

Designing Sustainable Supply Chain under Innovation Influence

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Abstract: The supply chain is increasingly becoming a source of competitive advantage. Supply chain innovations combine developments in information and related technologies with new logistic and marketing procedures to improve operational efficiency and enhance service effectiveness. This paper aims at assessing the sustainable supply chain and innovation management. The supply chain model presented as a complex system and innovations of each components were considered. Mathematical model that allows to estimate the influence of each supply chain system component to the system sustainability, its functioning and failure was presented.

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1. INTRODUCTION

The supply chain is increasingly becoming a source of competitive advantage. Firms have created superior firm performance at least in part through rivals via unique supply chain capabilities. These firms' successes highlight the use of a critical intangible resource, namely, innovations in supply chain management. Supply chain innovations combine developments in information and related technologies with new logistic and marketing procedures to improve operational efficiency and enhance service effectiveness. Innovations include efficient consumer response, continuous replenishment, automated ordering utilizing scanner data, and many other technology-enhanced processes and procedures in the out-bound supply chain. Importantly, these innovations consist of allocating new investments and activity sets to channel participants to maximize joint profit by reducing costs through greater operational efficiency and by increasing revenue through greater service effectiveness.

Innovation is a complex process as it normally involves many different functions, actors and variables. It comprises a whole sequence of events that occur over time and which involves all the activities of developing a new product/service or process. The development of innovation requires time for organisations and individuals to gain capability, experience, knowledge and information. It is a cumulative and evolutionary process (Clarke and Juma, 1987).

Innovation is increasingly defined as the interaction of the dynamics of the process, the firm and the environment in which the firm operates. Its development depends on feedback mechanisms between external environments and technical developments (Freeman, 1987). Innovation is increasingly generated by networks of relationships between firms, sub-contractors and government institutions rather than just within organisations (Cooke et al., 2000).

The paper is organized as follows. Section 2 discusses what supply chain innovation is in the state of the art. Section 3 presents the supply chain model formulation as a complex system, and here we focus on the following components: human, organisational and technological components. Section 4 analyses innovations in each component, section 5 presents

mathematical model that allows to estimate the influence of each supply chain system component to the system sustainability, its functioning and failure. Section 6 concludes the paper with limitations and future research opportunities.

2. LITERATURE REVIEW

The prior literature discusses innovations in channel relationship that always focus on advance information systems or IT improvement. Recently, the researchers begin to concentrate on creating value-adding innovation and how to make full use the resource, because of its relation to both the supply chain process and to business performance (Kim et al., 2006). Central to this theme is the need for firms to look outside of their organizations for opportunities to collaborate and coordinate with partners to ensure that their supply chain is both efficient and responsive to dynamic market needs. Kim et al. (2006) confines the scope of inter-firm systems integration to important collaborative channel activities, such as planning and forecasting with other channel members. The essential parts of collaborative planning, forecasting, and replenishment activities have been discussed recently in supply chain literature. In a study by Anantaram and Joseph (2004), for instance, they propose that such collaboration and coordination opportunities introduce new challenges and complexities as a result of the potentially conflicting incentives among different supply chain players. Motivated by these new challenges, our study explores a range of coordination and collaboration problems, stressing the role of information and associated technologies in facilitating and enabling supply chain integration. It emphasizes the importance of the innovation in channel integration between supply chain partners as they work together to co-create new customer value.

The significance and influence of interactions and feedback mechanisms on the development of innovation are largely explored in the literature, which has shifted the debate from an emphasis on internal structure to external linkages and processes (Tidd et al., 1997; Harland et al., 1999). These external linkages are increasingly being used as a rapid response to fast changing needs through the pooling of resources and the sharing of risk. This type of innovation can be seen as a way to deal with growing uncertainty, complexi-

ty and competition, and to facilitate learning and further innovation. It can be described as a collective process which depends on many different interactions and relationships between an organisation and its external environment, and which includes suppliers, customers, training bodies and government agencies (Gann and Salter, 2000).

