Proceedings of GLOGIFT 09
November 12 – 14, 2009
National Institute of Industrial Engineering
Mumbai, India

Discrete Event Dynamic Modeling for Flexible Closed Loop Supply Chain System

Prof. Subhash Wadhwa
Department of Mechanical Engineering,
Indian Institute of Technology,New Delhi

Dr Jitendra Madaan
Department of Mechanical & Automation Engineering,
Indira Gandhi Institute of Technology,New Delhi

Mudit Verma
Department of Electronics & Electrical Engineering,
Maharaja Surajmal Institute of Technology,New Delhi

Abstract

The need for holistic and flexible modeling efforts for product returns that capture the extended closed loop supply chain (CLSC) system at a strategic level has been clearly recognized by industry and academia. Strategic decision-makers need comprehensive models to guide them in efficient decision-making that increases the profitability of the entire return chain. Like any other supply chain management issues determination of optimal network configuration, inventory management policies, supply contracts, distribution strategies, integration, outsourcing and procurement strategies, and information technology are prime requirements of strategic decision-making that affect the long-term profitability of the closed loop supply chain. In this paper, we adopt the system dynamics methodology as a modeling and analysis tool to tackle strategic issues for closed loop supply chains. We present guidelines for the methodology and present its development for the strategic modeling of single and multi-level return chains. Finally, we demonstrate the methodological contribution by extending and improving the application of System Dynamics Modeling to closed loop supply chain management.

Keywords*: Reverse Logistics, flexible, Discrete Event Dynamic Modeling.*

1. INTRODUCTION

Closed loop supply chain networks have been an area of increasing attention during the last decade as their economic impact have been increasingly important and as environmental legislation has been becoming stricter (De Brito & Dekker, 2004 [3]). However, despite its significant advances and dramatic improvements in information technology (IT), closed loop supply chain remains incapable of addressing satisfactorily many real world challenges. One key reason for this inadequacy is the interdependencies among various logistics, reprocessing operations and the independent partners across the closed loop supply chain

which makes nearly all models for product return, insufficient to capture the reality (Wadhwa & Madaan 2004[12]). Therefore, strategic decision-makers require comprehensive models to guide them in the decision-making process so as to increase the total profitability of the closed loop supply chain. A critical shortcoming of most of the existing strategic models for closed loop supply chain is their inability to take into account the impact of regulatory environmental legislation, i.e. particularly important because of its unique characteristics. Product after return, either from customer or the business partner creates uncertainty for the enterprise with respect to product location, quality, safety and reliability (i.e. quantity) of supply after return. Products after return must be moved promptly to the reprocessing station in order to avoid loss in value (Davey, S. 2001 [4]).This further leads to the need for frequent delivery, through dedicated modes of reverse logistics. In addition, legislative issues for the product return issues have profound ramifications on the design of the closed loop supply chain. For instance, proper monitoring and response to problems requires the ability to trace back small lots, from retailer to processor or even back to the supplier. All these characteristics along with the dynamically evolving legislative framework further hinder the task of managing efficiently closed loop supply chains. The key motivation behind this paper include,

- ✓ To support the decision-making process for planning of multi level closed loop chains in uncertain environments by studying the long-term behavior of supply chains and

- ✓ To further offer a generic methodological framework that could address a wider spectrum of strategic CLSC (Closed Loop Supply Chain) related problems.

The main objective of this paper is to study the strategic behavior of closed loop supply chain with efficient reverse manufacturing and reverse logistics operation that influence, directly or indirectly, profits, costs and flows. Here we use the System Dynamics (SD) methodology, introduced by Forrester (1961) [5], in the early 60s as a modeling and simulation methodology for the analysis and long-term decision-making of dynamic industrial management problems. Since then, SD has been applied to various business policy and strategy problems (Sterman, 2000 [13]). SD methodology provides a more flexible modeling and simulation framework for decision making in dynamic management problems. The purpose of this paper is to introduce how the methodological tool of SD can be employed to assist the modeling of holistic model of the entire closed loop supply chain, which may be used as decision making tool, mainly for strategic

decision-making. More specifically we design single level model as a basic module we demonstrate how generic multi-echelon supply chain models can be constructed. We keep the proposed model as generic as possible to facilitate its implementation on a wide spectrum of real life cases. Finally, we demonstrate the methodological contribution by extending and improving the application of System Dynamics Modeling to closed loop supply chain management.

