System Dynamics as a tool for Green Supply Chain Management: A Theoretical Ransom

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Abstract

Under sustainable development pressures, organizations have to consider the relationship between the environment and activities of supply, production, distribution, consumption and disuse, which is known as "green supply chain management" (GSCM). The article presents an overview of research work in these areas, followed by an introduction of the green concept in SCM resorting to System Dynamics (SD). The research method was based on an extensive literature review to describe the simulation-based framework of SD modeling. Simulation approach enables performance to be analyzed from a variety of organizational perspectives. There is a critical need for gaining a deeper understanding of the impact of decisions on operations; it is a conclusion of the study. Simulation has been found to be one of the popular and suitable mechanisms for understanding Supply Chain Dynamics.

Keywords: Green Supply Chain Management. System Dynamics. Theoretical Ransom

1. Introduction

System Dynamics (SD) was conceptualized by Jay Wright Forrester, professor of the Massachusetts Institute of Technology, during the mid 1950s. The objective of this methodology and computer simulation modeling technique was to help corporate managers improve their understanding of industrial processes where variables are associated to a system that is considered to be dynamic in nature (one that owns an ever-changing attribute). A significant characteristic of the SD approach is that it monitors and interprets a given system over a period of time, and combines various theories, techniques, and philosophies that aid in providing effective framing, understanding and discussing the behavior exhibited by management systems (Forrester, 1989; Radzicki & Taylor, 1997).

Numerous problem areas come under the scope of applications of SD like studies in corporate planning and policy design (Forrester, 1958, 1961, 1969, 1973; Lyneis, 1980), economic behavior (Sterman et al., 1983), public management and policy (Forrester, 1969; Homer & St. Clair, 1991), biological and medical modeling (Hansen & Bie, 1987), energy and the environment (Ford & Lorber, 1977), theory development in the natural and social sciences (Dill, 1997). Other known applications are dynamic decision making (Sterman, 1989, 2001; Morecraft, 2008), complex non-linear dynamics (Mosekilde et al., 1991), software engineering (Abdel-Hamid, 1984), and supply chain management (SCM) (Towill, 1996; Barlas & Aksogan, 1999; AkkermaN et al., 1999).

There is a growing need for integrating environmentally sound decisions into SCM research and practice. Perusal of the literature shows that a broad frame of reference for green supply-chain management (GSCM) seems to be not adequately developed. Regulatory agencies that formulate regulations to meet societal and ecological concerns to facilitate the growth of business and economy also suffer from its absence. A succinct classification to help scholars, researchers and practitioners to understand the integrated GSCM from a wider perspective is needed.

The paper takes an integrated new looking into the area of GSCM that is covered exhaustively from its conceptualization, primarily taking a 'reverse logistics angle'. A review of the literature was adopted as the research method.

2. Emergence of Green Supply Chain Management

SCM comprises all steps involved in the process of goods distribution to clients/consumers. Therefore, co-ordination across multiple channel partners in the chain is required. The criticality of this management function is evident from the fact that the supplying process begins with raw materials sourcing, proceeds towards the manufacturing/assembling of parts, requires the selection and tracking of distribution channels, and ends at a final client/consumer by delivering a product to him/her- what accounts for 10.15% of product costs (Viswanadham & Gaonkar, 2003; Lambert et al., 2006).

The ultimate success of a supply chain depends upon various factors among which are customer's expectations, globalization, information technology, government regulations, competition, and the environment. The traditional supply chain represented through Figure 1 is an integrated manufacturing process where raw material is transformed into final products, and then delivered to customers.

Figure 1: Traditional Supply Chain

Source: elaborated by the authors

Presently, available SCM is based on the balance between cost and customer service. Following the best pace of trade liberalization and globalization in the 1990s, supply chain has become an important research field and draws more attention from both practitioners and the academia.

However, SCM has experienced a paradigm shift with the growth of environmental movements, and particularly with the "Global Consensus" about the human impact on climate change. As an example, carbon emissions have become an important SCM measure. In fact, pricing of carbon emissions is inevitably becoming a reality in Asia as it has already happened in the European and American continents.

GSCM has emerged as an important new archetype for enterprises to achieve profit and market share objectives by reducing environmental risk and impact. With the increased environmental concern during the past decade, the pollution of the environment that results from industrial development should be addressed together with SCM, which is a growing awareness contributing to the initiative of GSCM (Srivastava, 2007). In this way, GSCM has emerged as a blueprint for some leading companies such as Dell, HP, IBM, and Motorola.

GSCM implies that companies are now beginning to recognize that the environmental awareness can be a source of competitive advantage (Seuring et al., 2008). Meanwhile, the most far-reaching approach of environmental management is to create value through greening the supply chain.

Actually, to have well developed GSCM practices in place that comply with emerging environmental directives and customers' expectations is a need. They also should meet "business performance" strategic planning criteria.

GSCM finds its definition in SCM itself (Forrester, 1958) by adding the green component, and being enhanced by the most recent studies (Gimenez & Sierra, 2013; Carter & Rogers, 2008; Kuik et al, 2011). Then, GSCM involves the addressing of the influence and relationship of SCM to the natural environment, meaning:

GSCM = Green Purchasing + Green Manufacturing/Marketing + Green Distribution + Reverse Logistics.

This green supply chain management is represented in Figure 2.

