Reconfiguration of supply chain network: an ISM-based roadmap to performance

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1 Introduction

Supply chain management (SCM) is the coordination and management of a complex network of activities involved in delivering a finished product to the end-user or customer. The successful management of a supply chain is greatly influenced by customer expectations, information technology (IT), and competition. An important component in SCM is the development of high values of performance measures. Performance measurement and its application continue to grow and encompass both quantitative and qualitative measurements and approaches. Besides measuring performance based upon financial measures such as profitability, return on investment, etc. other measures such as customer service and inventory performance that are more operational oriented, may necessarily be linked to strategic level measures and issues have immense significance. A performance measure, or a set of performance measures, is used to determine the efficiency and/or effectiveness of an existing system, or to compare competing alternative systems (Beamon, 1998). Most of the companies realize that, in order to evolve an efficient and effective supply chain, SCM needs to be assessed for its performance from time to time. These efforts are central to total quality and continuous improvement programs, where performance measurement is critical to any organization in managing their operations. Consequently, continuous improvement warrants the organization to be highly responsive. The responsiveness of a manufacturing or supply chain system is defined by the speed with which the system can adjust its structure or operational setting (Holweg, 2005; Reichhart and Holweg, 2007). Further, in response to the ever increasing customer demands for variety and rapid delivery at acceptable costs, it is an expedient option increasingly being recognized by the organizations to pay continuous attention to the existing operational units that necessitate finding the best or the near best alternative configuration in order to harness high level of performance measures.

In market conditions of increasing levels of product variety and customization, the ability to respond to customer orders in a timely fashion can provide a critical competitive advantage. In this endeavour, manufacturing organizations have universally acknowledged the pivotal role played by their supply chain networks (SCNs). Furthermore, there is a need to build-in flexibility within the SCN to ensure the reconfigurability – a primary requirement when developing an agile supply chain system. Thus, we can consider “reconfigurability” as a synonym of “supply chain agility”. Henceforth, in the present paper we used these terms surrogate to each other. Supply chain agility is the key to high responsiveness, enabling enterprises to respond to consumer demand more quickly. Stevenson and Spring (2007) mentioned the importance of re-configuring the supply chain as needs change, providing a more dynamic and evolutionary means of being flexible. Moving a step forward from agility, researchers have discussed combining agility with leanness, resulting in leagile supply chains (Naylor et al., 1999; Van-Hoek, 2000; Mohammad et al., 2008). Leagility enables cost effectiveness of the upstream chain and high responsiveness levels in a volatile marketplace in the downstream chain.

An accurate assessment of the effectiveness allows the manager to better understand the overall process and the sub-processes and make a better judgment about his decisions about the operational performance (Ross and Droge, 2004). To facilitate a better understand of the operational enablers effecting performance of SCN, an analysis of “drivers”, the “inter-relationship” and the “hierarchy of importance” are essential. The interpretive structural modeling (ISM) can prudently be employed for getting better insights into the system. The ISM methodology is interpretive from the fact that as the judgement of the group decides whether and how the enablers are related while affecting an output (Mohammad et al., 2008). However, in a complex SCN wherein several stochastic operational variables (uncertain demand, lead time instability, inventory controlling policies, etc.) are affecting the system wide supply chain performance, it becomes difficult for a decision maker to precisely estimate the relation between them. Furthermore, as soon as the number of parameters affecting supply chain performance becomes high and the objective becomes the whole supply chain analysis, simulation plays conspicuously critical role in finding the optimal trade-off among the involved variables (Chang and Makatosoris, 2001). In such a case, given a set of alternate operational variables, the issue of developing a hierarchy of enablers through ISM methodology in order to enhance or maintaining high level of performance raises a question such as:

- Within the premise of several stochastic operational variables of a complex system wide SCN, how the relational matrix in ISM, structural self-interaction matrix (SSIM), be developed using simulation.

In view of this, the present paper contributes to developing SSIM relational matrix from the outcomes of simulation results for the given alternate SC operational configurations.

Consistent with the issue of leagile supply chain discussed above, we consider “average fill rates” performance as the surrogate measure of responsiveness. However, a high fill rate comes at a price: “average inventory levels” must go up in order to guarantee the lower stock outs needed to ensure the high levels of customer responsiveness. Also, since the present paper specifically focuses operational variables, according to Gunasekaran et al. (2001), the performance from operational view point can best be accessed where inventory levels can be measured and monitored. They also emphasized that the performance related to inventory levels is not just confined to production, rather spans the entirety of supply chain. Thus, the impetus for this research: given the alternate operational enablers, the supply chain performance is analyzed for “average fill rate” and “average inventory levels” performance. While “average fill rate” is the fraction of customer demand delivered directly from stock, “average inventory levels” is the average length of storage queue over the simulated time period.