2. MODEL DESCRIPTION FOR CLOSED LOOP SUPPLY CHAIN SYSTEM

Strategic closed loop supply chain management deals with a wide spectrum of issues that includes several types of decision making both for the forward and reverse movement of products and services efficiently. Main problems that affect the long-term development and operations of a firm, namely the determination of number, location, manufacturing, reprocessing plants and the flow of material through the logistics network forward and backward directions, inventory management policies, distribution and collection strategies, integration, third party outsourcing strategies, decision support systems and information technology etc. The methodological approach developed in this paper, could potentially be used for capturing many of the above strategic CLSC problems. Our approach utilizes a well-proven methodological tool for strategic decision-making, that of SD.

3. SYSTEM DYNAMICS MODELING FRAMEWORK FOR CLOSED LOOP SUPPLY CHAIN

A closed loop supply chain encompasses vendors, manufacturers/producers, distributors' retailers, customer, collectors/sorters, disposers; remanufactures is characterized by a stock and flow structure for the acquisition, storage, and conversion of inputs into outputs and the decision rules governing these flows (Forrester, 1961; Sterman, 2000[5] [13]). The flows often create important feedbacks among the customers and business partners, thus making SD a well-suited modeling and analysis tool for strategic closed loop supply chain management.

Here we assume that forward supply chain includes supplier, manufacturer, distributor and retailer and the reverse supply chain includes reuse/repair, remanufacture, and recycle activities under reverse manufacturing. Reverse manufacturing brings the product back into an "as good as new" condition by carrying out the necessary disassembly, repair and replacement operations (Fleischmann M. et al., 1997 [6]). Specifically, the finished products are first transferred to the distributor and then sold to satisfy market requirement. The product sales at the end of their life-cycle turn into used products, which are either disposed or collected for reuse. The collected products after inspection/selection are either rejected and controllably disposed or accepted and transferred for various reverse manufacturing functions according the condition. The loop "closes" with the reverse manufacturing operations into the forward chain in following ways. First, through the flow of "as good as new" products to the serviceable inventory, as repaired product back to customer, as reusable product back to manufacturer and through the resale via the "green image" in primary or secondary market shown in figure 1. Raw materials input, total demand and legislation acts (take-back obligation) shape the external environment of the system. A major assumption of our study is the demand for remanufacturing has a relatively small variation.

