibility to determine the level and type of DKS in a given scenario. We have suggested various partial and full DKS configurations based on the DKS framework as shown in figure 6. Our SCM simulation model can encompass all the essential features regarding information, decision and knowledge sharing with other parameter which improvise the performance of supply chains.

5. Results Analysis

In order to study the impact of alternative partial and full DKS scenarios at different stages of flexibility on the performance of the supply chains, a number of experiments were undertaken. The performance measures were cost related.

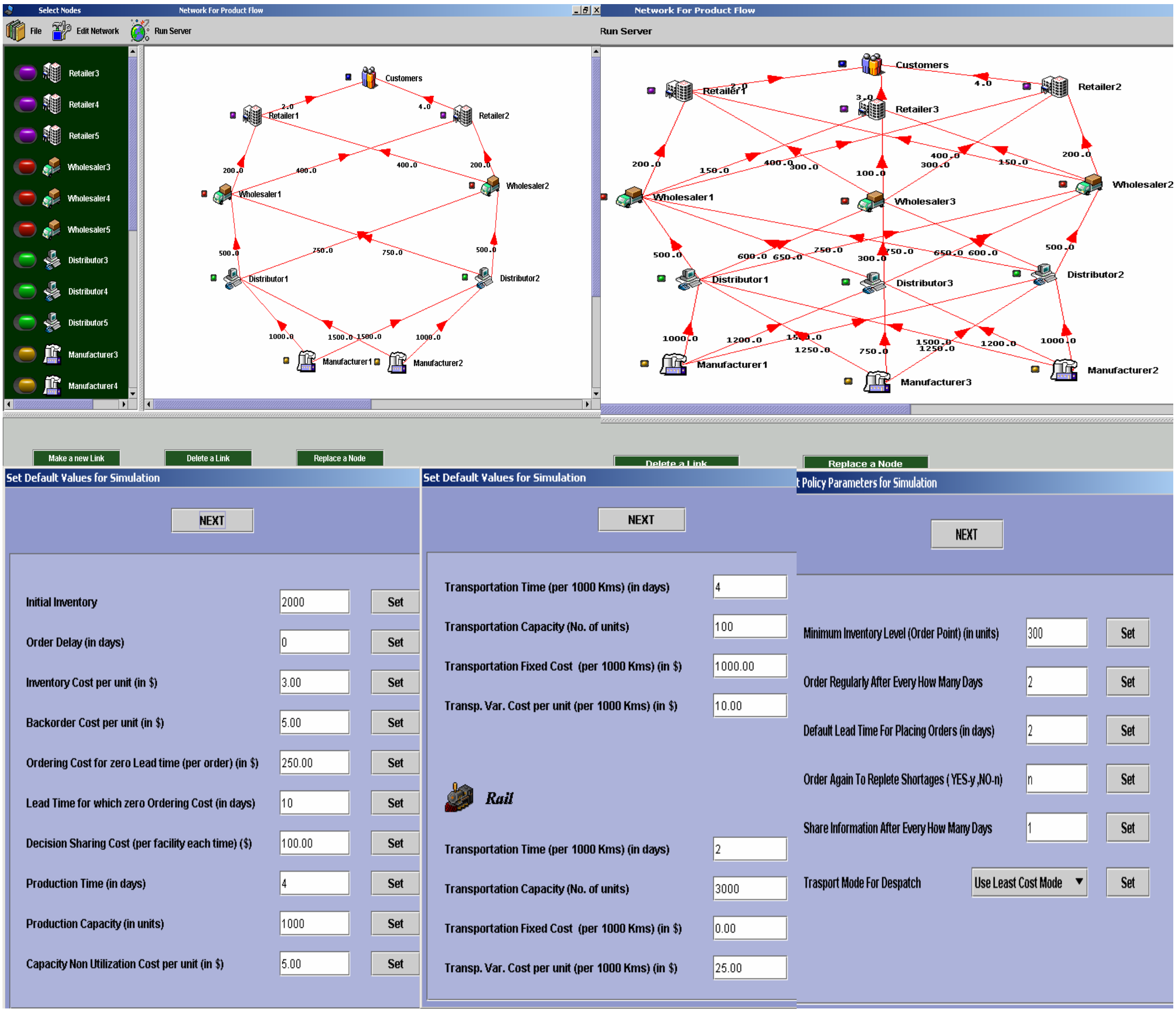

Figure 7: Snap Shot of Supply Chain Simulator Showing 2 and 3 Stage SC with its Properties

Figure 7 shows the network structure of supply chains in the simulator with its key features. This simulator includes various supply chain characteristics viz. dynamic control, distance between nodes, cost parameters, lead time, flexible networks, etc. Hence it is a dynamic supply chain simulator which has been developed with dynamic and static options to create complex scenarios and to make a detailed research analysis (i.e. dynamic control, IS, DKS, Flexibility, etc). This is also useful to demonstrate many similar real life industrial practices and their implications. For example one may select the transport mode on the basis of least cost. The results of some of the interesting experiments are now summarized and discussed. We simulated the process for 372 days with a warm-up period of 7 days, and collected necessary statistics for 365days (to reflect a year). Supply chains from stage 1 to stage 5 were considered (as given in figure 3). The controllable variables used in simulation environments are summarized in table 1.