3. MODEL FORMULATION

Innovation is a fundamental pillar upon which competition is built and an essential component of policies seeking best practices. The outputs of innovation directly affect productivity. On the global scene, rate of innovation is considered a major driver of competitiveness (Porter and Stern, 1999). Innovation can be defined as follows: (i) the renewal and enlargements of the range of products and services and the associated markets; (ii) the establishment of new methods of production, supply, and distribution; (iii) the introduction of changes in management, work organization, and the working conditions and skills of the workforce (European Commission, 1996). Continuous improvement, learning, problem solving, product development are all among the capabilities needed to be developed to execute successfully the policies suggested by the companies. These capabilities can only be nurtured in an environment open to innovation.

Sustainable supply chain system can be considered as complex system that includes four components of different types (Fig. 1): hardware, software, human factor and organization factor. In the paper have been shown that hardware and software components unite in one component for SC model. This component is named as technological component. The human and organization factor have been interpreted as two components.

It is true that innovation needs an environment conducive to innovation, but still the main drivers of innovation are the employees themselves. Thus, the main resource driving the companies' innovation strategies is their human capital.

4. INNOVATIONS

4.1 Human Component

In this section, we will concentrate on issues of human resource management, training and development of employees, and employee satisfaction.

Human resources management. An uncountable number of sources discuss the importance of human resources for competitiveness and conclude that human resources are at the centre of global competition. The Competitiveness Advisory Group (1999) state, for example, that the most radical change in the competitive environment and the structure of the firm, in Europe and worldwide, is the shift in paradigm toward the centrality of knowledge and intellectual capital. Keywords like problem solving organization and learning organization are cited frequently, and all have human factor at the centre. The study reveals the lack of an organization-wide training and development process, including career path planning; and employee relations.

Training and development of employees. The rapid pace of change in technology, products, and markets makes training a necessity for the companies. Organizations need to invest more in developing their own people since it is indeed difficult to recruit good quality personnel. Performance measures employed for evaluating training activities in companies are several. It can be number of hours of training per employee annually, or the annual cost of training as a percentage of the employee payroll. The second performance measure needs precise definition in order to be employed as a benchmark. For example, the payroll cost of the hours spent by the employees in training is not included in the cost of training. Also, whenever training is performed by company employees other than the trainers on the payroll of the company, no trainer cost is added to the cost of training but still this performance measure provides useful insight.

Employee relations. An area of major weakness in employee relations is the lack of a formal and regular process for the measurement of employee satisfaction. Employee morale is an indicator of employee satisfaction. Less than half of the