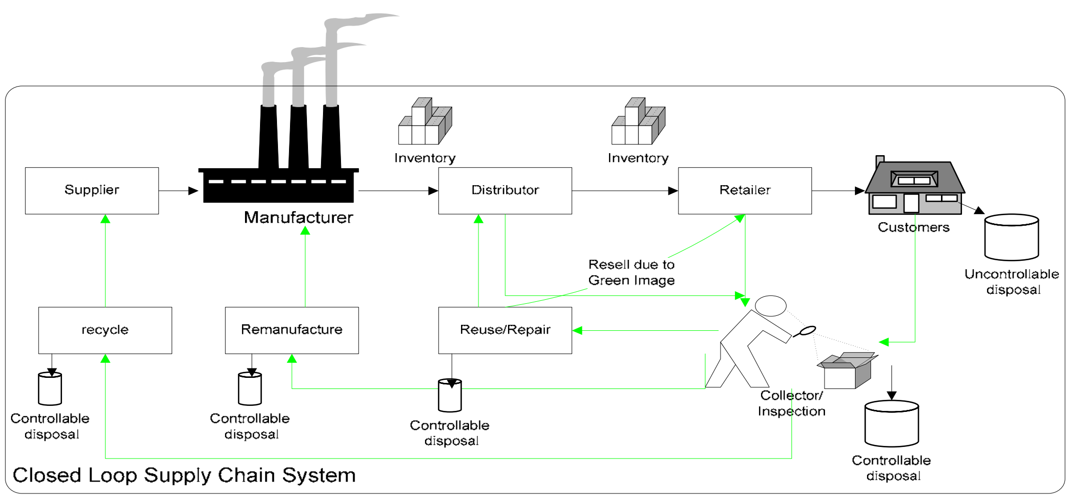

Figure 1. Closed Loop Supply Chain System

3.1 System Dynamics (SD) Methodology

The SD methodology, which is adopted in this paper, is a modeling and simulation technique specifically designed for strategic decision making problems (BarlasY. 2002 [2]). It focuses on understanding how the physical processes, information flows and managerial policies interact so as to create the dynamics of the variables of interest. The totality of the relationships between these components defines the "structure" of the system. Hence, it is said that the "structure" of the system, operating over time, generates its "dynamic behavior patterns". It is most crucial in SD that the model framework should provide a valid description of the real processes. The typical purpose of a SD in this paper is to understand how and why the dynamics of concern are generated and then search for policies to further improving the performance. Policies refer to the long-term, macro-level decision rules used by management. Therefore, the purpose of proposed framework would not be to predict the performance at tactical level but for the strategic level.

The structure of a SD model contains stock (state) and flow (rate) variables. Stock variables are the accumulations (i.e. inventories) within the system. The flow variables represent the flows in the system (for example reverse manufacturing function rate), which result from the decision-making process. Here it appears that a decision-maker could determine capacities for all these operations once in the beginning of the planning horizon, and that this could be done using a standard management procedure that includes steady-state conditions. However, this is not the case with environment under study since forward and backward product flows can change dramatically for several reasons; for example environmental legislation can impose a take-back obligation for a specific percentage of sales (e.g. in some countries of Western Europe there is an obligation to the manufacturers for 100% collection of "white" goods), or the expected demand may increase or decrease progressively because environmentally conscious customers decide to patronize or not a specific provider because of the provider's "green image" (Handfield R et al. 2002 [8]). Although, such demand shifts take time to materialize, they have to be considered for the development of efficient capacity planning policies. Thus, it is evident that the modeling methodology that will be employed needs to be able to capture the transient effects of flows in a supply chain. SD has this capacity and moreover, it easily describes the diffusion effects related to legal regulations or the firm's "green image" among customers.

3.2. System Dynamic Modeling Framework for CLSC

The structure of a system in SD methodology can be captured by the proposed framework. This framework plays two important roles in SD approach. First, during model development, this framework serves as preliminary sketches of causal hypotheses and secondly, it can simplify the representation of a model. Therefore, we try to capture the relationships among the system operations in a SD approach and to construct the appropriate framework for CLSC. Here in this framework we represent the major feedback mechanisms. These mechanisms are either negative feedback (-) or positive feedback (+) loops.