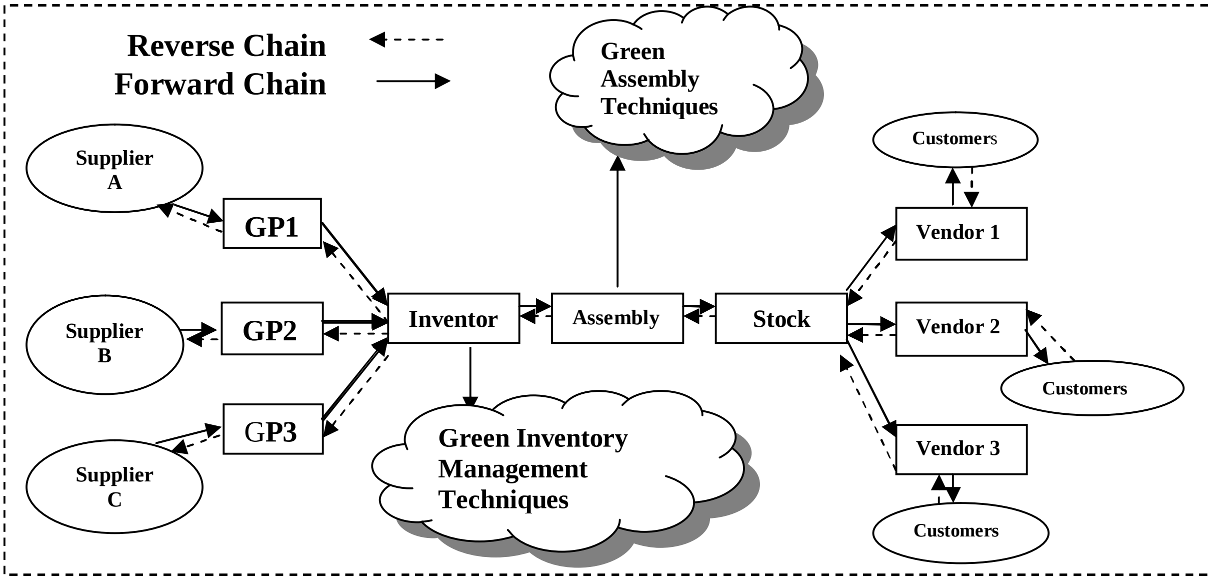


Figure 2: Green Supply Chain following Reverse Logistics

SCM has, over the years, leveraged itself as a tool for offering competitive advantage over other organizations in the industry. This can be quantitatively indicated by the fact that logistics costs are estimated between 9 - 20% of GDP (worldwide logistics is about 2 Trillion US dollars). Over the last decade, in industrialized countries such as the USA, logistics costs have come down from 15% to 9% by the use of SCM (Viswanadham & Gaonkar, 2003). However, in recent years, a modified concept of SCM for enhancing this competitive advantage has surfaced in the form of GSCM. The transition within various organizations from SCM to GSCM is due to the awareness increase with regard to environmental deterioration and its possible consequences on mankind. GSCM basis lies in the effort to contribute towards the ideal of a sustainable development, and thereby try to reverse the unequivocal impact on the environment. Thus, the primary objective of GSCM is to initiate and sustain the cause of reduction of hazardous effects on the environment due to rapid industrialization, along with the accomplishment of the universal purpose of making profit by organizations. Presently, GSCM has gathered acknowledgement and implementation in diverse business sectors such as electrical, electronic, automobile, and power generation industries among others (Johansson & Winroth, 2010).

3. System Dynamics Modelling

Essentially, SD is applying computer simulation to social and economical problems. Forrester organized the SD Group at the Massachusetts Institute of Technology's Sloan School of Management in 1956, and, with it, the field of SD studies was initiated. Forrester (1958) introduced the SD approach as a modeling and simulation methodology for analysis and long-term decision making in dynamic management problems. He has published extensively on SD and the main body of Forrester's ideas is collected in three books titled *Industrial Dynamics*, *Urban Dynamics*, and *World Dynamics* published in 1961, 1969, and 1971, respectively.

Since then, SD has been applied to various business policy and strategy problems. There are some publications using SD in supply chain modeling already. Forrester (1958) included a model of a supply chain as one of his early examples of applying SD methodology. Towill (1996a) uses SD in supply chain redesign to gain additional insight into SD behavior and particularly into underlying casual relationships. The output of the proposed approach is a collection of effective supply chain industrial dynamics models. SD was used to improve the knowledge of a complex logistic behavior of an integrated food industry. A generic model and some practical simulation results applied to the field of poultry production and processing are presented.

Hafeez et al. (1996) describe the analysis and modeling of a two-echelon industry supply chain that services the construction industry, using an integrated SD framework. Simulation results are used to compare various re-engineering strategies. Sterman (1989) presents two case studies where SD methodology is used to model reverse logistics problems. In the first case, a study analysis was undertaken for part recovering and material recycling in the USA auto industry to assist the industry to think about the future of enhanced auto recycling.

In the second case, the researcher concentrates on market mechanisms of paper recycling, which usually lead to instability and inefficiency in flows and prices. The application of SD in both cases shows that such approach can be a useful tool for long-term analysis of supply chains indeed.

In early years, the lack of computing power limited the applicability of SD. Recent advances in computing and simulation technology, as well as in large scale and nonlinear system theory, have enabled the development of SD theory and a large number of successful practical applications. The development of easy-to-use software packages, with graphical user interfaces and complex mathematics hidden to the background has further widened the SD community. Furthermore, as no standard tool has been suggested yet, the use of SD in GSCM is proposed. SD advantages make it a powerful tool for that purpose and its applications provide support for long-term decision making and environmental policy design.