The paper is organized as follows. Section 2 describes the literature concerning the enablers considered in this paper. A brief description of the interpretive structure modeling is presented in Section 3. In Section 3.1, we discussed various steps involved in ISM, while Section 3.2 explains the development of SCN structure and its execution through simulation for developing SSIM matrix. The development of ISM for “average fill rate” performance is shown in Sections 3.3-3.6 demonstrates ISM model for “average inventory level” performance. Section 4 discusses the managerial insights interpreted and finally discussions and conclusions are drawn in Section 5.

2 Literature review

There is plethora of literature available concerning operations related enablers that effects SC performance. Gunasekaran et al. (2001) and Huang et al. (2003) have widely elaborate various enablers that effect SC performance. However, to keep the results tractable, we limit ourselves to a few comprehensively examined operational enablers in literature as the present paper specifically focus on developing a hierarchy of enablers through ISM methodology using simulation under given alternate options of operational enablers. The enablers considered are:

- information sharing;
- review period;
- lead time;
- lead time standard deviation;
- inventory control policy;
- supply chain structure; and
- demand.

These enablers are now highlighted under the premise of SC performance which is extensively examined by various researchers in the literature.

Information sharing

The effective use of IT to integrate information across functions enables an organization to leverage the synergies among these functions. Therefore, IT is viewed as an enabler (Gunasekaran, 1999). Supporting a variety of configurations gives the process manager the flexibility to adapt many different business requirements. In a supply chain, process integration is achieved through collaborative working between buyers and suppliers. Information sharing is one of the significant collaborative/integrative processes (Pandey and Garg, 2009; Ramanathan et al., 2011). There is plethora of researches that suggest sharing point-of-sale (POS) data and operational alignment to final demand of channel member activities. These practices reduce system uncertainty and, in turn enhance performance (Ryu et al., 2009; Dev et al., 2011, 2012; Dev and Shankar, 2012). Gunasekaran et al. (2001) emphasized on buyer-supplier partnership in supply chain and suggested information sharing as one of the criteria of partnership for efficient and effective performance. Also, several researchers have observed that a prime objective in pursuing an information sharing policy is to downsize safety stock levels (and hence average inventory levels) by controlling the uncertainties arising from lead times and their standard deviations (Beamon and Chen, 2001; Aigbedo, 2004; Hwarng et al., 2005; Zanoni et al., 2006).

Inventory system (review period, lead time and their standard deviation, inventory control policy, and demand)

The overall performance of inventory flow and control through supply chain is not only dependent on the coordination and information sharing among the members of the chain, but also relies on the effectiveness of inventory control policies implemented within the independent tiers of the chain. Therefore, applying the right stock policies in any stage of the distribution process (from raw material supply to the end customer) remains to be a vital issue for achieving better performances from today's rapidly widening supply chains (Sezen, 2006; Dev and Shankar, 2012). Continuous review and Periodic review are the two major classes of review system in inventory control policies. There are two basic parameters to be controlled in a periodic review system:

1. how often to review inventories, i.e. review period; and
2. how much to raise the inventories at each review period.

The deployment of differing inventory review policies has sometimes been the suggested alternative for raising order fill rates. However, the method of deployment has been different: while Chopra and Meindl (2004) favour the adoption of a periodic review policy throughout the SC, Ahire and Schmidt (1996), and Beamon and Chen (2001) suggest a piecemeal approach wherein both continuous as well as periodic review policies are adopted in tandem between partnering echelons. Flores and Whang (2002) compared two review policies (continuous and periodic) for finding different production scheduling parameters. For carrying out this study the authors assumed warehouse and manufacturer operate under continuous and periodic review (i.e. (s, S) and (R, s, S)) policies separately to analyze the above scheduling parameters. Pawlak and Małyszek (2008) suggested that the companies should collaborate with other chain components in order to choose appropriate inventory control policies. Further they emphasize that companies which try to reduce their inventory costs independently must realize that policies used by other chain components can be changed and there is a high risk of failure when they select policies in isolation from others.