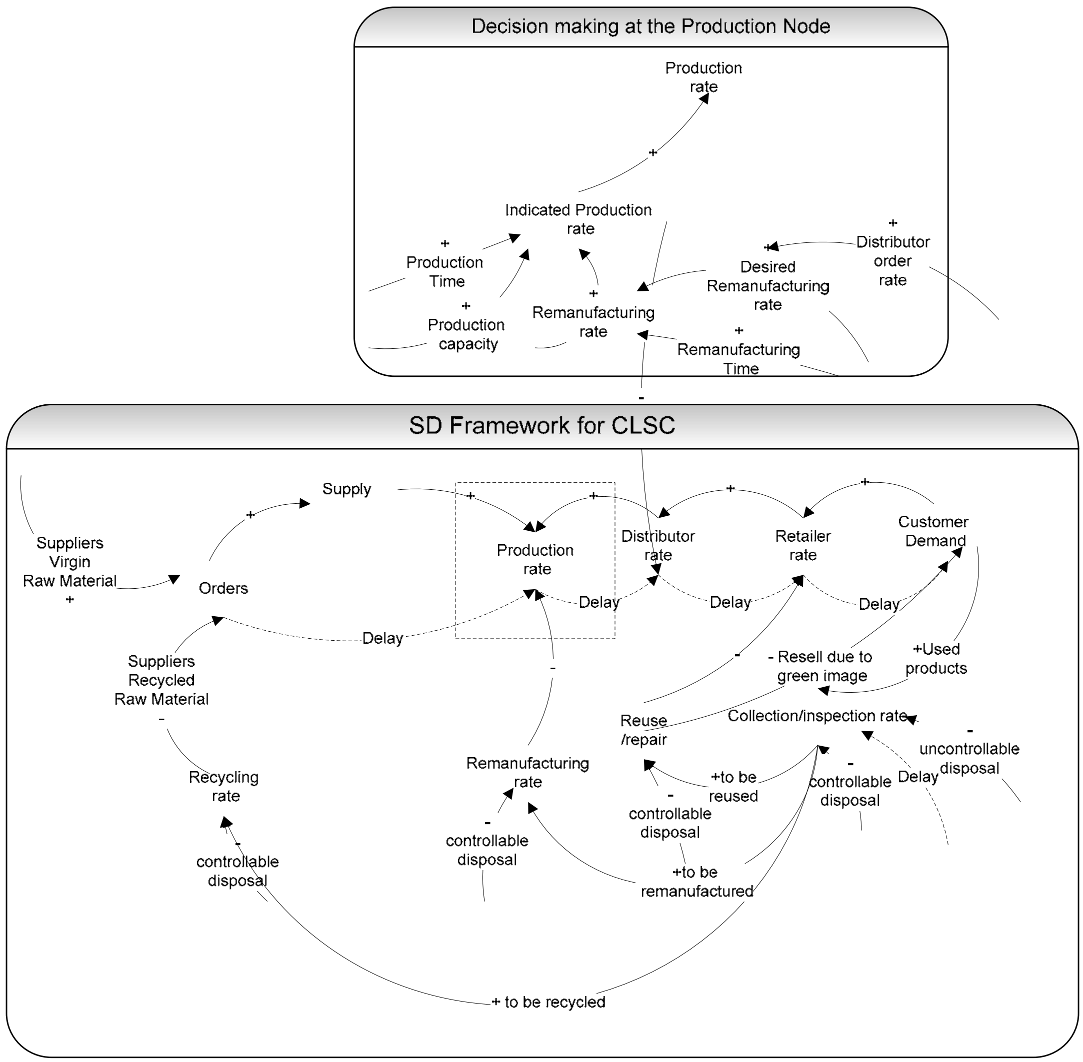

Figure 2. SD Framework for Closed Loop Supply Chain

A negative feedback loop exhibits goal-seeking behavior after a disturbance, the system seeks to return to an equilibrium situation. In a positive feedback loop an initial disturbance leads to further change, suggesting the presence of an unstable equilibrium. To determine the flows of Figure 2, we use a combined “pull push” policy; we adopt a “pull” policy in the forward channel to maintain better stock control, while we use a “push” policy in the reverse channel to achieve faster system response (Van der Laan et al. 1999). The size of the SD model is such that the analytical presentation of the two interconnected networks and of control rules cannot be given within the limited paper’s length. However, the general form of the embedded control rules is indicatively presented in form decision making box in Figure 2 for the case of controlling the Production Rate.

The supply chain in this framework begins with raw materials provided by external suppliers which consist of sum of virgin raw material and recycled material from the return chain. Therefore, total order fulfillment consists of difference of these two inputs. Production depletes raw materials and it is the sum of two terms. The first is a forecasted value given by the difference of the orders from distributors the input from re-manufacturing rate (since the remanufacturing process supplements the production process). The second term is proportional to the difference between desired remanufactured inventory and actual remanufactured inventory, and it represents how quickly the firm tries to correct this difference. Naturally, the production rate is restricted by production capacity, which is assumed to be an external variable. The desired inventory level after remanufacturing depends on the distributor's orders and the required delay to cover these orders. Inventory at the production end will consists of production of new products and remanufactured products, is depleted to satisfy as many as possible of the distributors demand through delay. The distributors demand depend on demand from retailers, which is satisfied through the difference of desired distributors inventory and actual distributor's inventory. Thus, distributor's inventory is depleted to satisfy retailers' demand which comes through sales to the customers. All these process requires delay time. Here, all unsatisfied demand is backlogged and may be satisfied in a forthcoming time period. Sales after their current usage turn into used products. The distribution of this usage time depends on the explicit product characteristics and it is easy to estimate by statistical study.

Furthermore, used products are either disposed through uncontrollable disposal or collected for reuse. The reverse channel starts with the collection and inspection procedures. Collected products after inspection are sent to respective reverse manufacturing function depending on state of product with some time delay. Here collection rate can either be increased or decreased depending on capacity. The stock of reusable products may be used for remanufacturing if the remanufacturing capacity which confines the remanufacturing rate is adequate. To prevent an endless accumulation of reusable products a controllable disposal mechanism has to be developed that exhaust them if they remain unused for some time unit depending on type of product characteristics. Here, we also discuss the return obligations imposed by environmental legislation. We assume that there is elasticity in the demand, due to the "green image" of the firm. This "green image" effect on product demand depends on the market's awareness that the specific producer supports and promotes product collection recovery, reuse and resell.