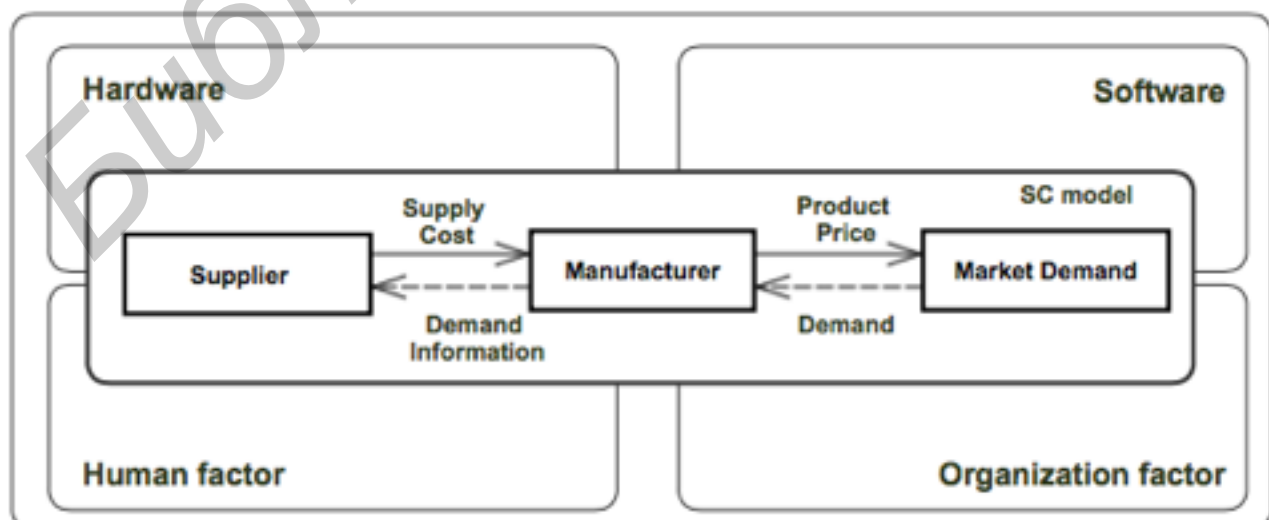


Fig. 1. The Supply Chain Model as a Complex System

companies in the overall sample reported high levels of employee morale. Companies need to introduce some formal mechanism for measuring employee satisfaction. An important result in this context has been reported earlier (Ulusoy and Ikiz, 2001). Two areas open for improvement are employee involvement in quality activities and delegation of work to operators, which can be considered a form of employee empowerment.

4.2 Technological Component

In this section we will consider technology strategy, technology monitoring and intelligence and technology acquisition and exploitation.

Technology strategy. In the literature, numerous approaches for the management of technology are discussed. These models aim to position technology strategy into the overall framework of competitive strategy. With the technology intensity increasing in all sectors of the economy, the successful integration of technology planning with business planning gains in importance for business success. One of the five technology planning best practices reported by Metz(1996) is to establish a structured process for technology planning. Among the automotive p&c suppliers surveyed, the proportion of companies reporting that they have a systematic process for technology planning and strategy development is only 33%. This fact indicates to a major weakness in that respect.

Technology monitoring and intelligence are important activities to secure the survival of the company. Most companies strongly emphasize that they monitor the developments in the field of their existing technologies. Companies strongly emphasize that they monitor technologies planned for future. The ratio of companies that monitor the technologies of competitors is substantially lower. With respect to relative frequency of usage and benefit, customers and product benchmarking appear to be the top two knowledge sources. Universities, professional associations, consulting companies, and disclosed patents turn out to be the least frequently used sources of knowledge.

Technology acquisition and exploitation. To a great extent, companies exploit the technologies available in their stock internally and although many companies have developed their own technological competencies, they lack experience in the external exploitation of these. The intensity level of technology transfer activities is very low. Just like in the case of technology acquisition, the highest rate of technology transfer is achieved through the mobility of qualified personnel. Equipment sale and providing consultancy services follow as the next more popular means of technology transfer. It appears that the greatest impact of new technology on operational results comes mostly as reduction in the production cycle time and as increase in the manufacturing capacity and conformance quality.

4.3 Organizational Component

This section is devoted to good design practice and new product ideas.

Good design practice is the key to manufacturing. Flexibility and cost of a product are determined largely by design. What

is meant by flexibility here is the ability to reconfigure the product easily; to change the design easily. For a flexible design, number of parts needs to be kept at minimum; the design of the parts and components should minimize the need for jigs and fixtures so that no special tooling is needed when a part or component is redesigned.

New product ideas. Top management conceives product innovation as a strategic issue to be closely monitored. Although the intensity of R&D activities in these firms is rather low in general, the fact that R&D Department is perceived as a major source of new product ideas indicates to an important function of R&D Departments; namely, to serve as a product innovation gate for their companies.

In a study conducted among the largest companies in Europe (MERIT, 1996), the most important external source of technical knowledge for innovative activities in the company turned out to be the technical analysis of the products of the competitors, i.e., product benchmarking. Customers and suppliers follow as the next most utilized sources.