Table 1: Simulation Environment of Controllable Variables		
Initial Inventory=2000	Order Delay (in days)=0	Inventory Cost per unit (in $)=10.00
Backorder Cost per unit (in $)=5.00	Ordering Cost for zero Lead time (per order) (in $)=250.00	Lead Time for which zero Ordering Cost (in days)=10
Decision Sharing Cost (per facility each time) ($)=00.00, IS penalty Cost = 0	Flexibility penalty = 1% at 2 stage and 1% increase at each subsequent Stage	Production Time (in days)=2 Production Capacity (in units)=5000
Capacity Non Utilization Cost per unit (in $)=5.00	Minimum Inventory Level (Order Point) (in units)=450	Order Regularly After Every How Many Days=3
Default Lead Time For Placing Orders (in days)=2	Order Again To Replete Shortages (YES-y ,NO-n)=y	Share Information / Knowledge After Every How Many Days=1

The demand data is chosen from an industry scenario to observe its impact and implications on a realistic environment. The product demand pattern is selected from an electronic goods manufacturing company. It is also strictly based on one product as was done by Raghuram and Rangraj, 2003. We also verified the results from Poisson statistical distribution analysis and it has been found to be almost the same percentage of difference, as in our case. Table 2 shows the description of flexibility and DKS options used for analyzing supply chain results. This also shows the cost of various DKS options that are not included to see the DKS and flexibility interaction effects.

Table 2: Description of Flexibility Options used in 9,10,11 and 12, Cost on Other DKS Options

Flexibility Options	X-Axis	Flexibility Options	X-Axis
Case 5 (A)	1	Case 3 (B)	16
Case 5 (B)	2	Case 3 ©	17
Case 5 (C)	3	Case 3 (A+B)	18
Case 5 (A+B)	4	Case 3 (B+C)	19
Case 5 (B+C)	5	case 3 (A+C)	20
case 5 (A+C)	6	Case 3 (A+B+C)	21
Case 5 (A+B+C)	7	Case 4 (A)	22
Case 2 (A)	8	Case 4 (B)	23
Case 2 (B)	9	Case 4 ©	24
Case 2 ©	10	Case 4 (A+B)	25
Case 2 (A+B)	11	Case 4 (B+C)	26
Case 2 (B+C)	12	case 4 (A+C)	27
case 2 (A+C)	13	Case 4 (A+B+C)	28
Case 2 (A+B+C)	14	Case 1	29
Case 3 (A)	15		

DKS Options	Plot X-Y (Cost)	Other Partial DKS Options	Total Cost
Case 1	DKS 1	Case 5 (S2, R-W-D-M)	DKS 7 (35.885)
Case 2	DKS 2 (32.457)	Case 5 (S3, R-W-D-M)	DKS 8 (33.902)
Case 3	DKS 3 (31.793)	Case 5 (S4, R-W-D-M)	DKS 9 (32.002)
Case 4 (Full DKS)	DKS 4	Case 6 (S2, R-D,W-M, M-R)	DKS 10 (35.579)
Case 5 (S5, R-W-D-M) (Partial DKS)	DKS 5	Case 6 (S3, R-D,W-M, M-R)	DKS 11 (33.785)
Case 6 (S5, R-D,W-M, M-R) (C. Partial DKS)	DKS 6	Case 6 (S4, R-D,W-M, M-R)	DKS 12 (30.886)