Managing risk in the supply chain has never been as challenging as it is today. Supply chain risks can come in a host of different kinds like natural disaster, terrorist attack, labor strike and accidents. These can all be the causes for supply chain disruption (Christopher and Lee, 2004; Tang, 2006). Supply chain disruption does not only halt the supply chain operations but without preparation and precaution, it takes time for the affected system to recover (Sheffi and Rice, 2005). Inventory management is an effective way of dealing with such disruption situations (Samvedi and Jain, 2011). Samvedi and Jain (2011) analyzed a serial supply chain through simulation subjected to supply disruptions with varying frequency and duration of review period across the supply chain. They found that the cost of the players in the chain increases with increasing maximum inventory level and decreases with increasing review period. Riezebos and Zhu (2010) considered a single echelon inventory system with periodic ordering. He discussed the effect on cost structure due to change in lead times that results in crossover given that the length of review period changes. Manufacturing lead time is a major factor effecting responsiveness or fill rate performance (Gunasekaran et al., 2001). The authors mentioned that high fill rates can be realized with shorter lead time. Furthermore, the complexity of the task of determining the optimum replenishment decision at any period is also dependent on several factors that are quite volatile. One of these factors is the nature of demand. Specifically, variability of demand has a direct influence on the inventory related performance of individual members in a SCN (Sezen, 2006). Thus, it is a prerequisite of an agile supply chain to adapt effectively to disruptions in changes in demand whilst maintaining customer fill rate performance. Kritchanchai and MacCarthy (1999) analyzed the order fulfillment process through case study by dividing various companies into four different groups based upon various components of order fulfillment like customer demand, sharing of production information, levels of safety stocks that eventually depend upon inventory control policy. Similar attributes under lean and agile supply chain concept are drawn by Christopher and Towill (2000).

Supply chain structure

According to Gunasekaran et al. (2001), in a typical distribution mode, the delivery channel plays an important role in fill rate performance. A change in one of the major entity of a distribution structure can effect the system as a whole. The authors suggest adopting total system view and measuring the performance as a whole. Lau et al. (2004) analyzed the behaviour of supply chain structure under the complexities of:

- different levels of lead time;
- different levels of demand information sharing factor in which different combinations of echelons constitutes levels of demand information sharing; and
- three different levels of complexity of hypothetical divergent supply chain structures.

They studied significance of these factors for average inventory level and average fill rates as the performance measures of interest. Reiner and Trcka (2004) studied two and three stage divergent product specific (food industry) supply chain structure. They showed that POS information may not be beneficial for upstream echelons if the variance of demand at retailer end is too high. Other researchers that have focused different SC structures for fill rate performance include (Lim et al., 2006; Jammernegg and Reiner, 2007; Dev et al., 2011). Dev et al. (2011) carried out a case study of a manufacturing firm. They carried out simulation of firm's supply chain distribution structure and suggest reducing the number of dealers for enhancing the inventory performance by rationalizing the inventory related policies.

From the above literature review, it is apparent that the assumed enablers mentioned above are often exploited to study their behavior on assumed performance measures. The researchers in the past have developed the hierarchy of various enablers from agility/reconfigurability perspective using ISM concept. In a few cases, they decide on the enablers from the past literature and cluster various functions at operational level to wider strategic or tactical functions. Kumar et al. (2008) consider the inventory control functions under the wider enabler “logistic flexibility”. Similarly, while the ability to adapt the demand fluctuations is considered under the enabler “volume flexibility”, the enabler “rerouting flexibility” is considered for change in distribution channel of “SCN structure”. Mohammad et al. (2008) and Pandey and Garg (2009) have developed hierarchy of enablers using ISM technique in similar manner. More and Babu (2011) established contextual relationship between various type of flexibilities through ISM. However, on developing hierarchy of operational enablers that form complex stochastic functions over the complete supply chain using simulation for SSIM matrix, is little to no literature exist. Thus, under the premise of SC reconfiguration, to facilitate a better understand of the operational enablers effecting SCN performance, an analysis of “drivers”, the “inter-relationship” and the “hierarchy of importance” under stochastic environment derived from simulation results, is the significant contribution of the present paper.

3 Interpretive structural modeling

ISM falls into the soft operations research (OR) family of approaches. The term ISM refers to the systematic application of graph theory in such a way that theoretical, conceptual, and computational leverage is exploited to efficiently construct a directed graph, or network representation, of the complex pattern of a contextual relationship among a set of elements. In other words, it helps to identify structure within a system of related elements. It may represent this information either by a digraph (directed graph) or by a matrix. Using the process view allows the researcher to pay explicit attention to the assumed nature of the causal relationships between the chosen variables (Anantatmula and Kanungo, 2008). The process of structural modeling consists of several elements: an object system, which is typically an approximate system to be described by the model; a representation system, which is a well-defined set of relations; and an embedding of perceptions of some relevant features of the object system into the representation system. Interpretation of the embedded object or representation system in terms of the object system results in an interpretive structural model (Sage, 1977). In ISM a set of different and directly related variables affecting the system under consideration is structured into a comprehensive systemic model. Therefore, in this paper, the enablers of performance measures in a supply chain have been analyzed using the ISM methodology, which shows the interrelationships of the enablers and their levels. With the results of digraph, a decision maker can specifically focus on the driving enablers while managing top level enablers of hierarchy. The application of ISM typically facilitates managers to reassess perceived priorities and improves their understanding of the linkages among key concerns (Mohammad et al., 2008).

3.1 ISM methodology and model development

From the literature review it is prudent that following are the enablers that effects the assumed performance measures; “average fill rates” and “average inventory levels”:

- information sharing;
- review period;
- lead time;
- lead time standard deviation;
- inventory policy;
- supply chain structure; and
- demand.