In order to limit the length of paper we can also exhibits various flows inactions within the chain as shown in figure 2. These point flows are governed by decision rules (policies). Every decision rule can be considered as information handling process. Here information feedback mechanisms couple the stocks to the flows and closes the loops in the system.

4. IMPROVING THE SYSTEM DYNAMICS MODELING APPROACH

Research within this class is seeking to make a methodological contribution by extending and improving the application of System Dynamics Modeling to closed loop supply chain management. Current study shows extensive range of different methods in this direction (Wadhwa & Jain 1999). Some approaches target the application of the simulation tool to the application domain, for instance, the combination of SD with management science others to the operation research approaches. Further a number of works is concerned with the combination of

Decision Support with System Dynamics Modeling, as Akkermans (1995) demonstrates with SD with Participative Business Modeling. Therefore, here we present integrated and participative business modeling approach to system dynamics framework in order to improve its application in CLSC.

4.1 Integrated System Dynamics Framework

On the basis study conducted on the case of a two-echelon steel industry supply chain, Hafeez et al. (1996) demonstrated the application of systems engineering to the supply chains and describe an integrated system dynamics framework, with the aim of giving an example to good total systems design. This modeling exercise can also be used to design a closed loop supply chain by moving towards a minimum reasonable inventory, capacity constraints, and virgin and remanufactured material supply lead-time bottlenecks for both production and retrieval system. This complex combination of integrating forward and reverse chain acts as one of the major problems in modeling a closed loop supply chains. By using an integrated system dynamics framework (Naim and Towill 1994), we can make an effort to take into consideration the complex details associated with modeling attitudinal, organizational and technological issues related to designing of an integrated CLSC. Here figure3 presents a generic system dynamics methodology. In this model whole procedure is divided into two phases. The first phase is qualitative phase of the system.

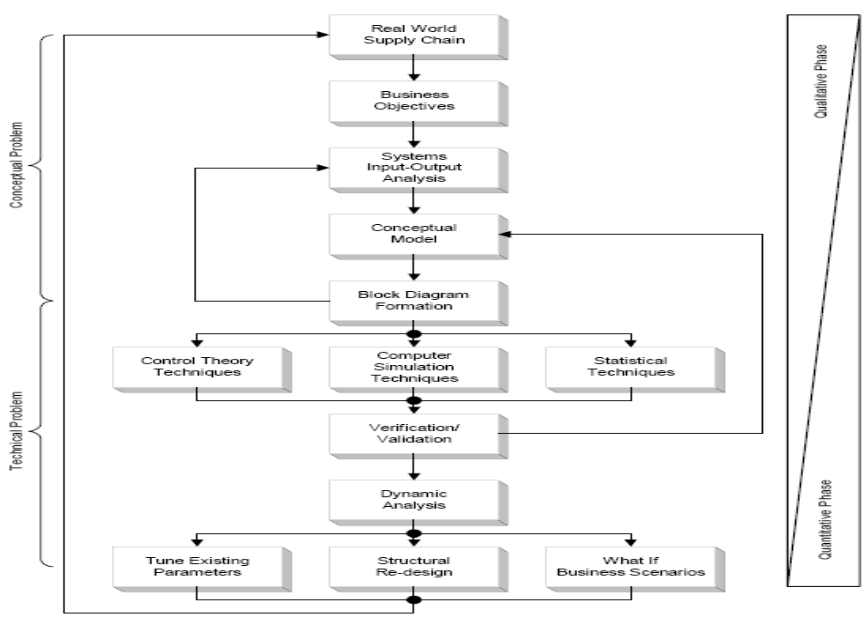

Figure 3. System Dynamics Methodology for CLSC (adapted from Towill, 1995)

During this phase, the influence diagram of the model is built and then transformed into a flow diagram. The second phase is the quantitative analysis of the system. During this phase flow diagram is translated into simulation program and is then verified and validated. The program is executed for what-if scenarios and the results are analyzed same to be done in SD modeling.