4. System Dynamics and Green Supply Chain Management

The application of SD modeling to SCM has its roots in Industrial Dynamics (Forrester, 1958, 1961). The ‘Forrester Model’ is described in terms of six interacting flow systems, namely the flows of information, materials, orders, money, manpower, and capital equipment. Based on the development and use of a SD simulation model, Forrester describes, analyses, and explains issues evolving around SCM. It is important to point out that many current research issues in SCM have already been emphasized, or even scrutinized by Forrester in 1961, including demand amplification, inventory swings, effect of advertising policies on production variations, de-centralized control, or the impact of the use of information and communications technology (ICT) on the management process. Since Forrester, who essentially viewed the supply chain as a part of an industrial system and in terms of policy design, researchers have covered issues ranging from inventory management to global supply chains integration. However, *“the use of industrial dynamics modeling of real-life supply chains has only recently re-emerged from the shadows and a lengthy gestation period”* (Towill, 1996).

In recent years, there has been a shift of focus in SCM towards a more integrated approach. *“Integrated Supply Chain Management is a process-oriented, integrated approach to procuring, producing, and delivering products and services to customers. International Supply Chain Management covers the management of material, information, and funds flows”* (Metz, 1998). Stevens (1989) describes a supply chain as *“a system whose constituent parts include materials, suppliers, production facilities, distribution services and customers linked together via the feed-forward flow of materials and the feedback flow of information”*.

The use of SD modeling in SCM has only recently re-emerged after a gap or slack period. The first published work in SD modeling related to SCM is found in Forrester (1958). Forrester (1961) expands on his basic model through further and more detailed analysis, and establishes a link between the use of the model and management education. In the original supply chain model that was used by Forrester in his simulation experiments there is a downstream flow of material from the factory via the factory warehouse, the distributor and the retailer to the customer. Orders (information flow) flow upstream and there is a delay associated with each echelon in the chain representing, for instance, the production lead-time or delays for administrative tasks such as order processing. Since then, researchers have coined the expression ‘Forrester Supply Chain’ or Forrester Model which is, essentially, a simple four-level supply chain (consisting of factory, warehouse, distributor, and retailer).

Using his Model as an example, Forrester (1961) describes continuous processes modeling, whilst clearly emphasizing the importance of information feedback to the SD method. Pointing out that the first step in a SD study is the problem identification and the formulation of questions to be answered, Forrester illustrates the stages of model conceptualization, parameterization, and testing through various experiments. Forrester (1958) disapproves the approach taken by operations research (OR) in the 1950s, where OR methods are applied to isolated company problems. He suggests that the success of industrial companies depends on the interaction between the flows of information, materials, orders, money, manpower, and capital equipment (Forrester, 1961), and states that the understanding and control of these flows is the main task of management. The Forrester Model received much criticism over the years, which served as a basis for applying and extending Forrester’s research further. Despite its simplicity, the Forrester Model yielded important insights into the supply chain dynamics. Demand amplification, a fundamental problem in supply chains, has only recently been recognized to the full extent of the problem (Towill, 1996).

This author says that Forrester established the ground rules for effective supply chain design accidentally, when he "*... showed that a medium period demand amplification was a SD phenomenon which could be tackled by reducing and eliminating delays with the proper design of feedback loops*".

The introduction of a reverse flow from a retailer to a factory as GSCM is shown in Figure 3. Application of system dynamics modeling to supply chain management covers the following facets:

1. International Green Supply Chain Management (IGSCM)
2. Green Inventory Management
3. Green Supply Chain Design
4. Demand Amplification
5. Information Visibility
6. Decision making in stock management
7. Supply Chain Re-engineering
8. Integrated System Dynamics Approach

