Modelling Integration and Responsiveness for Supply Chain

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Modelling Integration and Responsiveness for the Supply Chain

Abstract

A key feature of present day business is the fact that it is the supply chains that compete, not companies and the success or failure of supply chains is ultimately determined in the marketplace by the end consumer. Getting the right product, at the right time to the consumer is not only the linchpin to competitive success, but also the key to survival. Hence, customer satisfaction and market place understanding are critical elements for consideration when attempting to establish a new supply chain strategy. Based on the literature review, survey results, and discussion with experts, causal relationships among supply chain performance variables have been developed. On the basis of these causal relationships, a framework has been modeled using system dynamics approach to capture the dynamic impact of performance variables on the supply chain integration and responsiveness for a period of eighteen months. This framework is useful in analyzing the dynamic impact of different policies towards integration and responsiveness of a supply chain.

Keywords*: Supply chain performance, system dynamics, responsiveness, integration*

INTRODUCTION

A supply chain is the set of structures and processes a company uses to deliver product and services to a customer. It consists of:

(i) stock and flow structures for the acquisition of the inputs to the process, and

(ii) management policies governing various flows of material, information, and ownership.

Managing the flow of material from source to an ultimate customer involves many issues related to design, planning and control of supply chains. Efficient management of these activities offers opportunities in terms of cost and lead-time reductions and improves quality, the latter by employing a unanimous view on quality at the source (Person and Olhager, 2002). Many supply chains are complex systems having high-order, multiple loops, and non-linear feedback structures. Oscillation in order and inventory, amplification in order and expected inventory, and lag in order and material flow are aggregate behavior in these supply chains (Forrester, 1961). These behaviors are understood to occur due to weak supply chain integration and poor responsiveness (Towill, 1997; Christopher, 2000). To understand the effect of integration and responsiveness on the performance of a supply chain, a system dynamics (SD) model has been developed and presented in this paper.

In this paper, initial levels of certain performance variables of supply chain (SC) in fast moving consumer goods were obtained with the help of experts' opinion. After a period of twelve months, levels of these variables were again obtained by taking opinion from the same group of experts. These variables have causal relationships among them. Therefore the level of these variables, after a period of twelve months, can be obtained using system dynamics modeling. No significant difference is observed between perceived and simulated level of SC performance variables, hence the SD model is further used to analyze the variables responsible for SC performance improvement under different scenarios. The objective behind developing the SD model is to derive the learning insights (and not the quantitative estimate) from the causal behavior of variables and its impact on supply chain performance. As suggested by Sterman (2000), these insights are useful as an aid for policy formulation.

IDENTIFICATION OF SUPPLY CHAIN PERFORMANCE VARIABLES

The supply chain under study is a part of a supply chain involved in fast moving consumer goods (FMCG) business. This supply chain consists of FMCG Company, suppliers, and dealers (Figure 1).

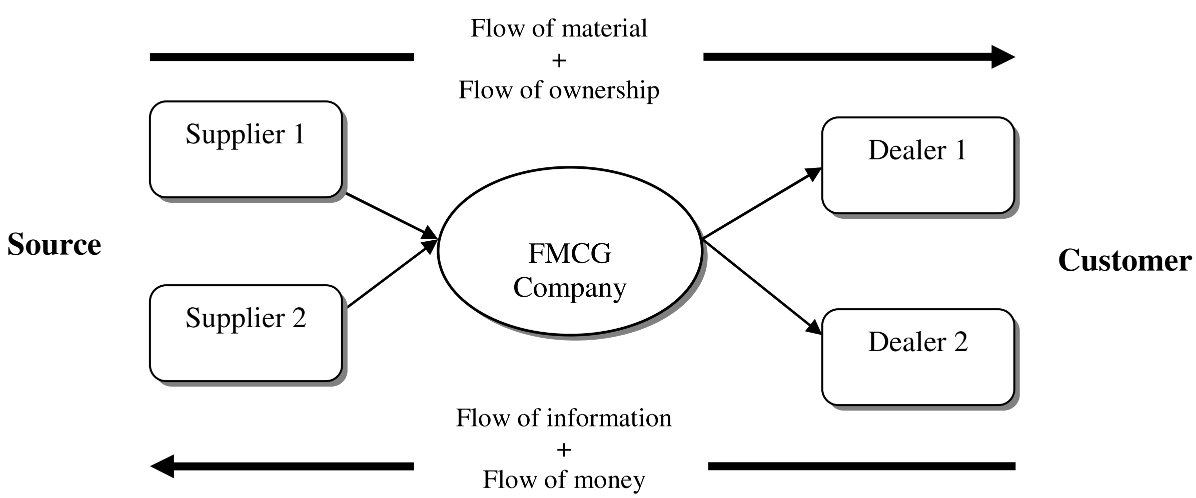

Figure 1: Supply Chain System

The Annual turnover of the company in FMCG business is approximately Rs. 400 crores. The company has single production plant in India with approximately 400 employees. Number of zone-wise suppliers is approximately 50. It has a nationwide network of approximately 800 dealers to facilitate the customers. Its top management is committed for integration of its supply chain. Majority of its dealers are connected to its extranet

These dealers provide real-time information about market conditions and demand. Based on the sales forecast and dealer orders, production plans are formulated. These plans percolate in the supply chain through communication to the suppliers to enable them to plan their production in advance. Latest IT tools such as extranet and e-mails are used to communicate these plans to the suppliers.

In the proposed system dynamics model, to identify supply chain performance variables, and to obtain their initial and expected values, brainstorming sessions were conducted with experts from the trading partners of the supply chain.