The various steps involved in the ISM methodology are as follows:

1. Variables affecting the system under consideration are listed, which can be objectives, actions, and individuals, etc.
2. From the variables identified in Step 1, a contextual relationship is established among variables with respect to which pairs of variables would be examined.
3. A SSIM is developed for variables, which indicates pair wise relationships among variables of the system under consideration.
4. Reachability matrix is developed from the SSIM and the matrix is checked for transitivity. The transitivity of the contextual relation is a basic assumption made in ISM. It states that if a variable A is related to B and B is related to C, then A is necessarily related to C.
5. The reachability matrix obtained in Step 4 is partitioned into different levels.
6. Based on the relationships given above in the reachability matrix, a directed graph is drawn and the transitive links are removed.
7. The resultant digraph is converted into an ISM, by replacing variable nodes with statements.
8. The ISM model developed in Step 7 is reviewed to check for conceptual inconsistency and necessary modifications are made.

These steps of ISM modeling are shown in Figure 1.

3.2 Structural self-interaction matrix

ISM methodology suggests developing the contextual relationship among the variables. In this paper, for developing the contextual relationship between the enablers, we assume a hypothetical SCN structure as shown in Figure 2. We carried out discrete event simulation of the assumed four-echelon SCN structure(s) using Arena® simulation language (Kelton et al., 2004). External Visual C++ code was linked into the Arena models to capture the inventory control logic utilized in the simulation models.

Figure 3(a)-(c) schematically shows the operations performed within and at the interface of each echelon while effecting various decisions in the SCN structure. Basically, the operations entails three distinct sub-operations comprising of:

1. demand fulfillment process;
2. inventory updating process; and
3. stochastic lead time process.

We assume three suppliers that supply sub-assemblies to a downstream manufacturer with normally distributed supply lead times. The manufacturer in turn, assembles the finished product using the sub-assemblies received from the suppliers in a constant duration of time. Without loss of generality, it is assumed that the manufacturing operation is accomplished without breakdowns. The next echelon comprises of two warehouses to which the finished product is sent, again with normally distributed lead times. We assume that Warehouse 1 (W1) fulfills the demands of Retailers 1 and 2 (R1 and R2), while Warehouse 2 (W2) caters to the demands of Retailers 3 and 4 (R3 and R4), respectively. Further, each of the four distinct retailers experience different demand patterns, each of which are exponentially distributed with differing parameters. Importantly, the retailers comprise the only echelon that experience external demand; accordingly, all customer orders are placed at these retail outlets alone and must be satisfied at the said location only. The second SCN structure, shown in dotted lines, assumed for reconfiguration of SCN, comprises of only one warehouse which fulfills the demand of each of the four retailers.

We assume the presence of a suitable mechanism, for example, an electronic data interchange (EDI) system, for enabling demand information sharing seamlessly upwards from the retailer-end to the upstream echelons. Such a situation is referred to as a “centralized” information sharing setup in the literature (Simchi-Levi et al., 2008). In contrast, a “decentralized” setup implies the absence of any information sharing between echelon members.

Further, we assume that the SCN is presently observing the following configuration of operational enablers which is regarded as the “base-setting” for the study of performance, “average fill rates” and “average inventory levels”: information sharing (IS) = all echelons are acting as decentralized manner; review period (RP) = periodic (6 days); lead time (LT)=3 days; lead time standard deviation (STD)=0.5 days; inventory control policy (IP) = conventional (S, s) policy consistent to Olhager and Persson (2006); supply chain structure (SCS) = two warehouses, each catering the demand from two retailers; and demand (D) at four retailers=low (exponentially distributed with different mean values). Each enabler is studied against an alternate operational enabler under the premise of reconfiguration, and compares the resulting performance of SCN with the existing value of performance. The existing (Level 1) and the alternate settings (Level 2) of operational enablers are shown in Table I. To develop the associated direction of relationship we carried out pair-wise comparison of various enablers.

The SSIM is developed observing the effect of pair-wise relationship that leads to increase in “average fill rates” in comparison to assumed existing base-setting. To reach at the decision about the relation between each pair of enablers in SSIM (V, A, X, and O), i.e. the relation of enabler “i” with enabler “j”, we carried out four experiments (2 enablers (“i” and “j”)×2 output (low and high)=4) using simulation model described above. The four experiments are:

(E1) The first experiment is carried out with the existing (base-setting) configuration in which all the enablers are assumed operating with Level 1 shown in column 3 of Table I. This experiment is assumed as a benchmark against which the results of second, third and fourth experiments are compared with.