Other Partial DKS Options	Total Cost	Other Partial DKS Options	Total Cost
Case 5 (S2, R-W)	37.002	Case 6 (S4, R-D,W-M)	33.635
Case 5 (S3, R-W)	36.669	Case 6 (S5, R-D,W-M)	30.767
Case 5 (S4, R-W)	33.095	Case 6 (S2, R-D)	34.108
Case 5 (S5, R-W)	31.321	Case 6 (S3, R-D)	33.100
Case 5 (S2, W-D)	36.943	Case 6 (S4, R-D)	33.358
Case 5 (S3, W-D)	36.301	Case 6 (S5, R-D)	32.558
Case 5 (S4, W-D)	33.024	Case 6 (S2, W-M)	34.096
Case 5 (S5, W-D)	31.103	Case 6 (S3, W-M)	33.004
Case 5 (S2, D-M)	36.805	Case 6 (S4, W-M)	32.937
Case 5 (S3, D-M)	35.781	Case 6 (S5, W-M)	31.863
Case 5 (S4, D-M)	32.878	Case 6 (S2, R-M)	33.745
Case 5 (S5, D-M)	31.045	Case 6 (S3, R-M)	32.851
Case 5 (S2, R-W-D)	33.641	Case 6 (S4, R-M)	32.559
Case 5 (S3, R-W-D)	32.551	Case 6 (S5, R-M)	31.537
Case 5 (S4, R-W-D)	30.558	Case 6 (S2, R-D,R-M)	33.009
Case 5 (S5, R-W-D)	29.702	Case 6 (S3, R-D,R-M)	31.885
Case 5 (S2, W-D-M)	33.305	Case 6 (S4, R-D,R-M)	31.201
Case 5 (S3, W-D-M)	32.236	Case 6 (S5, R-D,R-M)	30.321
Case 5 (S4, W-D-M)	30.349	Case 6 (S2, R-M,W-M)	33.005
Case 5 (S5, W-D-M)	29.401	Case 6 (S3, R-M,W-M)	31.738
Case 6 (S2, R-D,W-M)		Case 6 (S4, R-M,W-M)	30.885
Case 6 (S3, R-D,W-M)		Case 6 (S5, R-M,W-M)	29.998

Table 3 shows the summary of simulation results of performance improvement obtained with respect to cost output. As we move from no flexibility to 2-stage flexibility and than to 3-stage flexibility, we find significant improvements in performance. A 10.22% improvement is observed when we increase the flexibility from 0 to 1(no flexibility to two stage flexibility). For a further increase in flexibility (i.e. 3-stage flexibility), the performance enhancement was 10.94%. The total improvement in the system in stage 3 is 20.04%. The further increase in flexibility caused increase in performance by 4.36% (i.e. 4-stage flexibility). In stage 5, the increase in flexibility caused increase in performance by 1.77% and the total improvement in stage 5 was 24.90%. It is a very interesting result, which indicates that the improvement in the system performance drastically reduces with higher flexibility stages. In a similar manner, DKS application in the above discussed case further improved the performance. From stage 1 to stage 5, continuous improvement is observed and a total improvement of 25.71% is observed for full DKS (i.e. stage 5) against full flexibility (i.e. stage 5). The impact of DKS is greater in initial flexibility stages but improving flexibility from stage 3 to stage 4 and subsequently to stage 5 has relatively low DKS impacts. The results observed in all five cases show significant impacts of flexibility and DKS.

Table 3: No DKS and DKS Configurations for Full Flexible Supply Chains Stages

No DKS/ Full Flexibility	Total Cumulative SCs Cost (Millions)	Results/Improvement
1 Stage SC	51.598	-----------
2 Stage SC	46.321	1 Stage=10.22 %
3 Stage SC	41.253	1 Stage =20.04% and 2 Stage SC= 10.94%:
4 Stage SC	39.451	1 Stage =23.54%, 2 Stage SC= 14.83%, and 3 Stage SC=4.36%
5 Stage SC	38.749	1 Stage =24.90%, 2 Stage SC= 16.34%, 3 Stage SC=6.06% and 4 Stage SC= 1.77%
Full DKS/ Full Flexibility	**Total SC s Cost (Millions)**	**Results/Improvement**
1 Stage SC	42.493	1 Stage, No DKS =17.64%; 2 Stage SC, No DKS = 8.26%; 3 Stage SC, No DKS = No Improvement
2 Stage SC	35.847	1 Stage, No DKS =28.86%; 2 Stage SC, No DKS = 22.61%; 3 Stage SC, No DKS = 13.10%; 1 Stage, with DKS =15.64%
3 Stage SC	31.451	1 Stage, No DKS =39.04%; 2 Stage SC, No DKS= 32.10%; 3 Stage SC, No DKS= 23.76%; 1 Stage, with DKS =25.98%; 2 Stage SC, with DKS= 13.97%
4 Stage SC	29.573	1 Stage, No DKS =42.68%; 2 Stage, No DKS=36.15%; 3 Stage, No DKS= 28.31%; 4 Stage, No DKS=25.03%; 5 Stage, No DKS=23.68%; 1 Stage, DKS= 30.40%; 2 Stage, DKS=17.50%; 3 Stage, DKS= 2.79%
5 Stage SC	28.785	1 Stage, No DKS=44.21%; 2 Stage, NO DKS=37.85%;3 Stage, No DKS=30.2%; 4 Stage, No DKS=27.03; 5 Stage, No DKS=25.71; 1 Stage, DKS=32.25%; 2 Stage, DKS=19.70%; 3 Stage, DKS=8.47%; 4 Stage, DKS=2.66