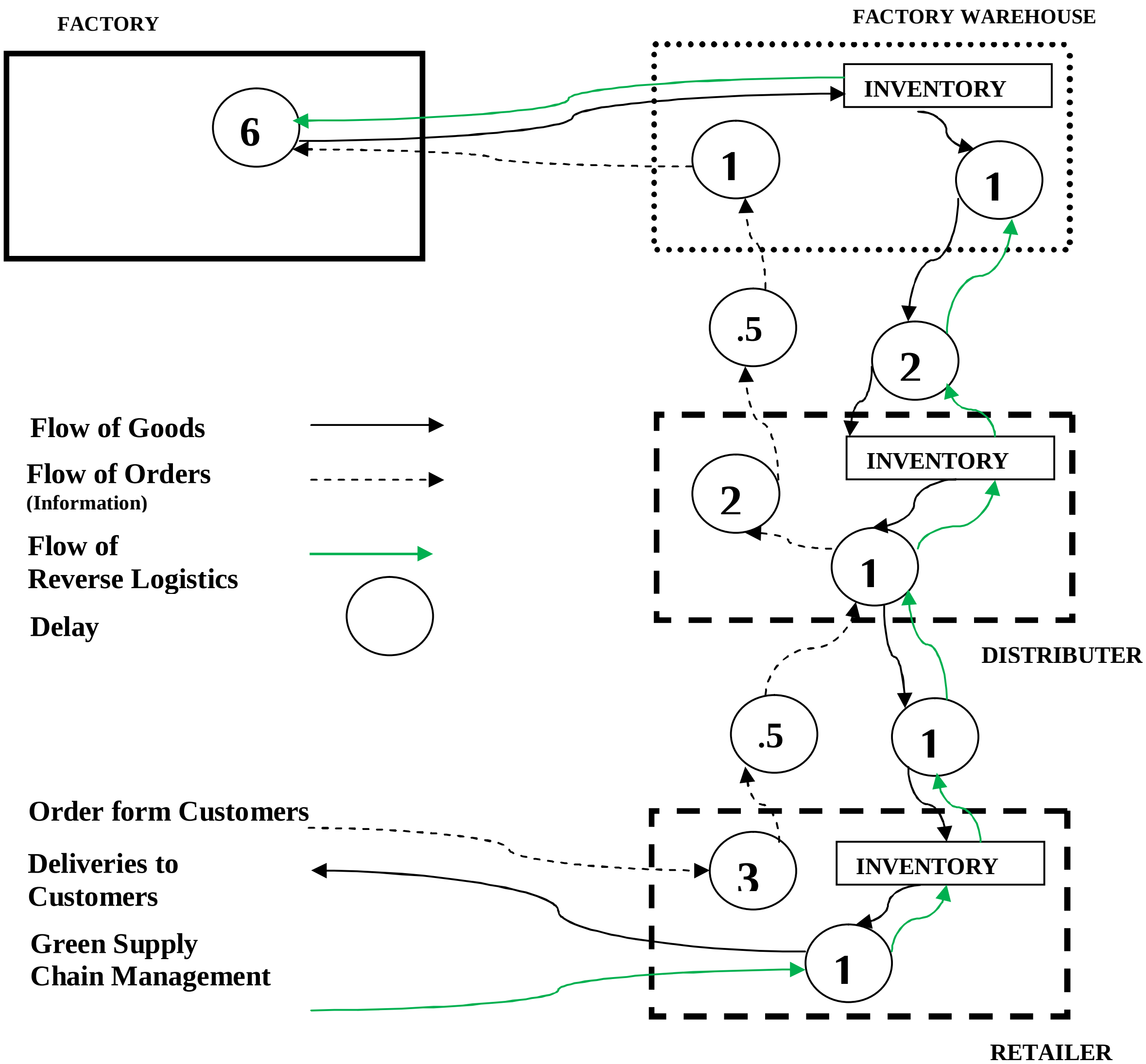


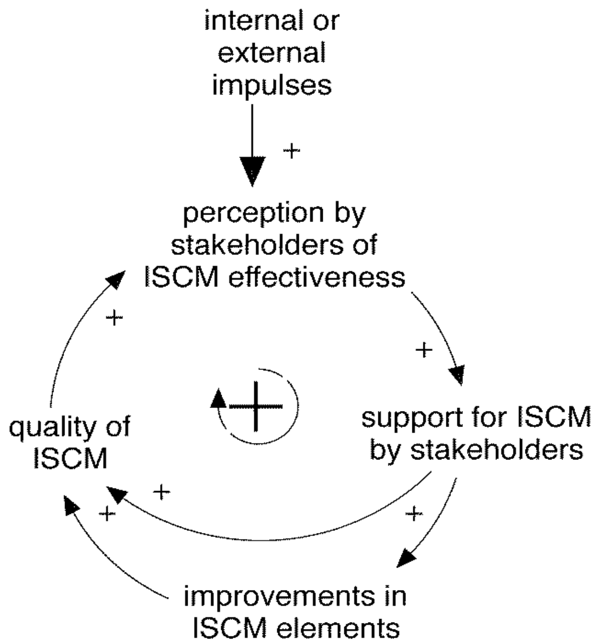
Figure 3: Forrester Model introducing Green Supply Chain

4.1 International Green Supply Chain Management

Akkerman, Bogerd & Vos (1999) proposed a theory of "Virtuous and Vicious Cycles" in ISCM through an exploratory causal model of goals, barriers, and enablers.

The roadblocks identified by them were: local optimization, lack of top management support, insufficient communication between supply chain and functional silos. ISCM facilitation can be achieved through demonstrating business success of ISCM to customers demanding ISCM services and promoting cross-functional careers. Leveraging the potential of information and communication technology systems also provides for the same. Figurre 4 shows a causal model of ISCM proposed by Akkerman et al. (1999). The core dynamics is straightforward: all companies seemed to be caught in a reinforcing loop of successes (a virtuous cycle) or failures (a vicious cycle), the latter being considered more frequent than the former (Akkerman et al. 1999; Akkerman, 1995). The scenario of the vicious cycle shows that if the current quality in managing a company's ISCM is low, then the main stakeholders (top management, other company functions, external partners, etc.) will treat ISCM as a not very effective means of improving business performance. Introducing green concepts at every step will also present similar loops.

Figure 4: Virtuous and Vicious Loops of ISCM Dynamics



Source: Akkerman et al. (1999)