After simulation and analysis several different scenarios based on a real-world cases the developed model can be viewed as generalized integrated system dynamics framework and can be tested regarding its effectiveness in various (other) sectors of forward and return chain. While integrated system dynamics framework for closed loop supply chain one should design the whole system in that allow holistic approach, through decomposition of the forward and return chain into distinct autonomous business units. After going through overlapping phases of qualitative and quantitative analysis, the partial models then are combined to represent the complete closed loop supply chain. The qualitative phase is concerned with the acquisition of intuitive and conceptual knowledge sufficiently comprehensive to understand the structure of chain and operation related to manufacturing and remanufacturing. Input-output analysis, conceptual modeling and block diagramming form part of this phase, which is aiming to deal with the conceptual problem. While dealing with technical problems during the quantitative phase, the development and analysis of mathematical and simulation models become focus of the approach.

4.2 Participative Business Modeling Framework

While designing and improving the application of System Dynamics Modeling to closed loop supply chain management we can use “Participative Business Modeling” (PBM) approach by Akkermans (1995) to address not only the technical, but also the organizational complexities inherent in the development of forward and reverse logistics strategies. Nowadays there are few methods that generally focus on technical complexity, and although they are also well versed in tackling these issues, often the implementation success does not come up to the expectations. This is due to low management participation and the resulting lack of commitment towards the proposed strategies. Participative Business Modeling combines intensive management participation with thorough analysis and extensive modeling, aiming to facilitate learning about strategic issues of closed loop supply chain and therefore the gaining of insights decision-making in dynamic industrial management problems.

Starting with qualitative analysis, the method gradually leads to more formal, quantitative modeling. PBM draws from several different methods, including System Dynamics Modeling, Operational Research, Social Sciences and process consultation, and aims to combine them for greater benefits. It contains an implicit conceptual model which can be used as technique that can specifically be used for long-term, chronic, dynamic management related problems and effective strategic decision-making in closed loop supply chain. Figure 4 shows the conceptual model for the PBM in CLSC.

Participative Business Modeling comprises of four project phases:

(1) The definition phase, using cognitive mapping of all the process involved in both forward and reverse direction the supply chain;

(2) The model conceptualization phase where we employ brainstorming, causal loop diagramming, and stock and flow diagramming for the CLSC

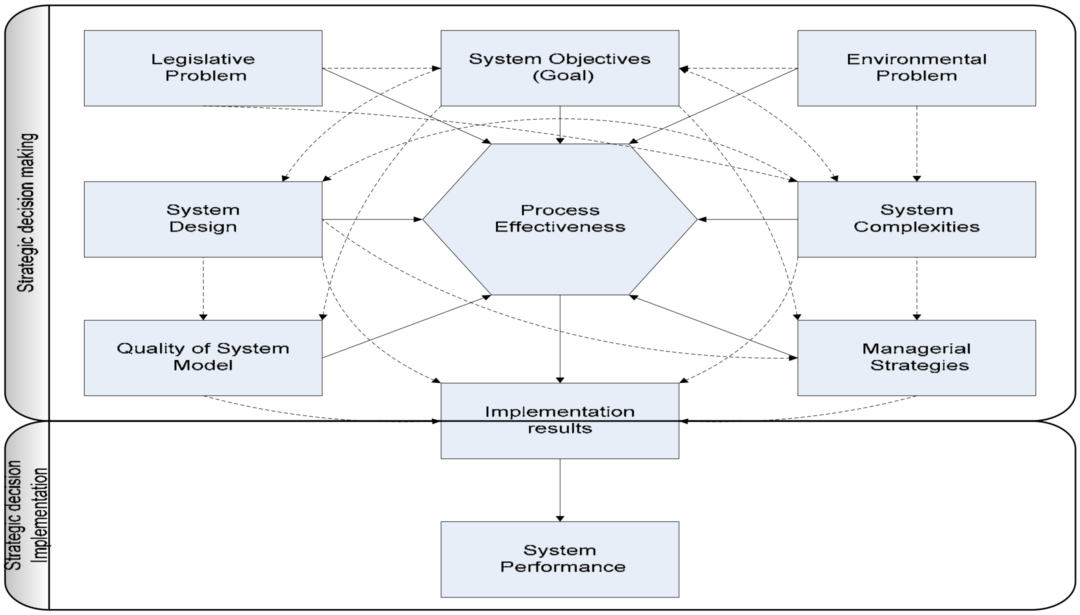

Figure 4. A Conceptual Model for Strategic Decision-Making in CLSC

(3) The model formalization phase, where System Dynamics Modeling as well as discrete event simulation can be applied; and

(4) The knowledge dissemination phase, where simulation models can be used for sensitivity and state analysis.