Initial meeting was held with the management of supply chain. In this meeting, 5 experts from the company and its trading partners had been identified. These five experts had more than ten years of experience in the area of purchasing and supply chain management. Literature related to responsiveness and integration of supply chain had been circulated among the experts. Within a period of fifteen days, a brainstorming session was organized to identify the variables. In all, twenty-six variables had been identified in this session. The number was reduced to fifteen as some variables were of same nature. The literature related to these fifteen variables had been circulated among the experts. After seven days, a session was organized to establish the causal relationship among the variables. Since the causal relationships among all variables could not be identified in this session, so another meeting was conducted to complete this task. In this meeting, experts were also asked how these variables could be benchmarked.

After five days, the list of variables and causal diagram were circulated among the experts for any further modification. According to experts' opinion causal diagram was reconstructed.

The major purposes of the brainstorming sessions were:

(i) *To develop a causal diagram of the whole supply chain system:* Experts were asked about the causal relationship among variables (how change in a particular variable affects the other variables?). The integrated causal loop diagram of the proposed model reflecting the interactions of the supply chain performance variables is shown in Figure 2.

(ii) *To guesstimate the initial value of enabling and resulting factors:* A complex system like this does not easily yield model parameter values; hence there was a need to take experts' opinion on the initial value of model parameters.

(iii) *To capture experts' expectation on plausible model behavior, which could be used as reference mode for model validation:* Experts were asked to project (estimate) the desired value of different enabling and result variables at the end of twelve months of operation of the supply chain system.

Fifteen supply chain performance variables are considered for developing system dynamics model. These variables are categorized as enablers, results and inhibitors. The seven enabling variables are *market sensitiveness* (*MS*), *process integration* (*PI*), *delivery speed* (*DS*), *centralized and collaborative planning* (*CCP*), *new product introduction* (*NPI*), *data accuracy* (*DA*), and *use of IT tools* (*UIT*). Out of these variables *MS, DS, DA* and *NPI* are responsiveness enablers (RE) while *PI*, *CCP*, and *UIT* are integration enablers (IE).

Five variables have been identified as indicator of outcomes or results. Results are important for the improvement of supply chain performance. It is observed that *lead-time reduction* (*LTR*), *service level improvement* (*SLI*), *cost minimization* (*COM*), *customer satisfaction* (*CUS*), and *quality improvement* (*QI*) are achievable through efficiently managing the IE and RE enablers.

Inhibitor variables reduce the effect of enablers and results on supply chain performance. The identified inhibitor variables are *uncertainty* in the market (*UNC*), *lack of trust* among trading partners (*LOT*), and *resistance to change* among partners as well as among employees (*RTC*).

Improvement in the performance level of enablers helps in achieving better level of results. Inhibitors retard the rate of improvement of enablers and results. However, continuous improvement in the levels of enablers reduces the rate of influence of inhibitors on them. Overall improvement in enablers and results indicates the improvement in performance of the supply chain.

CAUSAL RELATIONSHIPS AMONG SUPPLY CHAIN PERFORMANCE VARIABLES

In a causal loop diagram (Figure 2), the arrows indicate the direction of influence with the plus or minus sign depending upon the type of influence. All other things being equal, if a change in one variable generates a change in the same direction in the second variable relative to its prior value, the relationship between the two variables is referred to as positive. If the change in the second variable takes place in the opposite direction the relationship is negative (Forrester, 1961; Goodman, 1983; Mohapatra *et al.*, 1994). For the proposed SD-model, causal loop relationships among fifteen performance variables are presented in Figure 2.