Market related risks, high innovation costs, pay-off period of innovation being too long and lack of appropriate sources of finance are cited by the companies as the major obstacles to innovation activities. [6]

5. RESEARCH METHODOLOGY

5.1 Background and mathematical model

The main objective of the research methodology is that it helps in determining the best supply chain scenario that will enable sustainable supply chain performances for given circumstances. Supply chain system is a typical complex system, which is characterized by its components. In our context we consider suppliers as components of supply chain. To analyze sustainability and reliability we propose to consider supply chain model as multiple state system (MSS). MSS is mathematical model in reliability analysis that is used for description system with some (more than two) levels of performance (availability, reliability). MSS allows presenting the analyzable system in more detail than traditional Binary-State System. We use reliability analysis of MSS developed by Zaitseva (2006).

In MSS is proposed, that system model for reliability analysis consist of n components. The system components are denoted as x_i ($i = 1, \dots, n$). A system and its every component have two states of efficiency: “zero” designates system or component failure (is not working) and state “one” declares of working of system or its component. The system reliability (system state) is depend of its components efficiency and is defined by the structure function:

$$\varphi(x_1, \dots, x_n) = \varphi(x): \{0, 1\}^n \rightarrow \{0, 1\} \quad (1)$$

Every system component x_i is characterized by probability of the performance rate:

$$p_i = Pr\{x_i = 1\} \text{ and } r_i = (1 - p_i) = Pr\{x_i = 0\} \quad (2)$$

Definition of structure function (1) it is well known as definition of Boolean Function (Ushakov 1994, Shooman 2002, Ryabinin 2004). This condition permits to use tools of Boolean Function analysis for the structure function measure. The dynamic properties of Boolean Function are revealed through

Logic Derferential Calculation (Bochmann & Posthoff 1981). Therefore this tool can be use for analysis of dynamic properties of structure function too.

MSS probability state, $R(j)$, is one of the best known MSS reliability measures [12]. It is the probability that system performance level is equal to the level j :

$$R(j) = Pr\{\varphi(x) = j\}, j \in \{0, 1, \dots, m-1\}. \tag{3}$$

Probability states (1) don't enable the analysis of the change in system reliability that is caused by a change in component states. Importance analysis of SC system allows estimating the influence of every system component state changes to system performance. Consider some of importance measures and their calculation by Direct Partial Logic Derivative.

Structural Importance (SI) is one of the simplest measures of component importance and this measure is concentrated on the topological aspects of the system. According to Zaitseva (2011) this measure determines the proportion of working states of system in which the working of the i -th component makes the difference between system failure and its working. SI of MSS for the i -th component state s is probability of this system performance level j decrement if the i -th component state changes from s to $s-1$ depending on topological properties of system:

$$I_S(s_i|j) = \rho_i^{s,j} / m^{n-1}, \tag{4}$$

where $\rho_i^{s,j}$ is number of system states when the change component state from s to $s-1$ results the system performance level decrement and this number is calculated as numbers of nonzero values of Direct Partial Logic Derivatives (4).

There is one more definition of SI. It is modified SI that represent of the i -th system component state change influence to MSS performance level decrement for boundary system state. In terms of Direct Partial Logic Derivatives (4) modified SI is determined as:

$$I_{MS}(s_i|j) = \rho_i^{s,j} / \rho_i^{(s,j)}, \tag{5}$$

where $\rho_i^{s,j}$ is defined in (4), $\rho_i^{(s,j)}$ is number of boundary system states when $\varphi(s_i, x) = j$ (it is computed by structure function (1)).

Modified SI I_{MS} is probability of MSS performance decrement depending on the i -th component state change and boundary system states. A system component with maximal value of the SI measure (IS and IMS) has most influence to MSS and this component failure causes high possibility of MSS failure (Zaitseva, 2011).

SI and modified SI measures don't depend on components state probability (2) and characterize only topological aspects of MSS performance. These measures are used for prevention system analysis or reliability analysis in step of a system design previously.