(E2) In the second experiment, the enabler “i” is considered at the level of existing configuration (Level 1) while the enabler “j” is perturbed to Level 2. For instance, in case of pair-wise relation between enablers 2 (i) and 3 (j), the simulation experiment is carried out with enabler “review period” as “periodic”, i.e. with Level 1 and enabler “lead time” is perturbed to “6 days”, i.e. with Level 2. The rest of the enablers remain at Level 1.

(E3) In the third experiment, the enabler "j" is considered at the level of existing configuration (Level 1) while the enabler "i" is perturbed to Level 2.

(E4) In the fourth experiment, both "i" and "j" are perturbed to Level 2.

As shown in Figure 4, with seven enablers there are 21 pair-wise relations in the SSIM. Since experiment (E1) assume SCN operating with existing configuration (base-setting), the result obtained in experiment (E1) is compared with the results of experiments (E2), (E3), and (E4) for developing all the relations in SSIM. Therefore, beside the base-setting experiment (E1), in total 63 (=21×3) simulation experiments were carried out.

Since there are three experiments: (E2), (E3) and (E4); for determining relation between each pair-wise enablers with two outputs, high (H) or low (L), we need to interpret eight (23) possible outcomes (combinations) so as to select one relation symbol out of V, A, X, and O for each combination. The eight combinations and their description of interpretations for selecting one relational symbol from V, A, X, and O are shown in Table AI of the Appendix. The results of experiments (E2), (E3) and (E4) for each pair-wise relations (21 Nos) and their combinations of output (high (H) or low (L)) vis-à-vis (E1) is shown in Table AII of the Appendix. The resulting table of SSIM is shown in Figure 4.

3.3 Reachability matrix for average fill rate performance

The SSIM is transformed into a binary matrix, called the initial reachability matrix. The transformation from the SSIM to the reachability matrix format is accomplished by transforming information in each entry of the SSIM into 1s and 0s in the reachability matrix. The rules for the substitution of 1's and 0's are the following:

1. If the (i, j) entry in the SSIM is V, then the (i, j) entry in the reachability matrix becomes 1 and the (j, i) entry becomes 0.
2. If the (i, j) entry in the SSIM is A, then the (i, j) entry in the reachability matrix becomes 0 and the (j, i) entry becomes 1.
3. If the (i, j) entry in the SSIM is X, then the (i, j) entry in the reachability matrix becomes 1 and the (j, i) entry also becomes 1.
4. If the (i, j) entry in the SSIM is O, then the (i, j) entry in the reachability matrix becomes 0 and the (j, i) entry also becomes 0.

Following these rules, reachability matrix for the enablers is drawn as shown in Table II. From the table of reachability matrix, it is clear that Step 4 of methodology of ISM is confirmed in which it is required that transitivity of the contextual relation must be maintained.

3.4 Partition on reachability matrix for average fill rate performance

Once the reachability matrix is created, it must be processed to extract the digraph and associated structural model. We follow Warfield (1974) that uses series of partition which are induced by the reachability matrix on the set and subsets of the elements P={p i }. From these partitions we can identify many properties of the structural model. We present below various partitions.

3.4.1 Π_1 (P×P), the relation partition

The set of P×P contains all ordered pairs of the elements. The reachability matrix induces a partition on these ordered pairs into two blocks, Z and Z^{-}. An ordered pair (p_i, p_j) is contained in Z if p_i reaches p_j, i.e. if the matrix entry P_{ij}=1. Otherwise, (p_i, p_j) is contained in Z^{-}. Thus, Π_1(P×P) separates the ordered pairs into those for which p_i Rp_j and those for which p_i $R^{-}$$p_j$. R and R^{-} represent "related to" and "not related to", respectively. The partition may be written as: Equation 1 As seen from Table II, we have 21 elements in Z, since 21 ones and 28 elements in Z^{-}. These are: Equation 2

3.4.2 Π_2(P), the level partition

An element p i is a top-level element if the intersection of the reachability set and the antecedent set will be the same as the reachability set. Therefore, it may be written as: Equation 3 where, R(p_i) and A(p_i) are reachability set and antecedent set, respectively. After identifying the top-level elements, we remove them from consideration and find the top level elements for remaining sub-graph. This is continued until all levels of the structure are identified. The iterative algorithm may be written as: Equation 4 where, L_0 and L_j is the set of elements at 0th and jth level, respectively, $R_j{-}1(p_i)$ and $A_j{-}1(p_i)$ are the reachability and antecedent set determined for the sub-graph consisting of elements in $P-L_0-L_1-\dot{c}-L_{j-1}$. Table III shows the sets $R(p_i)$, $A(p_i)$ and $R(p_i) \cap A(p_i)$ for $P-L_0$, where $L_0=\varphi$, an empty set.