Figure 8 shows the effects of partial and full DKS option on supply chain routing flexibility options. We have analyzed the effects of full DKS (Case 4), partial DKS with adjacent node (case 5), and partial DKS with non-adjacent node for 29 defined flexibility options (i.e. point 7 (case 5(A+B+C)) is the full flexibility case and point 29 refers to the case 1 for no flexibility). The details of flexibility options can be seen in figure 3 and table 2. Performance of partial flexibility is very close to the performance of full flexibility in full DKS mode. From results, it can be seen that the partial DKS is more useful to full flexibility options and shows very close results as against Full DKS in full flexibility. We suggest that the judicious combination of DKS and flexibility options can significantly improve the performance of supply chains.

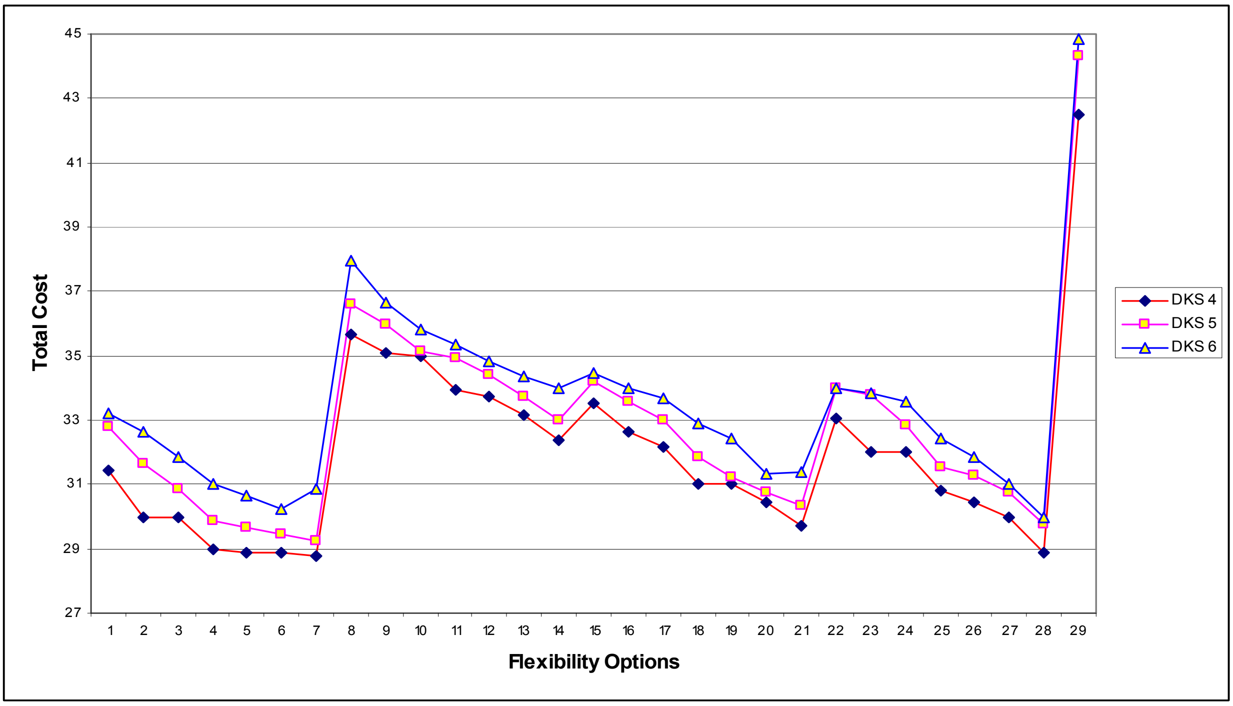

Figure 8: Supply Chain Routing Flexibility Options vs. Decision Knowledge Sharing (Full and Partial DKS) Options

Figure 9 shows a more focused view to explain flexibility and DKS options. It considers the performance of supply chain in five different stages and evaluates the effects of DKS in SC stages. The results show that the DKS offers significant impact and helps to achieve highest performance improvement in 3-stage flexibility.