4.2 Green Inventory Management

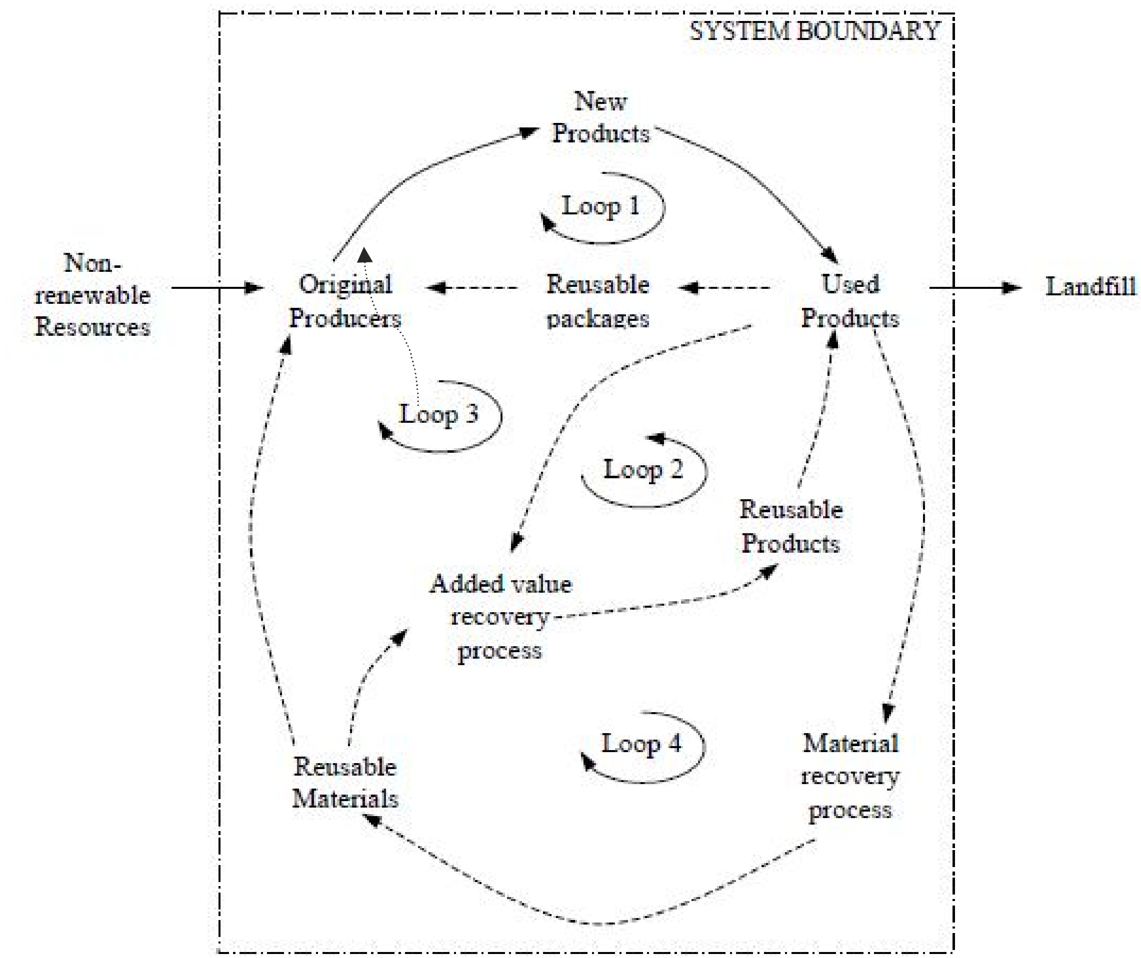
Barlas & Aksogan (1999) developed the inventory management policies where a quick response SCM system was designed to meet changing requirements of a competitive market. The textile and apparel industry used for the study included from textile suppliers to final consumers. Between these were the textile producer, apparel manufacturer, wholesaler, and retailer, similar to what is shown in Figure 1**.** The primary focus of the work was to build a SD simulation model of the portion of the pipeline including retailing and wholesaling processes to search for inventory decisions and policies that yield reduced costs and increased revenues for the retailer, and particularly to examine the effectiveness of some quick response principles for that purpose. Another intention of the study was to examine the effect of diversification and the different assumptions about the effect of product diversity on customer demand, possible stock outs, and inventory levels. The simulation model of the apparel supply chain represents the physical structure of the system and also incorporates ordering and production decision rules. Simulation run was carried out, using different ordering and production policies under various inventory levels and demand patterns. Results highlighted that order policies as used in continuous systems are not adequate for partially discrete, partially continuous inventory systems. The outcome of the modeling effort led to the proposition of new ordering policies for particularly continuous, partially discrete inventory systems, which are robust in terms of fluctuations in demand (Barlas & Aksogan, 1999).

The traditional 'one-way' supply chain network experiences a unique transformation to closed-loop network by the combination of forward and reverse flow channels. Figure 5 shows various loops and flow of resources for implementation of what is known as Closed-Loop Logistics Network.

The figure comprises of forward and reverse channel of flow of resources, depicted by solid and dashed lines respectively, and four loops refer to the suggested types of reuse of available resources – direct reuse, re-manufacturing, repair and recycling. ‘Loop 1’, existing within the system boundary, represents direct reuse of articles.

As an example, packaging materials (such as bottles, containers) that exhibit feature characteristics of reusability can be sent back to the original producer’s site and treated with standardized measures (as per the benchmark for safety of use) and finally sent for reuse by the consumers. ‘Loop 2’ represents the re-manufacturing/repair of available resources. The initiative suggested by this loop refers to reuse of the (un)used in whichever way is more suitable to the respective organization. This is an added value recovery process wherein the firm may either reuse parts of the disposed-off material or it may repair the product such that the commodity can be used by the consumer. The third and fourth loops in the diagram, known as ‘Loop 3’ and ‘Loop 4’ respectively, represent the recycling procedure. The major difference between them and ‘Loops 1 an 2’ is that while these send resources to the original producer for recycling, ‘Loops 3 and 4’ use a common site for reusable materials in such a way that any organization in the industry may procure and reuse recovered material for their processes, i.e. the reusable material can be sent to original producers (‘Loop 3’) or to an adding value recovery process (‘Loop 4’), as per requirement (Georgiadis & Vlachos, 2004).