Inspection of Table III shows equation (2) is satisfied for elements 4 and 6 which we identify as top-level elements. Thus, we have: Equation 5 We now delete L_1 from consideration and find the top-level element of $P-L_0-L_1$. This will constitute the second level. Table IV shows the sets $R(p_i)$, $A(p_i)$ and $R(p_i) \cap A(p\ i)$ for $P-L_0-L_1$. Inspection of Table IV shows that equation (2) is satisfied for the elements 1, 2, 3, 5, and 7. Therefore, level $L\ 2$ comprises of: Equation 6 Thus, we completed the partition by identifying two levels and the elements contained in them. The partition $\Pi_2(P)$ is expressed as: Equation 7

3.4.3 *$\Pi_3(P)$, the separate parts partition*

The separate part partition $\Pi_3(P)$ is used to identify the disjoint parts of the structural model. Before identifying the separate part partition, bottom-level elements are identified. The bottom-level elements p_i is an element whose antecedent set $A(p_i)$ is the same as the intersection of its reachability set $R(p_i)$ and its antecedent set $A(p\ i)$. If B is the set of bottom-level elements, $p_i \in B$ if and only if: Equation 8 From Table III, we find that equation (4) is satisfied for elements 1, 2, 3, 5, and 7. Thus, the bottom-level set becomes: Equation 9 Further, any two elements $p\ i$, $p\ j \in B$ are placed in the same block of a digraph if and only if: Equation 10 Inspection of Table III shows that R(1), R(2), R(3), R(5), and R(7) include elements 4 and 6. Therefore, we see that: Equation 11 Thus, as per equation (5) there is no disjoint set and we have only one digraph that constitutes all the elements. Therefore, $\Pi_3(P)$ consist of: Equation 12

3.4.4 *$\Pi_4(L_k)$, the disjoint and strong partition of $L\ k$*

Within each level, the elements may be classified as either being part of a strongly connected subset or not being part of a strongly connected subset. That is, if an element p_i is not part of a strongly connected set: Equation 13 where, $R_{Lk}(p_i)$ indicates reachability with respect to the elements of level L_k .

The reachability matrix induces a two-block partition $\Pi_4(L_K)$ on the elements of each level L_k : Equation 14 An element is contained in "I" if it satisfies equation (6), otherwise, the element is contained in S, i.e. those elements are contained in "I" which are not strong components, whereas block S contain elements which are strong components.

For $L\ 1$ of our problem, $R_{L1}(4)=[4, 6]$ and $R_{L1}(6)=[4, 6]$. Thus, we have: Equation 15 For L_2, $R_{L2}(1)=1$, $R_{L2}(2)=[2, 7]$, $R_{L2}(3)=3$, $R_{L2}(5)=5$, $R_{L2}(7)=[2, 7]$. Therefore: Equation 16 From the partitions $\Pi_4(L_1)$ and $\Pi_4(L_2)$ we conclude that element [4, 6] and [2, 7] are strongly connected subset at Levels 1 and 2, respectively.

3.4.5 *$\Pi_4(S)$, the strongly connected subsets partition on S*

The reachability matrix induces a partition Π4(S) on the strongly connected subsets such that a group of elements are in the same block if and only if every element in the group is reachable from and antecedent to every other element in the group. In our problem, inspection of the reachability metrics in Table II shows that at level L_1 both enablers 4 and 6 are antecedent to and reachable from each other. Similarly, at level L_2, the enablers 2 and 7 are antecedent to and reachable from each other. Therefore, these enablers are identified as cycle contained in level L_1 and L_2, respectively. With this information we obtain the structural model shown in Figure 5.

3.5 SSIM for average inventory levels performance measure

As was done in "average fill rate" performance case, for "average inventory level" performance also, we developed SSIM with the same existing (base-setting) configuration of SCN. The SSIM is developed observing the effect of pair-wise relationship that leads to decrease in "average inventory level" in comparison to assumed existing configuration. Since the performance improvement in this case is viewed from decrease in inventory levels, the pair-wise relations are interpreted in contrary to the interpretations made in case of “average fill rate” performance. The results of experiments (E2), (E3) and (E4) for each pair-wise relations (21 Nos) and their combinations of output (high (H) or low (L)) vis-à-vis (E1) is shown in Table AIII of the Appendix. The resulting table of SSIM is shown in Figure 6.

3.6 Reachability matrix for average inventory level performance

Reachability matrix for the enablers is drawn as shown in Table V. From the table of reachability matrix, it is clear that Step 4 of methodology of ISM is confirmed in which it is required that transitivity of the contextual relation must be maintained.

As was done in “average fill rate” performance case, after carrying out various steps of ISM for “average inventory level” performance also, the results of experiments (E2), (E3) and (E4) for each pair-wise relations and their combinations of output (high (H) or low (L)) vis-à-vis (E1) is shown in Table AIII of the Appendix. Finally, we obtained the structural model shown in Figure 7.