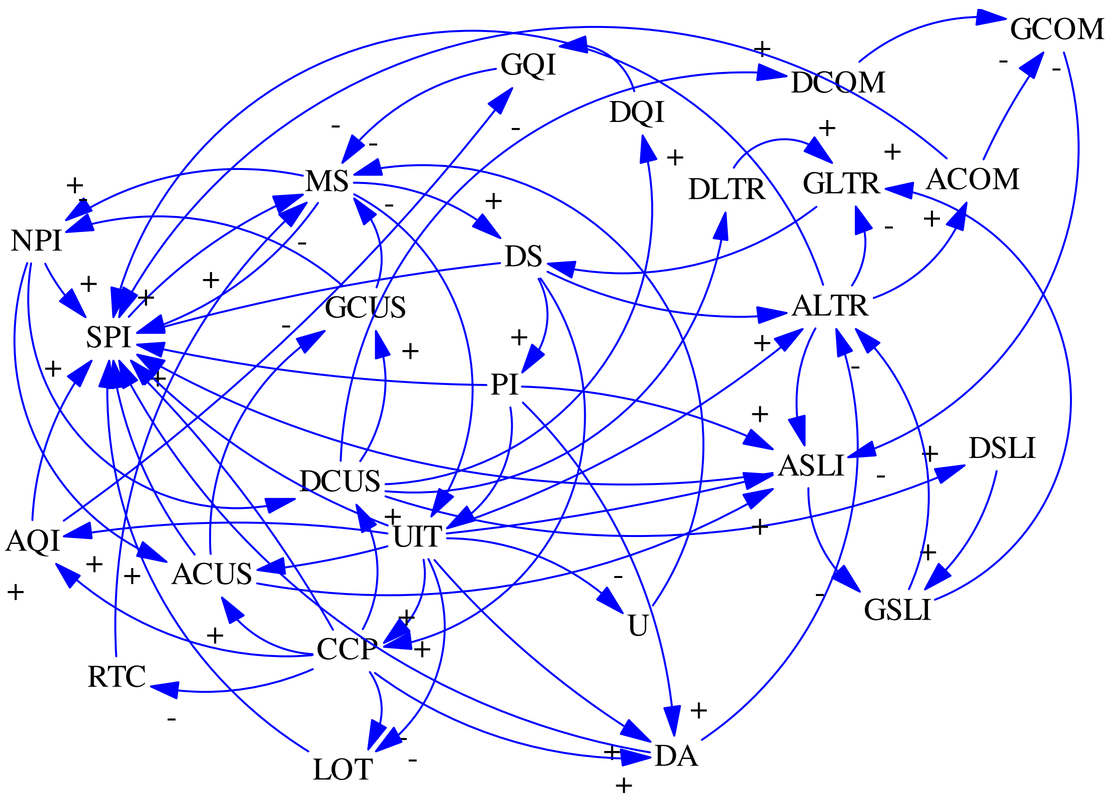

Figure 2: Causal Relationship among Supply Chain Performance Variables

In this figure, one of the responsiveness enablers for supply chain performance improvement is market sensitiveness. Market sensitiveness means that the supply chain is capable of judging and responding to the real demand (Christopher, 2000). Increase in the *market sensitiveness* will improve the supply chain performance. Increase in this enabler also makes an effect on results like *service level improvement, lead-time reduction* and *customer satisfaction*. Present level of *service level improvement* is indicated as 92 units while desired level is of 99 units. Therefore, there is a gap of 7 units in the *service level* *improvement*. Improvements in the level of enablers will minimize the gap, which results in the improvement in Supply-chain Performance Index (*SP Index*). *SP Index*, *gap in lead time reduction* (*GLTR*), *gap in cost minimization* (*GCOM*), *gap in service level improvement* (*GSLI*), *gap in quality improvement* (*GQUI*), *gap in customer satisfaction* (*GCUS*), *actual lead time reduction* (*ALTR*), *actual cost minimization* (*ACOM*), *actual service level improvement* (*ASLI*), *actual customer satisfaction* (*ACUS*), *actual quality improvement* (*AQUI*), *desired lead time reduction* (*DLTR*), *desired cost minimization* (*DCOM*), *desired service level improvement* (*DSLI*), *desired customer satisfaction* (*DCUS*), and *desired quality improvement* (*DQUI*) are the other variables considered in this model. *SP Index* is an additive function.

An increase in *market sensitiveness* rate in the supply chain will increase *new product introduction* (Power *et al*., 2001; Christopher, 2000; Jayaram *et al.*, 1999). Customers are the final judge of how well the organization performs, and what they say counts. It is their perception that will determine whether they remain loyal or seek better providers. An increase in *market sensitiveness* will drive firms to listen to the customers and act quickly on what they say. Dissatisfied customers must be heeded closely, for they often deliver the most valuable information (Christopher, 2000). An increase in *new product introduction* will induce the organization to set high *desired customer satisfaction* goal (Jayaram et al., 1999) which in turn will increase *gap in customer satisfaction*. *Gap in customer satisfaction* is the result of difference between *desired customer satisfaction* and *actual customer satisfaction*. *Gap in customer satisfaction* will also have a positive effect on *new product introduction*.

An increase in *market sensitiveness* rate will have a positive impact on *use of IT tools*, which in turn will have positive relation with *customer satisfaction, lead-time reduction, quality improvement, service level improvement, and cost minimization*. Increase in the level of *desired customer satisfaction* is possible through increase in *desired service level*, assuming same level of actual service level. Increase in *gap in service level improvement* will have effect on gap in *lead-time reduction*, which in turn attempts to accelerate the growth in *SP index*. To remain competitive, it is very important that all trading partners collaborate with each other in the supply chain.

An increase in c*entralized and collaborative planning* will tend to increase *actual quality improvement* in supply chain (Handfield and Pannesi, 1992). *Quality improvement* is very important for the success of any SC. Increase in *actual quality improvement* will tend to increase *SP index*, which will have a positive effect on *market sensitiveness*. Increase in *actual quality improvement* will reduce *gap in quality improvement*, which in turn will have a positive effect on c*entralized and collaborative planning*.

Increase in *use of IT tools* helps to improve *centralized and collaborative planning* among trading partners of a supply chain. Increase in the level of these enabler variables reduces the level of *uncertainty*, *lack of trust*, and *resistance to change and innovation* (Holmberge, 2000; Svensson, 2001; Agarwal and Shankar, 2003, Swaminathan and Tayur, 2003). Decrease in the level of inhibitors accelerates the growth in the levels of enabler, result and *SP index*.

MODEL VALIDATION

Validation of the SD model is necessary to establish sufficient confidence in a model on some chosen criteria. The results of the proposed model are validated for the SC, which incorporates a network of suppliers, company and distributors. The company was doing well in 2003 but it was not able to fully meet the customer demand and gain its market share. Its trading partners did not have significant level of trust among themselves. Resistance to change was another barrier for the trading partners in implementing any new policy to improve its business performance (Agarwal and Shankar, 2002). The management of the company was unable to predict the influence of uncertainty on the performance. The SD model approach appears to be useful for them to capture and analyze the impact of variables on the SC performance. The average levels of the variables to gauge the SC performance for the year 2003 and 2004 are judged by the experts from the trading partners of the SC in fast moving consumer goods business.

In the proposed system dynamics model, initial level of SC performance variables was obtained during a brainstorming session. In this session, experts were asked to judge the present levels of enabler, result, and inhibitor variables for the supply chain on a scale of 1 to 100. Experts were also asked to give their opinion regarding the desired level of variables. Finalization of the levels of the variables could not be completed in one meeting; so two more meetings were conducted. After getting the levels of variables, flow diagram was developed for the proposed model.