Figure 5: Major Causal Loops in a Closed-Loop Logistics Network



Source: Georgiadis & Vlachos (2004)

Implementation success of the Closed-Loop Logistics Network does not single handedly depends upon the process/concept of material reuse. Rather, there are many actors that can collectively contribute to this action: suppliers, original producers, value added recovery producers, distributors, users, collectors, and recyclers (Angerhofer & Angelides, 2000). The participating actors may be manufacturers, retailers, and logistics service providers, i.e. members belonging to the forward channel of supply chain.

Members of private third parties such as secondary material dealers, material recovery facilities, added value recovery facilities, and even the municipal government (public sector units) can proceed towards the execution of this logistics network. Involved parties can be expected to join the network due to a probable economic and/or ecological gain. Especially for original producers, the reverse inbound flows can be economically attractive when the value gain, i.e. the price of a used product minus the cost of the required reverse activities (used material recovery), is positive. The motivation to claim ecological benefits can be initiated by legal binding on firms to ensure that recycle processes constitute an equally important facet of the manufacturing industry. Another significant reason for firms to participate in this logistics network is to gain competitive advantage over other organizations in the industry by projecting an environmentally responsible image of the firm. Hence, this may help in the decrease of the rate of disposal of used products and, subsequently, the rate of usage of environment-friendly materials would increase.

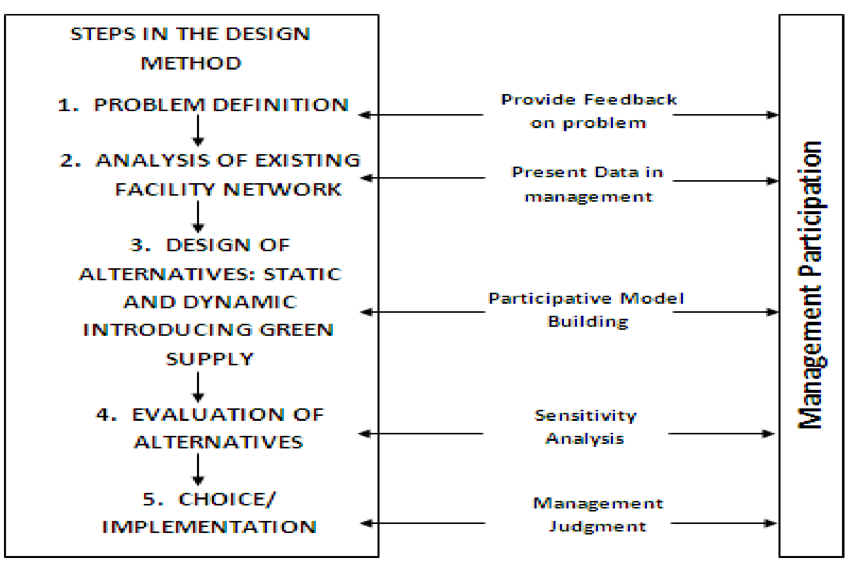
Forward and reverse channel members of supply chain such as suppliers, producers, distributors, and the market also can collectively join this logistics network. Traditionally, the producers' output is utilized by consumers, and then it is disposed off. Reverse channel members can contribute by participating in disposing, repairing, remanufacturing, recycling, and reusing activities. Following this, forward supply chain members may collect the material and opt for direct reuse, reuse of some product parts, re-manufacture or repair, as per requirement.
The following statements explain the process:

Loop 1: Reusable packages return to new products serviceable inventory;
Loop 2: Products after remanufacturing return to "as good as new" products serviceable inventory;
Loop 3: Products after repair return to new products serviceable inventory;
Loop 4: Recycled products provide raw material to materials inventory.

4.3 Green Supply Chain Design

Allocation of facilities in multinational companies is challenging in the wake of globalization due to the increased complexity of managerial decision-making on allocation issues. Vos & Akkerman (1996) focused on strategic decisions concerning the (re)design of international networks (Towill, 1996). The main focus of their work was to develop models to support managerial decision-making. The design method was primarily based on three premises: identification and design phases of strategic participation of decision makers in practical - system dynamics modeling is used to overcome restrictions imposed by the static nature of the original method presented by Vos & Akkerman (1996). The extended method is represented in Figure 6. Author's model offers various advantages: dynamic behavior variables can be incorporated and the model can be used for incremental implementation strategy in relocation, thus improving the fit with reality and decision-making processes applications.

Figure 6: Design Method



4.4 Demand Amplification

Anderson et al. (1997) worked on demand amplification in supply chains. They explored the implication of demand amplification on lead-time, inventory, production, productivity, and workforce machine tool industry. Capital equipment firms are subject to large variances in demand, because a small change in end-product demand creates dramatic changes in the demand for capital equipment required to manufacture those products. The authors have resorted to a system dynamics model to explain demand amplification along capital equipment supply chains, and to test various strategies that could improve the functioning of the industry. SD modeling methodology allowed them to incorporate typical features of the capital equipment industry such as feedback loops, delays, and non-linear ties.