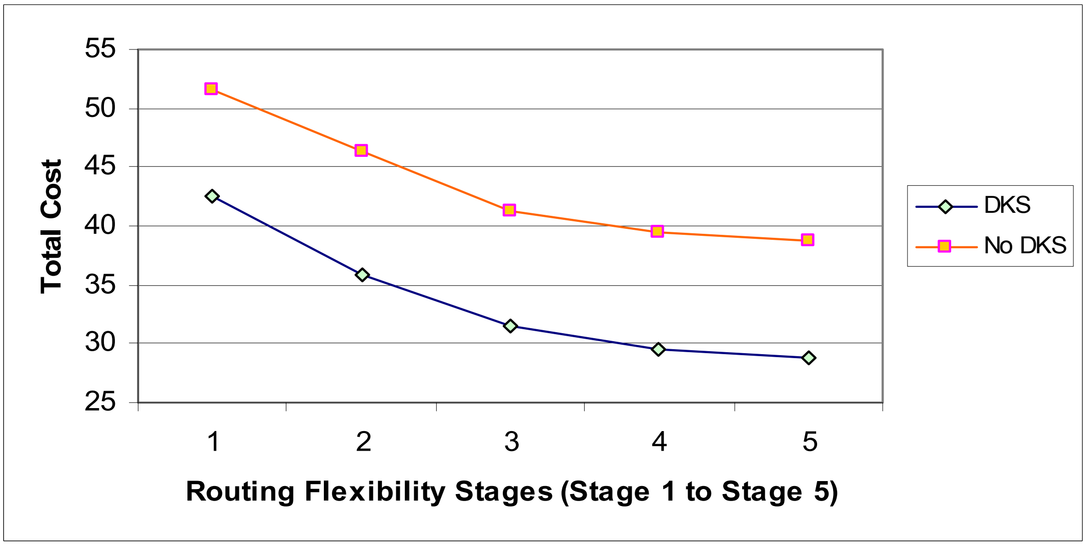

Figure 9: Performance of Supply Chain Routing Flexibility Stages with and without Decision Knowledge Sharing (DKS)

DKS cases. The results are interesting from both the industry and research point of view. They motivate greater emphasis on development of partial flexibility and DKS options in dynamic supply chains.

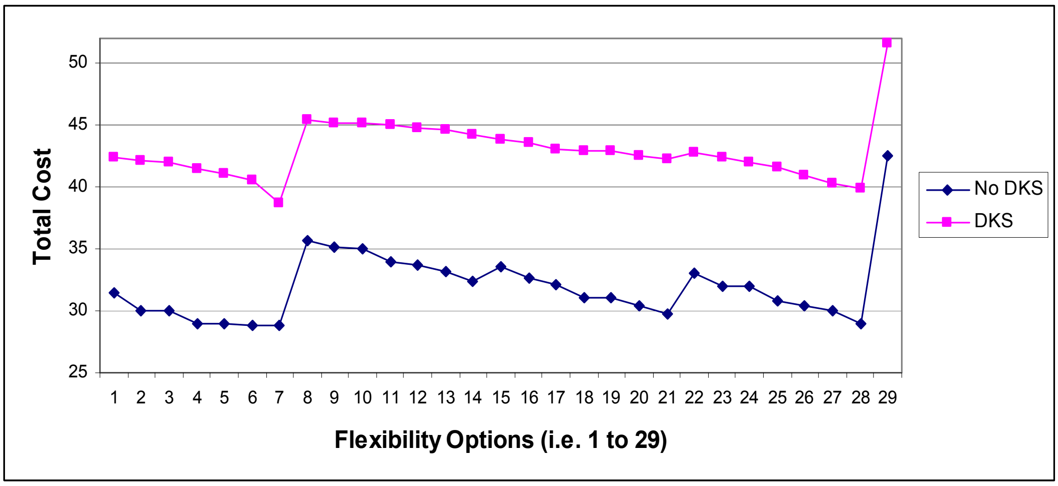

Figure 10: Flexibility Options vs. Decision Knowledge Sharing (DKS)

In a similar way, we applied partial flexibility with a means to restrict some options available to customers. Figure 9 and 10, depict the performance of supply chains in dynamic, flexible and decision knowledge shared environment. These are for different flexibility configurations. It can be noted that the performance of 5-stage partial flexibility is far better than that of 3-stage full flexibility. The performance further depends on the type of flexibility. Figure 11, shows the result of each individual dynamic control parameter along with the combined effects of all dynamic control parameters. It can be seen that the selection criteria of dynamic control parameters is important from an industry point of view. As the number of parameters increase the performance of dynamic control will also improve significantly (but this will also increase the control complexity). Thus industry practitioners are likely to work with few key parameters only.