The score for each variable was averaged and presented in Table 2. It has been assumed that *SP Index* is an additive function of enabler and result variables and has a maximum score of 1200. The term *SP Index* has been developed to indicate the level of performance status of the supply chain.

The level of the SC performance variables after a period of three months was obtained through SD modeling using *ithink* 7.0.2 software. Results obtained from the simulation were neither shown nor discussed with the experts to avoid any biasness. After a period of three months, all the experts were requested to make judgment related to current levels of the variables. This exercise was carried out to find out the variation between the level of the variables obtained through simulation and the level perceived by the experts. This variation was found to be significant. The values of decision fractions used in the SD modeling were then modified in consultation with experts. The simulated values of levels of variables were compared with judgmental values after a period of five months. After little modification in the values of decision fractions, the variation between the levels of the variables obtained through simulation and the levels judged by the experts after twelfth month was not found as significant. The insignificant variation in these two values (Table 1) validates the proposed SD model.

MODEL RESULTS

The maximum levels of variables are obtained in brainstorming session for the SC, which reflect business performance of the supply chain for the year 2003-2004. The causal relationship between market sensitiveness and other performance variables is presented as a closed loop in Figure 2. On the basis of causal relationship, a system dynamics model is developed.

Table 1: Validation of Results Based on Experts' Opinion and SD Model in the Twelfth Month

Enablers	Initial Levels (at base month)	Desired Levels	Score of variables in the twelfth month		
			Avg. score (Experts opinion)	Results (based on SD)	% Deviation from SD prediction
Delivery speed	89	95	91	90.25	0.82
Data accuracy	95	98	96	95.10	0.94
Centralized and Collaborative Planning	30	70	45	44.18	1.82
Market sensitiveness	60	70	70	69.5	0.71
New product introduction	65	85	69	67.41	2.30
Process integration	60	75	65	61.24	5.78
Use of IT tools	50	85	60	59.28	1.20
Total score of enablers	449	578	496	486.86	1.82
Results					
Cost minimization	73	80	77	76.36	0.83
Customer satisfaction	92	95	93	93.46	-0.49
Lead time reduction	90	98	95	95.54	-0.57
Quality improvement	95	100	97	96.17	0.86
Service level improvement	92	99	95	94.99	0.01
Total score of results	442	472	457	456.52	0.11
Inhibitors					
Lack of trust	25	10	10	20.74	-9.16
Uncertainty	20	10	10	13.62	2.71
Resistance to change	10	5	05	6.10	12.86
Total score of inhibitors	55	25	25	40.46	-1.15
SP Index	891	1050	953	943.48	1.0

Here, for example, the SD equations for *market sensitiveness* are represented in the following set. Here, "*L*" denotes level equations and "*N*" denotes initial value.

L	$MS.L = MS.K + (DT)\,(RMS.\ KL)$
N	$MS = 60$
MS	*Market sensitiveness* (*Units*)
RMS	*Market sensitiveness Rate* (*Units/Month*)

The *rate of market sensitiveness* (*RMS*) during time interval "KL" depends on level of *market sensitiveness, gap in lead time reduction result, gap in customer satisfaction, gap in service level improvement, gap in cost minimization* and *gap in quality improvement.* In the above set of SD equations, "R" denotes a rate variables equation.

It is assumed that the *market sensitiveness* rate depends entirely on the level of *market sensitiveness, gap in lead-time reduction, gap in customer satisfaction, and gap in service level improvement*. Similarly other equations have been developed for other variables.

The base year for the model has been taken as year 2003 when scores are captured for different variables for the supply chain. The simulation time period is 20 months. Rate of improvement in the levels of enablers and results is high during first few months. Later, this rate of improvement decreases. Level of inhibitors also gradually decreases. The decrease in the level of inhibitors is due to improved *process integration, centralized and collaborative planning* and effective *use of IT tools*. As the impact of inhibitors reduces, and the influence of enablers and results increases, *SP Index* gradually improves. Increase in *SP Index* indicates the performance improvement of the supply chain (Figure 3).