4 Managerial insights

The analysis of the ISM provides interesting managerial insights. The results show that in case of “average fill rate” performance, the ISM model categorizes the enablers selected for supply chain reconfiguration into two levels. The enablers at bottom level: “information sharing”, “review period”, “lead time”, “inventory policy”, and “demand” have the potential to drive the enablers at top level: “lead time standard deviation” and “supply chain structure”. The effective use of enablers at bottom level helps to manage the next level of enablers which are at top level. Further, managing the top level enablers helps to achieve the performance indicator: “average fill rates”. In Table II and eventually in Figure 5, it is seen that at bottom level, “review period” (enabler 2) and “demand” (enabler 7) have the cyclic effect, that is, they are antecedent to and reachable from each other. In other words, any action on these enablers will have an effect on other and also a feed back on themselves. The result makes sense as the selection of review period in operations largely depends upon the demand rate. A similar cyclic relation is also seen at top level between “lead time standard deviation” (enabler 4) and “supply chain structure” (enabler 6). The implication of above results are obvious: the assumptions considered in for the driving enablers at bottom level, i.e. exponential distributed demands with varying mean values at each of the four retailers, normally distributed lead times, demand information sharing, review periods and inventory policy at differing levels, can be relaxed and detailed simulation runs can then be performed with the revised/reconfigured values of the assumed parameters. For example:

- In the enabler “information sharing”, the SC structure may assume to have partial information sharing among echelons consistent with Dev and Shankar (2012).
- For the enablers “review period”, “lead time”, “lead time standard deviation”, and “demand”, simulation may be performed at different values of these parameters.
- The distribution end of supply chain structure may be assumed to have different channels of distribution consistent to Beamon (1998).
- The different inventory policies may be assumed consistent with Dev et al. (2012).

It is conjectured that the revised/reconfigured parameter values could impact the top level enablers (lead time standard deviation and supply chain structure) in differing ways. However, we interpret that the directionality of the results would largely remain unaltered. From the directionality we mean: with the increasing values of “lead time standard deviation”, a single-warehouse operating under decentralized scenario has larger value of re-order point. Consequently, when demand of four retailers is aggregated, more frequent and larger lots are placed by the downstream echelon to upstream echelon. Thus, the availability of product in inventory would be high, thereby resulting high fill rates.

Similarly, in case of “average inventory level” performance also, the ISM model categorizes the enablers selected for supply chain reconfiguration into two levels. However, in this case the driving enablers at bottom level are different and comprise: “review period”, “lead time standard deviation”, “inventory policy”, “supply chain structure”, and “demand”. These bottom level enablers if used effectively can manage the top level enablers: “information sharing” and “lead time”. Further, managing the top level enablers helps to achieve the performance indicator: “average inventory levels”. In this case also, as seen in Table V and eventually in Figure 7, there is a cyclic relation between enablers “information sharing” and “lead time”. The implications of result in this case are apparent: the values considered for enablers can be relaxed and detailed simulation runs can then be performed with the revised/reconfigured values of the assumed parameters. The revised/reconfigured values of the assumed bottom level enablers could have impact on top level enablers in differing ways. However, we interpret that the directionality of result remains unaltered. The directionality of result in this case ponders to a situation in which supply chain is operating under centralized demand information scenario (real time demand at retailers are accessed by all upstream echelons). In this case the order size from a downstream echelon to the immediate upstream echelon would be less as compare to decentralized case. Due to increased value of lead time, we interpret that by the time products reaches in storage of upstream echelon, more number of products is depleted from its inventory, thus result in low “average inventory levels”. We reiterate here that “average inventory levels” are the average queue lengths over the simulated period.

A manager should focus more on bottom level operational enablers, which helps to achieve managing top level operational enablers. Effective management of top level enablers will drive the assumed performance measure of the supply chain: “average fill rate” and “average inventory levels”. The top level operational enablers have low driving power as compared to bottom operational enablers. This indicates that those managers who focus only on top level operational enablers may not achieve sustainable advantage of enhanced performance through reconfiguration. The bottom level operational enablers followed by top level operational enablers should be well managed for effective reconfiguration of a SCN. From management of enablers we mean that, the decision maker should analyze the effect of varying values of driving enablers keeping top level enablers constant through simulation experiments. The setting of driving operational enablers that results maximum assumed performance would be the effective reconfigured setting.

5 Discussion and conclusions

Short product life cycle has made the global markets customer oriented. Rapid response rates are now often among the most important metrics in business. To achieve the required flexibility, leanness and agility, many companies are forced to reconfigure their supply chain operational units very frequently. It is very difficult to understand “drivers”, the “inter-relationship” and “hierarchy of importance” between various operational enablers in stochastic environment of system wide SCN. The driving operational enablers are very important to focus upon and analyzing comprehensively so as to manage the top level enablers which are considered as the responsible enablers for enhancing the performance of SCN. The top level enablers are the dependent enablers and require all driving enablers to be used effectively so as to enable top enablers to be realized for the successful reconfiguration of SCN. However, we would like to emphasize here the limitations of this paper. The hierarchical influencing structure of operational enablers may change from industry to industry because of different types of products and their product mix. Further, hierarchical influencing structure has not been statistically validated.