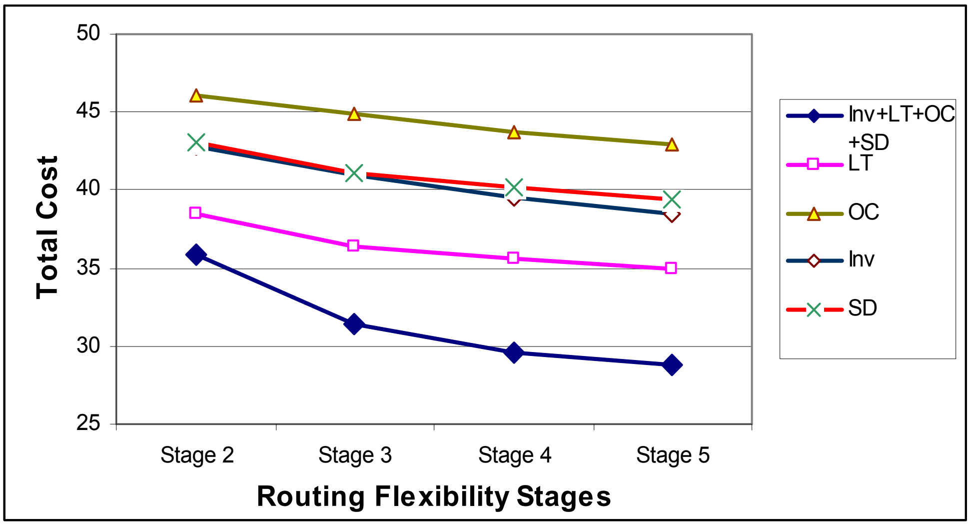

Figure 11: Routing Flexibility Stages vs. Dynamic Control Options

The selection of the immediate supplier is based on the dynamic parameters (i.e. buyers or customers inside the SC decide the best supplier, based on their preferences). Based on the product demand pattern, each node will check the inventory status of the supplier's node. If the supplier has sufficient inventory to supply the product, then selection of the best node will be finalized. This is based on the dynamic parameters, like in this case of ordering cost, lead time and distances. This shows the dynamics in the behavior of supply chain when there is a selection of the immediate nodes or SC members. The effect of the DKS and flexibility at the alternative decision stages of the supply chains can be visualized by comparing all cases based on individual stage or implementation in whole SC_s. It is clear that such decisions in supply chains can have significant impact on the total cumulative supply chain costs. The results support our view that the partial flexibility may be more appropriate in real industrial practice and may offer most effective cost reduction. As a consequence, it can be referred that the decisions of level of flexibility (i.e. 2 to 5 stage of SC) and level of DKS (i.e. no, full or partial) are very important. The above results also suggest that the partial DKS is more reliable and practical option. It is clear that there is not much difference in partial and full flexibility results. So, based on our results we suggest that the practitioners can select the best partial DKS scenario using the simulation model. This result also suggests that as we increase the number of stages, the supply chain flexibility increases and hence provides more benefits to the supplier by providing more options. This is also useful in reducing the bullwhip effect by better integration and by dynamic selection based on shared information and knowledge. This may be further beneficial to fulfill customer demands quickly and effectively. The best feasible partial DKS can often serve our purpose at lowest cost compared to full DKS based mode. Dynamic switching is also one of the key components of DKS framework. Our research motivates that it needs greater research attention. Dynamically switching among different nodes in every stage of the supply chain is necessary so that the most appropriate node results in better (i.e. total cost) performance. This paper presents an integrated conceptual model of DKS based supply chain routing flexibility and examines the partial and full flexibility with decision knowledge sharing levels. Even though, there has been a tremendous amount of research on the topic of flexibility, most of it has been confined to manufacturing flexibility or intra firm flexibility. As supply chain management goes beyond firm boundaries, the flexibility study must also extend beyond the firm (Duclos et al., 2003). Wadhwa and Rao (2004) propose a unified framework to relate flexibility in manufacturing systems with the flexibility in supply chains. This paper is motivated by this thinking. The enrichment is at the level of incorporating KM in the form decision knowledge sharing (DKS). Thus it may inspire the practitioners in selecting the right levels of flexibility and right levels of DKS (i.e. partial and full DKS) under the various influencing dynamic factors. In our opinion there is growing need to develop such KM based (here shown as DKS focused) supply chain models to help change the mindsets of the managers towards integrating the supply chains more effectively by suitable knowledge sharing.