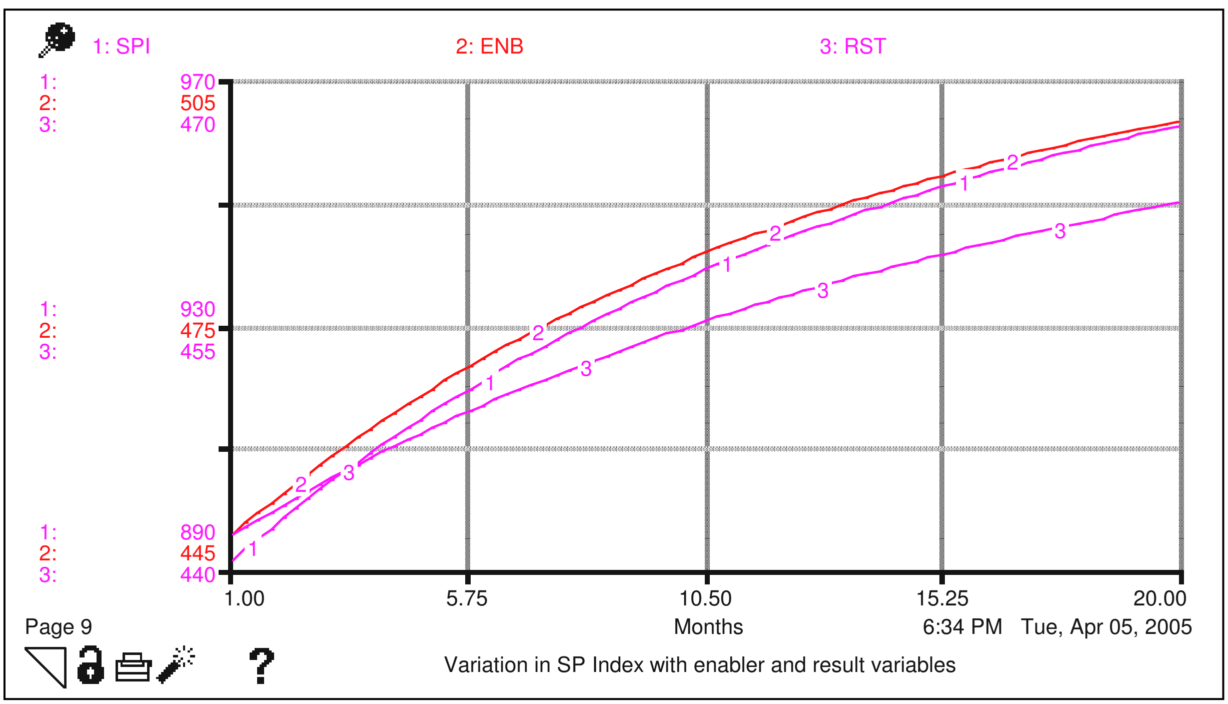

Figure 3: Variation in SP Index, Enabler (ENB), and Result (RST) Variables

MAPPING OF SUPPLY CHAIN

Performance of a supply chain depends on the growth in integrating enablers (IE) and responsiveness enablers (RE) (Agarwal et al., 2005;Gunasekaran et al., 2004). According to its ability to achieve growth in the levels of integrating enabler and responsiveness enabler, supply chains can be put into four categories namely: *laggard, complacent, disillusioned* and *leader*.

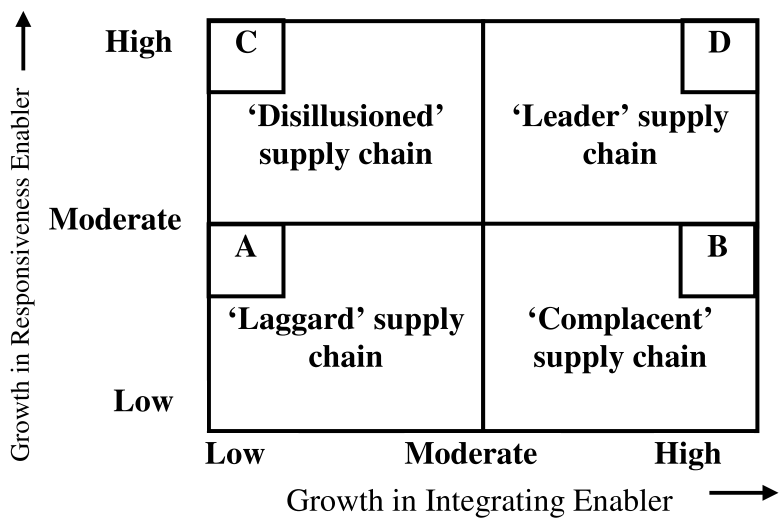

Figure 4: Integrating Enabler – Responsiveness Enabler Grid

These are shown in the integrating enabler– responsiveness enabler grid-graph in Figure 4.

Type 'A': Laggard Supply Chain

The group of supply chains falling under this category is not able to achieve high growth in the levels of integrating and responsiveness enablers, resulting into low growth in results. The *SP Index* of such supply chains does not improve even after a long period.

Under severe competition when there is no protection from customers, the performance of such supply chains crashes to the bottom. These supply chains hardly survive.

Type 'B': Complacent Supply Chain

The group of supply chains that fall in this category is capable of deploying strong integrating enablers for survival and growth. Still these SCs are not able to achieve high responsiveness enablers. The SC is also aware of need to deploy responsiveness enablers, but their inclination is more towards waste reduction, quality improvement, and cost minimization. Normally, such supply chains are able to survive only under protected environment. Despite capabilities to better serve the customers under uncertainty, these are complacent.

Type 'C': Disillusioned Supply Chain

This group of supply chains is capable in deploying strong responsiveness enablers but is not able to deploy strong integrating enablers in supply chains. This appears to be a very temporary but unsustainable phase.

The level of results is high due to high growth in the level of responsiveness enablers. Normally, such supply chains are able to respond to customer demand, but internally these are weak in a volatile market.

Type 'D': Leader Supply Chain

Such group of supply chains is capable in deploying strong responsiveness as well as integrating enablers. Internal integration as well as supply chain capability related to responsiveness is very high. The SC believes in the strategy to implement strong enablers to achieve high results. It has high conviction that there is a direct relationship among enablers, results, inhibitors, and *SP Index*. Management of the SC focuses on integrating enablers like use of advanced IT tools for information sharing across the supply chain, and also believes that this is only a first step towards improving performance. There is no quick way to achieve the high performance level. Such supply chains have high top management commitment. There is a total involvement of each and everyone in the supply chain to achieve the performance maturity level to sustain the survival and growth.

The model helps the companies to take policy decisions arising out of the dynamic nature of the system. Therefore, policy experimentation and scenario analysis are undertaken to see the effect of different scenarios. The results of these experimentations and scenario analysis may help the companies to take timely action in unfavorable scenario to avoid adverse effect on the performance. Policy experimentation and scenario analysis have been attempted for deriving better insight so that timely actions can be taken to bring supply chain on a right path of performance journey.