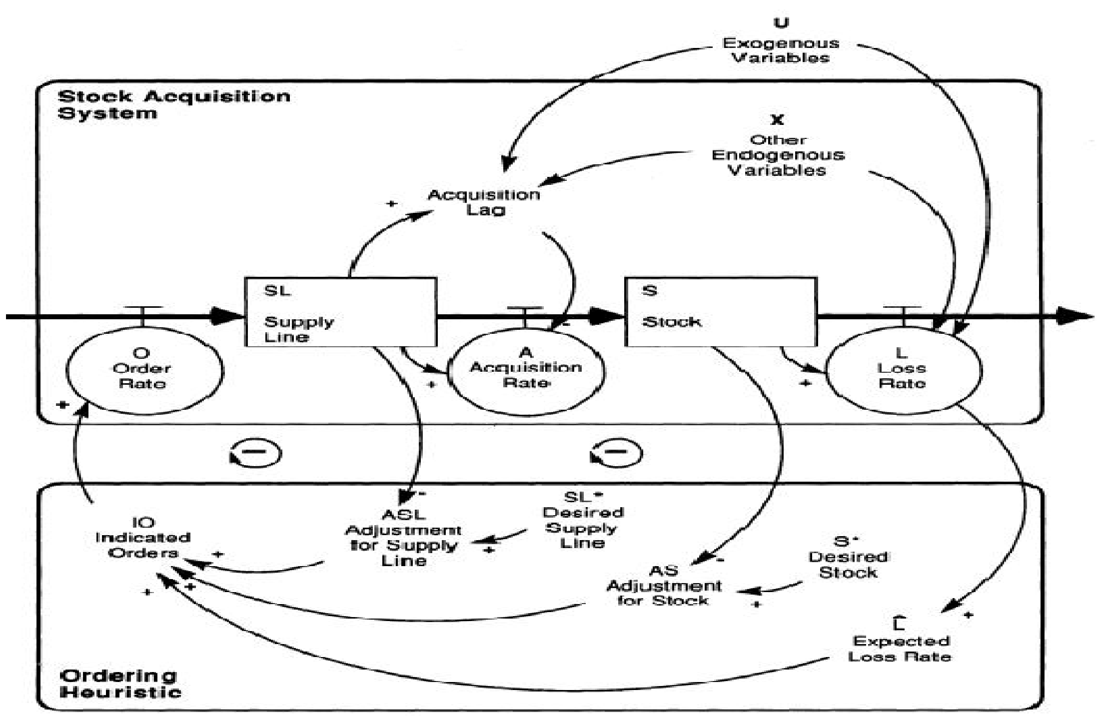
4.4.1Information Visibility

In the global marketplace most companies compete with relatively similar machines, technology, and expertise. Establishment of a world-class enterprise depends on the use of appropriate business strategy. Company strategies can benefit from information visibility (availability) in supply chains. Joshi (2000) developed a framework of information visibility for supply chains and explained its importance by developing an SD model. Taking the beer game as a realistic simplification of the supply chain, he used a system dynamics model with SD software, and developed scenarios to demonstrate the importance of information visibility. He used both forecast and smooth demand functions for forecasting with/without information visibility. Scenarios with information visibility did show better results.

4.4.2Decision-Making in Stock Management

Sterman (1989) proposes that misperceptions of feedback account for poor performance in dynamic decision-making, as the decision processes, are based on an anchoring and adjustment heuristic. Feedback is defined not only as outcome feedback, but also as changes in the environment or condition of choice, which are caused by past action. Such multiple feedbacks are the norm in real problems of choice. The author presents a generic model of a stock management system as shown in Figure 7, which forms the basic structure in an environment for a decision-making experiment. This generic stock management structure is applicable to many different scenarios, including raw material ordering and production control or, at a macroeconomic level, for controlling the stock of money. The model consists of two parts: (1) the physical stock and the flow structure of the system, and (2) the decision rules used to control the system.

Figure 7: Generic Stock Management System



Source: Sterman (1989)

4.4.3Supply Chain Re-Engineering

Towill's (1996) work represents research on supply chain redesign. He states that rapid, effective and efficient response to changes in the market is one of the main challenges in modern supply chains. Therefore, time compression is an answer to these challenges. Towill (1996) proposes that simulation based time compression strategies allow to predict supply chain performance improvements. Resorting to Forrester's Model (Forrester 1961) as a framework to improve systems performance, he provides a ranking of supply chain re-engineering strategies. A performance metric as proposed by Johansson et al. (1993) is used for supply chain benchmarking.

$$PI = \left[\frac{Quality * Customer\ Service\ Level}{Total\ Cost * Lead\ Time}\right] \qquad (1)$$

Equation (1) displays the performance metric consisting of four components. Each of these components may be adjusted by adding a relative weight age, allowing for adaptation to different preferences. According to Towill (1996), the cycle time compression paradigm suggests that reduced lead-times will also positively influence the other three components. While lead-time has a critical effect on the stability of a supply chain, the key benefits of time compressing are improved demand forecasting, quicker defect detection, quicker to market, and also a forward shift of decoupling points towards the customer (Barlas & Aksogan, 1999).

Based on simulation results, Towill (1996) proposes the use of reengineering strategies as follows: (1) reduction of all lead-times (material-, information- and cash-flows); (2) elimination of time delays in decision points; (3) provision of marked information to all upstream decision makers.

4.5 Integrated System Dynamics Framework

Based on the case of a two-echelon steel industry supply chain, Hafeez et al. (1996) demonstrate the application of 'systems engineering' to supply chains and describe an integrated SD framework, with the aim of giving an example to 'good total systems design'. The modeling exercise deals with the design of a supply chain for the purpose of moving more rapidly towards a minimum reasonable inventory, whereby the chain exhibits capacity constraints, breakdowns, and material supply lead-time bottlenecks. Hafeez et al. (1996) describe the complex combination of 'man' and 'machine' as one of the major problems in modeling supply chains. By using an integrated SD framework Naim and Towill (1994) made an effort to take into consideration the complex details associated with modeling attitudinal, organizational, and technological issues.

Having simulated and analyzed several different scenarios based on a real-world steel supply chain case, Hafeez et al. (1996) propose that the developed model may be viewed as a 'Management Information System' and suggest that the generalized integrated SD framework should be tested regarding its effectiveness in various (other) market sectors.