6. Industrial and Research Implications

This paper establishes the motivation and need for flexibility modeling and the impact of decision knowledge sharing on the performance of supply chains. The modeling of DKS and flexibility of supply chains are more complex than simple supply chain, as they involve explicit consideration of the logical relationships resulting from decision and knowledge flows in SCs. From the industry point of view, the motivation is to basically study the combined impacts of changing flexibility, decision knowledge and dynamic control, under a full scope of partial and full configuration. Our model, suggests one such approach, to reduce the supply chain costs by using flexibility, DKS (KM motivated, IT facilitated knowledge sharing) and dynamic control (Use of knowledge to opportunistically improve the control). This paper leads the dynamic supply chain management through a process of cost reduction using KM facilitated shared information and control. This implies the reduction of the cost for both the individual (i.e. SC member) and overall supply chain through dynamic control, DKS and flexibility in stages. Our study has provided a number of observations that indicate the need to study the synergistic issue of flexibility, and DKS in the context of a given supply chain environment. The study approach is relatively generic and may be applied to green supply chains and or Reverse Enterprise Systems also. In many industries, the full knowledge or information sharing is a complex issue. Thus as an alternative we have proposed DKS, which can provide useful solutions in such chains. Judicious use of flexibility and DKS in SCs relates to the development of guidelines that may help the management to start with lower cost alternatives that offer acceptable performance. The findings of the study have multiple implications in terms of performance enhancement of supply chains as discussed below:

1. The studies indicate that the supply chain flexibility (Wadhwa and Rao (2004)) has significant effect on the cost performance of the supply chains.
2. We have developed a KM motivated Decision Knowledge Sharing (DKS) framework which can be very useful for industry. This is so especially in the growing IT and globalization based environments. This facilitates SCs to overcome the limitation of full information sharing.
3. We have developed a framework for flexibility (i.e. partial and full flexibility) and DKS (i.e. partial and full DKS) which can open new directions for researchers and practitioners in this direction. Opportunities are identified for future cross functional decision knowledge sharing and supply chain flexibility research that builds more effective foundation for supply chain strategies.

4. The studies also show the combined effect of supply chain flexibility (Innovation or System motivated), decision knowledge sharing (KM motivated) and dynamic control (IT motivated knowledge Innovation) in improving the SC performance. The results of these studies indicate the importance of ensuring adequate level of decision control and flexibility (i.e. especially PF vs. FF) to keep the supply chain costs low for all members and the entire system. This implies extra benefits for SMEs even in cases where a dominant SC player exists.
5. Overall it is shown that suitable supply chain flexibility, DKS and dynamic control have beneficial influence on the supply chain performance. Different supply chain flexibility stages, DKS and dynamic control will lead to different benefits. However higher levels may have lesser benefits and hence suitable levels need to be carefully analyzed.
6. The results of the above studies further suggest that under certain conditions, the combined role of suitable dynamic control, DKS and flexibility may be more beneficial to improve the cost based performance. Also, since the partial flexibility gives the greatest benefits of cost reduction; it offers an extra industry motivation to focus on SC flexibility stages. Partial DKS also shows the significant influence on SC performance and thus may be most useful for SMEs facing multi-SC pressures.
7. The studies on partial flexibility and DKS are useful findings, which suggest the application and judicious use of partial flexibility and DKS in the dynamically controlled systems. Since flexibility and dynamic control are expensive, the industry should identify right level of flexibility and a suitable dynamic control to exploit it effectively.
8. The study critically focuses on both the supply chain (SC) system and its individual SC members. It motivates industry to develop flexible supply chain systems where both the members as well as the entire system benefits significantly. This may also be most beneficial to SMEs.
9. This research can motivate the industry to adapt more dynamic control and apply various flexibility measures in supply chains with alternative DKS possibilities. To enhance this model, we also propose appropriate decision and knowledge sharing options between supply chain members and their optimum synchronization.
10. The capability to improve market responsiveness to meet future uncertain demands is a critical imperative for many firms today. Our DKS model is capable to meet market responsiveness and has greater benefits with different flexibility stages. Our background works have shown that under the conditions of higher levels of decision information synchronization delays (Wadhwa and Rao, 2003, 2004), the effect of flexibility can become counterproductive. Our simulation model may help in finding suitable solutions motivated by KM efforts (DKS, Flexibility and Dynamic Control) to obviate these critical problems. This is part of our ongoing research.

The model used can be further enriched by incorporating optimization algorithms such as GA and SA etc. to this complex domain operating as a discrete event dynamic system. The direction of evolution of events is changed by the use of flexibility. One of the limitations of the model is that it works in a very descriptive manner. The practitioners often need tools that offer prescriptive suggestions for improvement. Further, a wider variety of operating conditions need to be simulated to generalize such prescriptive answers. Our research is in progress to address such issues. This paper is thus aimed at presenting some useful possibilities to inspire greater industry and research interest in the KM motivated supply chain flexibility and decision knowledge sharing domain.