POLICY FORMULATION

Experimentations have been conducted for the sub-models depicted in Figure 5. The first sub-model deals with situation when growth in the levels of integration, as well as responsiveness enablers is low. In second sub-model, effect of high growth in the level of integrating and responsiveness enablers has been analyzed. Third sub-model describes the effect of low growth in the level of integrating enablers and high growth in responsiveness enablers on supply chain performance. Forth sub-model analyzes the effect of high growth in integrating enablers and low growth in responsiveness enablers.

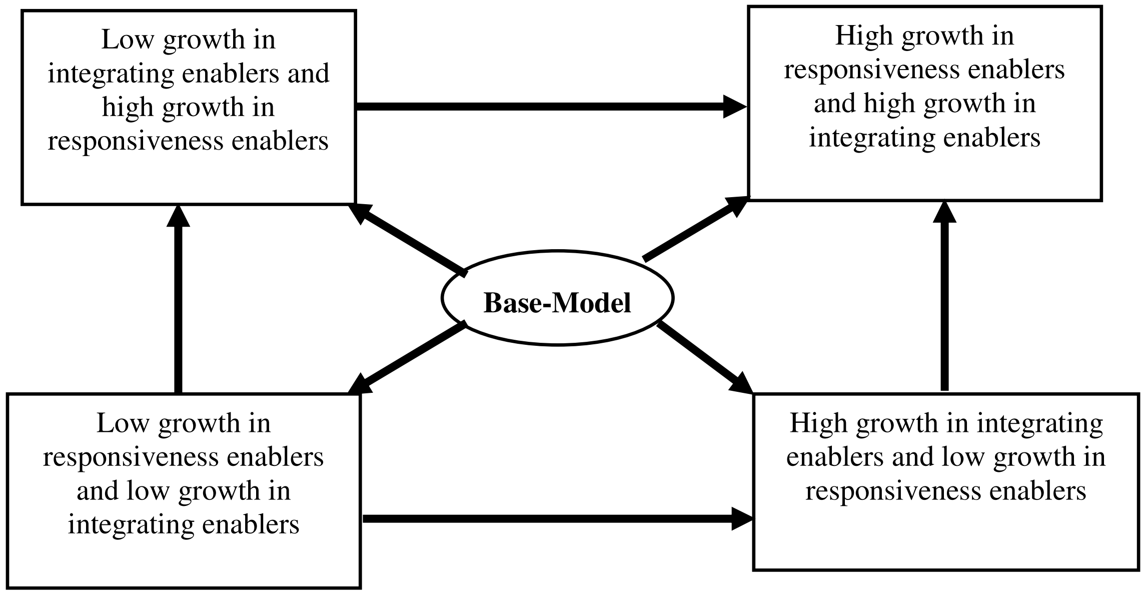

Figure 5: Framework for Policy Experimentation

The objective of these models is to get insights for making policy formulation to improve *SP Index* of the supply chain under consideration (Mohapatra et al., 2000). Results obtained from SD modeling analysis are displayed in Table 2. Second column of the table shows the desired percentage improvement in the level of *SP Index* compared to the level at base month in year 2003. Third and forth columns indicate the percentage improvement required in IE level and the percentage improvement required in RE level respectively. Third and forth columns show the alternative policy to achieve the desired target range of corresponding second column. For example, if management wants to improve the *SP Index* level by 3% from its initial level, the proposed SD model provides three alternative policies to bring the *SP Index* to the desired level (Table 2). Similarly, many such combinations may be evolved.

(a) By Improving the Levels of IE by 3.9% and RE by 5% from their Initial Levels

Incremental change in the levels of *CCP, PI,* and *UIT* have been made to improve the level of *IE* by 3.9 % while the levels of performance variables like *MS, DS, DA* and *NPI* have been changed to improve the level of *RE* by 5% from its initial level. Simulation results indicate that with 3.9% growth in IE and 5% growth in RE, desired improvement in the level of *SP Index* up to 3% could be achieved.

(b) By Improving the Levels of IE and RE by 7.7% and 3.1% from their Initial Levels, respectively

Levels of variables like *CCP, PI* and *UIT* have been incrementally changed to improve the level of *IE* by 7.7%. Similarly, incremental change in the levels of *MS, DS, DA* and *NPI* has been made to improve the level of *RE* by 3.1%. With these growths in IE and RE, desired improvement in the level of *SP Index* (up to 3% from its initial level) can be achieved.

Similarly under alternative policy (c), desired level of *SP Index* is achieved by making incremental changes in the levels of *IE* and *RE* variables.

(c) By Improving the Levels of IE and RE by 11.7% and 1.2% Times from their Initial Levels, respectively.

The policy formulation helps to derive insight that desired percentage improvement in SP Index (up to 3%) can be achieved with higher growth in the level of IE (11.7%) and comparatively lower growth in the level of RE (1.2%). The desired percentage improvement up to 3% can also be achieved with lower growth in the level of IE (7.7%) and higher growth in the level of RE (3.1%). Therefore, relative influence of change in the level of IE and RE on *SP Index* can be analyzed for making policy for the supply chain under consideration.

Table 2: Alternative Policy for Improving the Level of *SP Index*

S.N	Range of *SP Index* Improvement Level (L) (%)	Alternate Policy for Improving *SP Index*	
		IE Improvement level (%)	RE Improvement level (%)
1	3.0<L<0.0	3.9	5.0
		7.7	3.1
		11.7	1.2
2	6.0<L<3.0	11.8	10.2
		15.7	8.2
		19.8	6.3
3	9.0<L<6.0	28.1	10.6
		32.3	8.6
		36.6	6.7
4	12.0<L<9.0	32.3	10.7
		36.6	8.7
		40.9	6.7

Results provide learning insights to the management of the supply chain to take strategic policy decision for its performance improvement. Using SD modeling result, management can analyze the impact of varying growth in responsiveness level and integration level. The simulation results for the considered model indicate that influence of growth in integration level is more significant on *SP Index* than that of responsiveness.