Here in this study we have identified two types of constrains:

Firstly, technical complexities regarding designing products for return, time-critical operation after products has reached to sorting/inspection centre, marketing for remanufactured product, environmental and legislative constraints, and the requirement of efficient and effective forward and reverse logistics structure; and

Secondly, organizational complexities include management support and geographically separated decision-makers. In applying the PBM method, the involved management should go through phase of structured interviews.

Further quantitative models are developed, before these models are finally used to understand and improve the performance of the proposed closed loop supply chain system. Thus this model can be used to analyze various scenarios and identifying efficient policies for the whole system. Thus, it may prove useful to policy-makers/regulators and decision-makers dealing with long-term strategic closed loop supply chain management issues along with researchers in environmental management.

5. CONCLUSION

This paper has presented the SD-based modeling framework and addressed the need for improving the application of system dynamics modeling for closed loop supply chain. The model also considers for ever increasing environmental concerns impose constant pressure on regulators for stricter policies and/or legislation. The developed model allows the comprehensive description and analysis of the system operations, alternative environmental protection policies involving a take-back obligation and a "green image" effect on product demand. The model can also be used to develop and analyze various scenarios (i.e. to conduct various "what-if" analyses) and answer questions about the long-term operation of supply chains using total supply chain profit as the measure of performance. The model can further be tailored and used handling for wide range products after return in a closed loop supply chains. Thus, it may prove useful to policy-makers/ regulators and decision-makers dealing with a wide spectrum of strategic closed loop supply chain management issues.

REFRENCES

[1] Akkermans, H. A. Developing a logistics strategy through participative business modeling *International Journal of Operations & Production Management*,1995: 15 (11), 100-112.

[2] BarlasY System dynamics: systemic feedback modeling for policy analysis in knowledge for sustainable development—an insight into the encyclopedia of life support systems. Paris, France, Oxford, UK, *UNESCO Publishing*, Eolss Publishers, 2002.

[3] De Brito M, Dekker R. A framework for reverse logistics, Dekker R, Fleischmann M, Interfurth K, Van Wassenhove L, editors. Reverse logistics-quantitative models for closed-loop supply chains. Berlin, *Springer*; 2004: 3–27.

[4] Davey, S. Personal communication with the authors World wide product returns manager, Inkjet Products Group, *Hewlett-Packard Company*, 2001.

[5] Forrester, J. W. *Industrial dynamics*, Cambridge, MA, MIT Press, 1961

[6] Fleischmann M, Dekker R, Van der Laan E, Van Numen J, VanWassenhove L, Ruwaard J. Quantitative models for reverse logistics: a review, *European Journal of Operational Research* 1997: 103, 1–17.

[7] Hafeez, K., M. Griffiths, J. Griffiths, and M. M. Naim. Systems design of a two-echelon steel industry supply chain. *International Journal of Production Economics*1996:45, 121-130.

[8] Handfield R, Walton S, Sroufe R, Melnyk A. Applying environmental criteria to supplier assessment: a study in the application of the analytical hierarchy process, *European Journal of Operational Research* 2002:141(1), 70–87.

[9] Naim, M. M., and D. R. Towill. Establishing a Framework for effective Materials Logistics Management. *International Journal of Logistics Management* 1994:5 (1), 81-88.

[10] Van der Laan, E., Salomon, M. and Dekker, R., "An Investigation of Lead-Time Effects in Manufacturing/Remanufacturing Systems under Simple Push and Pull Control Strategies", *European Journal of Operational Research*, 1999: 115, 195-214.

[11] Wadhwa, S., Jain, A. M., "Simulation Study of a Decision Focused Supply Chain Model**",** Studies in Informatics and Control, 1999: 8(3), 133-147.

[12] Wadhwa, S. & Madaan, J. Role of Quality Management Self Assessment Model to Promote Reverse Logistics Operations, *ICQCC–2004*, Bangkok ,2004

[13] Sterman, J. D. Business dynamics: Systems thinking and modeling for a complex world, *McGraw-Hill*, New York, 2000.

[14] Towill, D. R. Industrial dynamics modelling of supply chains, *Logistics Information Management*, 1996: 9 (4), 43-56.