The effects of DKS strategy are rising when we move upwards and reduce when we move towards downwards node of the SC. This is because we have considered some time to pass on the knowledge from one end to another. Also the time incurred for knowledge flow reduces the overall effect in performance, which should be effectively minimized. The SC performance can further be improved by better control over the parameters used in the SC environment. The knowledge-based integration of the various parameters highly influences the SC behavior, which may be an important future research issue. Wadhwa[1] et al. (2005) suggested a vision for KM Focused e-Learning architecture for SMEs is shown in figure 12. In order to pursue DKS benefits for supply chains, we can deploy and exploit the benefits of this vision. E-learning can offer an excellent platform for KM driven processes to be shared and advanced for the wider benefit of SCs. This paper attempted to demonstrate the role of decision knowledge sharing amongst the supply chain members within an overall KM context. A DKS framework employing this simulator can help in new knowledge generation, improved application and scope for greater advancements. Various demo models with simulation of different knowledge sharing scenarios, clearly indicate the significant benefits that can be derived. In our opinion there is a need to evolve KM based supply chains using several mindset change demo models. Such models will enhance both conventional and e-learning environments in the education systems aimed at promoting greater understanding of supply chain flexibility and its dynamic use through KM based efforts.

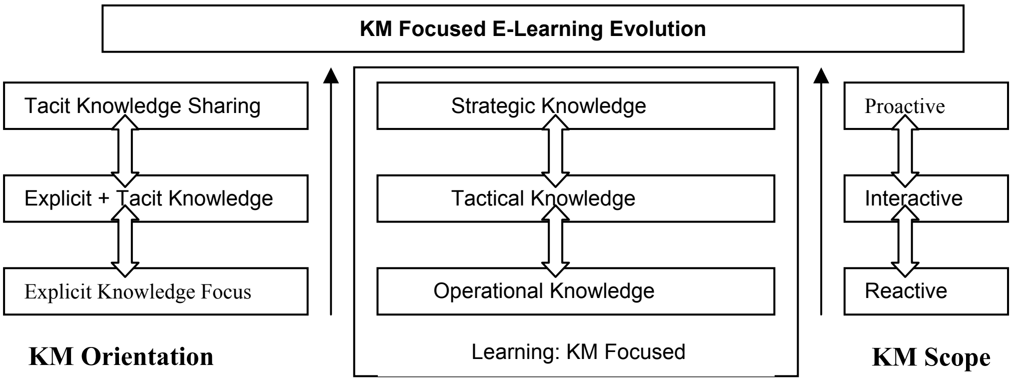

Figure 12: A KM focused Architecture supported by E-Learning (Wadhwa et al., 2005)

The major efforts presented in this paper can be summarized as key contributions including (1) Abstracting the overall research context from the background research to develop research and industry motivation (2) Literature review to identify the research gaps and areas needing sufficient enrichments (3) Development of conceptual framework for KM motivated Flexibility, DKS and dynamic control (4) Development of a relative generic modeling environment, to facilitate the development of a demo framework as a support to proposed models (5) Development of routing based supply chain flexibility, for NF, PF and FF (6) Studies on combined effects of flexibility, DKS and dynamic control (7) Limitation and direction for future research.

7. Conclusions

The supply chain flexibility with KM motivated Decision Knowledge Sharing (DKS) can have significant and potential benefits from supply chain cost performance point of view. This paper shows the need for explicitly modeling alternative levels of DKS, while studying alternative levels of flexibility in the supply chains. Different combination of supply chain flexibility types and supply chain DKS modes will lead to different situations. In addition, keeping in view the fact that the extent of benefit in each case appears to be significantly large in its magnitude, and the results are encouraging. Also, since the partial flexibility gives the greatest benefit of cost reduction, it offers industrial motivation towards initial investment in flexibility. The combination of partial DKS with full flexibility and partial flexibility with full DKS gives significant effects and needs greater research attention. However, since different types and stages of flexibility and DKS gives different performance, there is a need to arrive at judicious types and levels of supply chain flexibility (i.e. partial and full routing flexibility) and DKS (i.e. partial and full DKS). Perhaps, this is useful to reduce the cost of SCs (including SC partners) significantly. We have tested the model for many parameters like demand pattern, lead time, ordering cost, inventory and transport distance. Even though dynamic parameters are selected on the basis of experience, there is possibility to include other factors with more cases of flexibility types. Simulation of this model is aimed at understanding the impact of flexibility and DKS on the cost based performance of supply chain under dynamic control. It would be beneficial to run a real life model on a simulator designed for dynamic conditions before actual flexibility is put into practice. The key insights indicate that in some cases partial decision sharing have shown close performance as compared to full decision sharing. Research must be conducted that can aid enterprise in understanding how flexibility can improve their competitive positions. In our opinion there is a growing need for developing decision focused supply chain models (e.g. DKS) to help change the mindset of the chain members towards a more effective integration of the supply chains. Our research is continuing in this direction.

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