SENSITIVITY ANALYSIS

The proposed SD model provides an aid to management in policy formulation for improvement in *SP Index* of the supply chain. The effect of change in the levels of RE and IE on *SP Index* can be captured through the SD model by varying the growth in the level of one type of enabler with negligible growth in other type of enabler. Simulation results from the SD model show that the increase in the level of *SP Index* is less sensitive to the changes in level of RE (Figure 6 and Table 3).

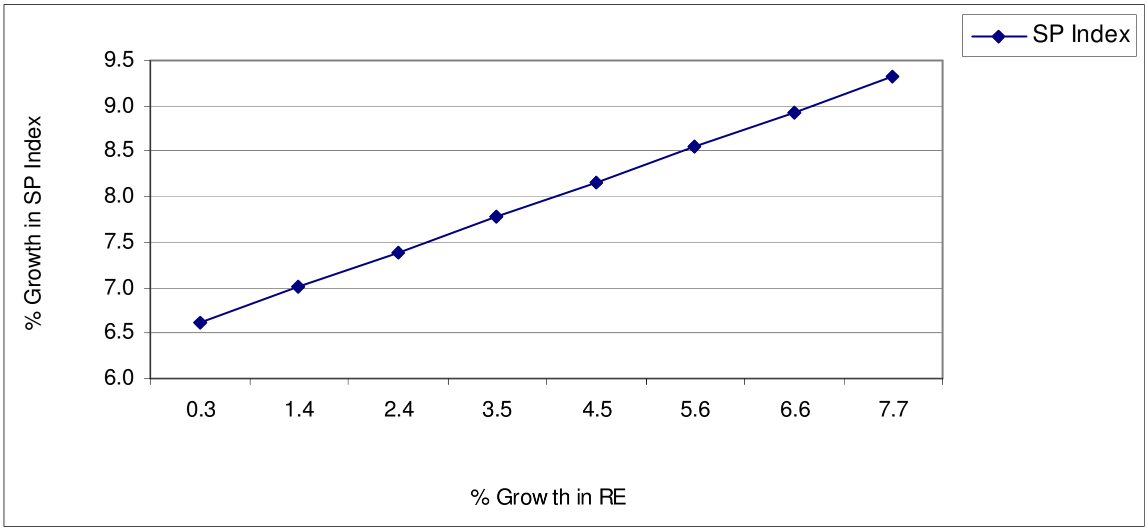

Figure 6: Growth in the Level of SP Index with Incremental Growth in the Level of Responsiveness Enabler (RE) and Constant Growth in the Level of Integrating Enabler (IE)

Table 3: Growth in the SP Index with Incremental Growth in the Responsiveness Enabler (RE) at Constant Growth in the Integrating Enabler (IE)

S.N.	Incremental Growth in the Level of RE		Constant Growth in the Level of IE		SP Index	% Increase in SP Index	Remark
	RE	% Increase in RE	IE	% Increase in IE			
1	309.00	-	140.00	-	851.00	-	Base Model
2	310.00	0.32	147.62	5.44	907.38	6.63	With incremental growth in the level of RE and constant growth in the level of IE significant growth up to 9.3 % in the level of SP Index has been observed. Growth in the level of RE can be only achieved up to 7.7 % at 5.4-5.5 % constant growth in IE.
3	313.22	1.37	147.63	5.45	910.63	7.01	
4	316.45	2.41	147.64	5.46	913.89	7.39	
5	319.70	3.46	147.65	5.46	917.16	7.77	
6	322.95	4.51	147.66	5.47	920.45	8.16	
7	326.23	5.58	147.67	5.48	923.75	8.55	
8	329.51	6.64	147.69	5.49	927.06	8.94	
9	332.81	7.71	147.70	5.50	930.38	9.33	

It has been observed from Figure 7 that increase in *SP Index* level is sensitive to the changes in level of IE (Table 4).

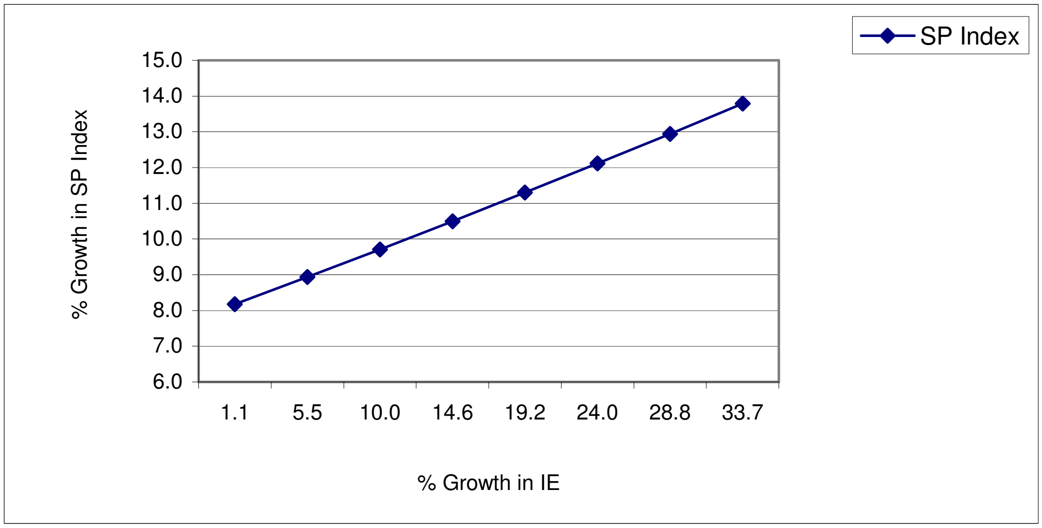

Figure 7: Growth in the Level of SP Index with Incremental Growth in the Level of Integrating Enabler (IE) and Constant Growth in the Level of Responsiveness Enabler (RE)