5.2 Example of importance analysis

Consider the SC system in Fig. 1. The structure function of such system is declared based on an expertise for every real system. This function is defined based on the expert knowledge and influence form the area of the system application. For example, the Decision Support System has structure

function (1). The MSS mathematical model of this system has three levels of performance ($m = 3$) and four components ($n = 4$). The system component state 0 considers to the component failure; the component state 1 is component functioning with some unimportant restriction; the component state 2 is perfect functioning. The component probabilities in Table 1 have been determined for this system by the expertise.

Table 1. Component state probability

	m	0	1	2
i				
1		0.1	0.2	0.7
2		0.1	0.4	0.5
3		0.2	0.4	0.3
4		0.3	0.5	0.3

So the system state probabilities (1) for this SC system are calculated based on component probabilities in Table 1:

$$R(0) = p_{1,0} + (p_{1,1} + p_{1,2}) \cdot p_{2,0} \cdot (p_{3,0} + (p_{3,1} + p_{3,2}) \cdot p_{4,0}) = 0.137,$$

$$R(1) = (p_{1,1} + p_{1,2}) \cdot p_{2,0} \cdot (p_{3,1} + p_{3,2}) \cdot (p_{4,1} + p_{4,2}) + p_{1,1} \cdot (p_{2,1} + p_{2,2}) + p_{1,2} \cdot p_{2,1} \cdot (p_{3,0} + p_{3,1}) \cdot (p_{4,0} + p_{4,1}) = 0.488,$$

$$R(2) = p_{1,2} \cdot p_{2,1} \cdot p_{3,2} \cdot p_{4,2} + p_{1,2} \cdot p_{2,2} = 0.375$$

Therefore the performance level 1 of the SC system is more probably than system perfect functioning (the performance level 2) and system failure that have probabilities 0.137 and 0.375 accordingly.

Table 2. Importance measures for the system

i	1	2	3	4
Importance measures				
$I_S(x_i 1)$	0.222	0.123	0.049	0.049
$I_S(x_i 2)$	0.123	0.099	0.025	0.025
$I_S(x_i)$	0.173	0.111	0.027	0.027
$I_{MS}(x_i 1)$	1	0.588	0.308	0.308
$I_{MS}(x_i 2)$	1	0.889	0.400	0.400
$I_{MS}(x_i)$	1	0.739	0.354	0.354

Importance measures of this system are in Table 2. According to data in Table 2 case the first system component change has maximal influence to the system reliability. Therefore correct functioning of special devices is important condition for reliability of the SC system with structure function (1). But need to say that the modification of the structure function of this system causes change of the importance analysis result. The positive result of importance analysis will be obtained based on investigation of some structure function of this system.

The impediment for this analysis is caused by generation of structure function based on expert knowledge only that is subjective.

6. CONCLUSIONS

In this study, we find further evidence supporting the argument that network structures and relationships that form supply networks are critical components for identifying strategic imperatives in supply chain management (Borgatti and Li, 2009; Kim et al., 2011). The paper contributes to a better understanding of the concepts of innovation and of related issues in designing sustainable supply chains. In this paper an integrated methodology is developed that guides companies in determining and managing innovations in designing sustainable supply chains. Our findings suggest improved knowledge and information flows arising from supply network accessibility influences a firm's innovation output. We proposed innovation analysis to use for MSS reliability estimation depending on the system structure and its components states. Importance measures are widely used as tools for identifying system weaknesses, and to prioritize reliability improvement activities. The results also indicate that the research framework supports the analysis of supply chain's innovations, and helps in finding and categorizing disturbances, vulnerability sources and appropriate design principles and strategies. Additionally, the results show that firm's performance can be enhanced by the innovation influence of the three supply chain components. In sum, the study contributes to the body of literature on both supply chain management and innovation management by highlighting the role of the structural characteristics of supply networks.

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