The present paper positions its novelty and practical aspect in real-world industry in a way that the hierarchy of operational enablers can be developed by integrating the simulation results to the ISM model under the premise of reconfiguration of SCN. The approach reported in this paper is beneficial in a way that:

- The relationship matrix developed among stochastic operational enablers is more precise through simulation results. Thus, the driving enablers and dependent enablers in hierarchical structure are more accurately constructed through ISM.
- Due to more precision in “what-if” analysis through simulation, reconfiguring a supply chain becomes comparatively a justifiable process from investment view point.
- Supply chain disruptions can comparatively be handled proactively with a more accurate reconfiguration of operational enablers.

- The desired responsibility among SC echelons is developed while reconfiguring the enablers in context of information sharing.

$$\Pi_1(P \times P) = [Z; \bar{Z}] \qquad (1)$$

Equation 1

$$\begin{aligned}\Pi_1(P \times P) = [&(1,1),(1,4),(1,6),(2,2),(2,4),(2,6),(2,7),(3,3),(3,4),(3,6),\\ &(4,4),(4,6),(5,4),(5,5),(5,6),(6,4),(6,6),(7,2),(7,4),(7,6),(7,7)];\\ &[(1,2),(1,3),(1,5),(1,7),(2,1),(2,3),(2,5),(3,1),(3,2),(3,5),(3,7),\\ &(4,1),(4,2),(4,3),(4,5),(4,7),(5,1),(5,2),(5,3),(5,7),(6,1),(6,2),\\ &(6,3),(6,5),(6,7),(7,1),(7,3),(7,5)]\end{aligned}$$

Equation 2

$$R(p_i) = R(p_i) \cap A(p_i) \qquad (2)$$

Equation 3

$$L_j = \{p_i \in P - L_0 - L_1 - \cdots - L_{j-1} | R_{j-1}(p_i) = R_{j-1}(p_i) \cap A_{j-1}(p_i)\} \qquad (3)$$

Equation 4

$$L_1 = [4, 6]$$

Equation 5

$$L_2 = [1, 2, 3, 5, 7]$$

Equation 6

$$\Pi_2(P) = \{[4, 6]; [1, 2, 3, 5, 7]\}$$

Equation 7

$$A(p_i) = R(p_i) \cap A(p_i) \qquad (4)$$

Equation 8

$$B = [1, 2, 3, 5, 7]$$

Equation 9

$$[R(p_i) \cap R(p_j)] \neq [\phi] \qquad (5)$$

Equation 10

$$[\mathrm{R}(1) \cap \mathrm{R}(2) \cap \mathrm{R}(3) \cap \mathrm{R}(5) \cap \mathrm{R}(7)] = [4, 6] \neq [\varphi]$$

Equation 11

$$\Pi_3(P) = [1, 2, 3, 4, 5, 6, 7]$$

Equation 12

$$R_{Lk}(p_i) = p_i \qquad (6)$$

Equation 13

ImageFigure 1

$$\Pi_4(L_K) = [I, S]$$

Equation 14

$$\Pi_4(L_1) = \{[\varphi]; [4, 6]\}$$

Equation 15

$$\Pi_4(L_2) = \{[1, 3, 5], [2, 7]\}$$

Equation 16

Flow diagram of

Figure 1 Flow diagram of ISM [not available in this version]

Figure 2 Hypothetical SCN structure with the two-warehouse case and the one-warehouse case [not available in this version]

Figure 3 (a) Demand fulfillment process flow within an echelon, (b) inventory updating process flow within an echelon and (c) lead time logic at the interface of echelons [not available in this version]

Figure 4 SSIM for average fill rate performance [not available in this version]

Figure 5 Diagraph of average fill rate performance [not available in this version]

Figure 6 SSIM for average inventory levels performance [not available in this version]

Figure 7 Diagraph for average inventory level performance [not available in this version]

Table I Levels of configuration of enabler parameters of supply chain [not available in this version]

Table II Reachability matrix for average fill rate performance [not available in this version]

Table III Iteration 1 for average fill rate performance [not available in this version]

Table IV Iteration 2 for average fill rate performance [not available in this version]

Table V Reachability matrix for average inventory levels performance [not available in this version]

Table AI Descriptions of interpretation for selecting relation symbol for SSIM [not available in this version]

Table AII Results of experiments (E2), (E3) and (E4) for pair-wise relations in average fill rate performance [not available in this version]

Table AIII Results of experiments (E2), (E3) and (E4) for pair-wise relations in average inventory levels performance [not available in this version]

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