Table 4: Growth in the SP Index with Incremental Growth in the Integrating Enabler (IE) at Constant Growth in the Responsiveness Enabler (RE)

S.N.	Incremental Growth in the Level of IE		Constant Growth in the Level of RE		SP Index	% Increase in SP Index	Remark
	IE	% Increase in IE	RE	% Increase in RE			
1	140.00	-	309.00	-	851.00	-	Base Model
2	141.52	1.09	329.32	6.58	920.61	8.18	With incremental growth in the level of IE and constant growth in the level of RE significant growth up to 13.8 % in the level of SP Index has been observed. Growth in the level of IE can be achieved up to 33.7 % at 6.6-7.0 % constant growth in RE.
3	147.69	5.49	329.51	6.64	927.06	8.94	
4	153.97	9.98	329.71	6.70	933.63	9.71	
5	160.37	14.55	329.90	6.76	940.32	10.50	
6	166.90	19.21	330.10	6.83	947.14	11.30	
7	173.55	23.96	330.30	6.89	954.08	12.11	
8	180.32	28.80	330.50	6.96	961.15	12.94	
9	187.21	33.72	330.70	7.02	968.35	13.79	

LIMITATIONS OF THE MODELS

SD models are developed to derive insights related to implications of different scenarios and policies (Sterman, 2000). The numerical values are only indicators of the situation. Proper benchmarking and scaling have not been carried out in this research. The model is specific to a particular supply chain. The values are captured after discussing with managers. However, there may still be gap in making them understand the model, scale of measurement etc.

However, since the insights are quite generic and carries a lot of meaning for practicing managers, this research has been attempted in this paper.

DISCUSSION

One of the main purposes of system dynamics is to model the ways in which its information, action and consequences components interact to generate dynamic behavior. The results of the system dynamics model show that the supply chain performance index improves as the level of integrating and responsiveness enablers improves. The advantages of using simulation are to test proposed SD model for different levels of RE and IE under different scenarios. The causes of faulty behavior can be easily diagnosed and feedback loops can be tuned to obtain better behavior. The management group can derive insights from the simulation results and take policy decisions for supply chain performance improvement.

From Figure 3, it has been observed that the levels of *SP Index* and enablers for the supply chain initially improve during first and sixth month. This improvement is a result of management efforts towards supply chain integration. In integrated supply chain, all trading partners work with common goal and interact with each other. Frequent interaction among them reduces the influence of inhibitors like *lack of trust, resistance to change and innovation,* and *uncertainty*. Trading partners are involved at planning stage of product development. Clear picture of customer demand is available to all trading partner; therefore they act on the same data set. These, in turn, enhance the responsiveness of the supply chain. Improvement in the level of enabler results into reduction in lead-time, improvement in service level, cost minimization, quality improvement, and customer satisfaction. During ninth and thirteenth month, rate of improvement in enabler and result is slower than the earlier months, which may be due to arrival of new competitors and enhanced desired value of customer satisfaction.

Table 2 displays four desired ranges of *SP Index* for which management of the supply chain wants to formulate policy. From the results, it has been observed that the desired range of *SP Index* could be achieved by varying the growth in responsiveness enabler and in the integrating enabler. Figures 6 and 7 illustrate that change in the rate of *SP Index* is slightly more sensitive towards growth in integration level as compared to growth in responsiveness level of the SC.

CONCLUSIONS

A system dynamics model has been developed to understand the behavior of RE and IE on the performance improvement of a supply chain involved in fast moving consumer goods business. Supply chain performance Index (*SP Index*) is a measure of performance level of the supply chain and is an additive function of certain variables. The simulation has been carried out for a period of eighteen months to capture the influence of RE and IE on *SP Index*. Result from SD model shows that though both responsiveness and integration are important for improving *SP Index* of the supply chain but high growth in integration level significantly influences the *SP Index* of the supply chain. High growth in integration level can be achieved through strategic partnership, process integration, centralized and collaborative planning and use of IT tools. System dynamics model developed in this paper is based on causal relationship among performance variables for the supply chain. Causal relationships among variables have been established in a brainstorming session. These relationships are generic in nature and are well-established statements in the literature on supply chain. According to Lalonde and Masters (1994), a supply chain can only succeed if all the members of the supply chain have the same goal and the same focus of serving customers. Establishing the same goal and the same focus among supply chain members is a form of policy integration.

The primary purpose of developing a SD model is to develop an understanding that provides insight into the system and helps solve important problem (Sterman, 2000: page 850). Insights are important in such models rather than numerical values of variables. The model can predict the rate of improvement of different performance variables based on their specific strengths and gaps. The SD model helps managers to get insight for continuously monitoring the performance and taking corrective measures on problem areas. Therefore, SD model presented in this paper helps management to understand the implication of interdependence of variables on supply chain performance, which is the goal of every member in the supply chain. The model recommends dedicated focus on the improvement in the integration level of supply chain along with reinforcement in the responsiveness capability for creating value for the ultimate customer.

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