5 Findings and Results

Foregoing discussion on some research papers revealed the following:

- Akkerman, Bogerd & Vos (1999) proposed a theory of "Virtuous and Vicious cycles" in ISCM through an exploratory causal model of goals, barriers, and enablers. Roadblocks identified by them were:

- Local optimization,
- Lack of top management support,
- Insufficient communication between supply chain, and
- Functional silos.

Scenario of the vicious cycle envisages that if the current quality in managing a company's ISCM is low, then main stakeholders (i.e. top management, other company functions, external partners etc.) will treat ISCM as a not very effective means of improving business performance.

- Barlas & Aksogan (1999) developed the inventory management policies, where a quick response supply chain management system was designed to meet the changing requirements of a competitive market. Focus of the work was:

- To build a SD simulation model;
- To examine the effect of diversification;

- To examine the influence of assumptions about the effect of product diversity on customer demand, possible stock outs, and inventory levels.

- Vos & Akkerman (1996) focused on strategic decisions concerning the (re)design of international networks. The main focus of their work was to develop models to support managerial decision-making. The extended model offers various advantages:

- Dynamic behavior variables can be incorporated, and the
- Model can be used for incremental implementation strategy for relocation, improving the fit with reality and decision-making processes applications.

- Anderson's (1997) work on demand amplification in supply chains showed implication of demand amplification on lead-time, inventory, production, productivity and workforce machine tool industry. A SD Model was used to explain demand amplification along capital equipment supply chains, and to test various strategies that could improve the functioning of the industry. SD modeling methodology allowed them to incorporate typical features of the capital equipment industry.
- Company strategies can benefit from information visibility supply chains. Joshi (2000) developed a framework of information visibility for supply chains using a SD model with SD software, and developed scenarios to demonstrate the importance of information visibility. He used both forecast and smooth functions for demand forecasting. Scenarios with information visibility have shown better results.
- Sterman (1989) presents a generic model of a stock management system. It is applicable to many different scenarios, including:

- Raw material ordering;
- Production control or, at a macroeconomic level,
- Control of the stock of money.

- Towill (1996) found that time compression is an answer to the challenge represented by changes in the market. He suggests that reduced lead-times have a critical effect on the stability of a supply chain. The key benefits of time compression are:

- Improved demand forecasting;
- Quicker defect detection;
- Quicker to market;
- Forward shift of decoupling points towards the customer.

Based on simulation results, the use of reengineering strategies is proposed as follows:

- Reduction in all lead-times (material-, information- and cash-flows);
- Elimination of time delays in decision points;
- Provision of marked information to all upstream decision makers.

- Hafeez et al. (1996) demonstrate the application of 'systems engineering'. Modeling exercise deals with the design of a supply chain with respect to moving more rapidly towards a minimum reasonable inventory, whereby the chain exhibits capacity constraints, breakdowns and material supply lead-time bottlenecks. Hafeez et al. (1996) describe the complex combination of 'man' and 'machine' as one of the major problems in modeling supply chains. Naim and Towill (1994) make an effort to take into consideration the complex details associated with modeling attitudinal and technological issues. Hafeez et al. (1996) propose that the developed model may be viewed as a 'Management Information System' and suggest that the generalized integrated system dynamics framework should be tested regarding its effectiveness in various market sectors.

6 Conclusion

There is a growing need for integrating environmentally sound choices into supply-chain management research and practice. A broad reference frame for green supply-chain management (GSCM) is not adequately developed yet. GSCM has emerged as an important new archetype for enterprises to achieve profit and market share objectives by reducing environmental risk and impact. With the increased environmental concerns during the past decade, there is a growing awareness that the issue of environmental pollution accompanying industrial development should be addressed together with the supply chain management. Far-reaching approach of environmental management is to create value through the supply chain greening.

The GSCM issue is significant because recent studies have shown that the majority of the world manufacturing will be carried out in Asia within the next couple of decades. SCM has, over the years, leveraged itself as a tool for offering competitive advantage over other organizations in the industry. GSCM has gathered acknowledgement and implementation in diverse business sectors such as the electrical, electronic, automotive, and power generation industries among others.

This paper presents an overview of Green Supply Chain Management and its evolution. It approaches fundamental aspects of system dynamics and areas to which SD has been applied to solve problems. The paper discusses how and why SD has been applied to Green Supply Chain Management. It approaches also the application of SD to various facets of GSCM such as inventory management, international green supply chain management (IGSCM), demand amplification, green supply chain design, and, finally, information visibility in green supply chain management.

In any attempt to increase supply chain performance by an organization, there is a critical need to gain a deeper understanding of the impact of decisions on operations as well as of those of their partners. Simulation has been found to be one of the popular and suitable mechanisms for understanding supply chain dynamics. Many times supply chain re-engineering decisions are made under a probabilistic view of the future. As a result, authors feel that there is a necessity for decision support tools that can help managers to understand costs, benefits, and risks associated with various alternatives. In this paper, it was described a simulation-based SD modeling framework for developing customized supply chain models.

These models capture generic supply chain processes and concepts, thereby promoting modular construction and reuse of models for a wide range of applications. Using these components, it is possible to incorporate supply, process and demand uncertainty as well as to integrate analytic and heuristic decision procedures. This approach underscores the importance of model in which different entities in the supply chain operate subject to their own local constraints and objectives, and have different local views of the world. This simulation approach enables performance to be analyzed from a variety of organizational perspectives. As an evidence of practical utility, a subset of concepts is being used by IBM for supply chain reengineering efforts.

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