British Journal of Business Design & Education
ISSN (Print): 2222-7426, ISSN (Online): 2222-8412
Vol 09 No 02

Supply Chain Performance and System Dynamics Modeling: A Literature Review

Md. Aynul Hoque
aynulsae@gmail.com
Lecturer (Management),
Room#2007, School of Business, Independent University, Bangladesh (IUB)

Qantara Khaleda Khan
qantarak@gmail.com
Lecturer (Management),
Room#2007, School of Business, Independent University, Bangladesh (IUB)

Abstract
Any integrated supply chain encompasses all the operations related to cost, quality, delivery and flexibility that arise from the very first suppliers to the end customers. As a result, it requires setting some best practices to measure the supply chain performance to control and improve operational efficiency and effectiveness. When all these variables are simultaneously taken into consideration then the scenario can optimize the business efforts although the situation becomes quite complex. This dynamic complexity can be handled through system dynamics modeling. Articles that provide best practices for measuring supply chain performance as well as inter-connection with system dynamics are very rare. This paper attempts to provide a review of best practices on supply chain performance measurement and system dynamics modeling solely in the field of supply chain management.

Keywords: Supply chain performance measurement, system dynamics modeling, standard parameters for supply chain, supply chain metrics.

Literature Review

British Journal of Business Design & Education
ISSN (Print): 2222-7426, ISSN (Online): 2222-8412
Vol 09 No 02

1.0 Introduction:

When the concept of supply chain management evolved as a management tool that can increase competiveness and ameliorate business performance, simultaneously the concept and efforts of measuring supply chain performance came into existence. There is a saying that "if you cannot measure what you do, you cannot control and improve it" which is very much applicable to supply chain performances. Many scholars used different attributes and metrics to measure the effectiveness of supply chain. Some argued for financial indicators and others argued for non-financial indicators as the performance measurement of supply chain. Although there is no consensus on performance measuring parameters or indicators in all industries or any single industry to date, a number of researchers have shown common measures that are used in particular sectors and others (Tan, 2002) have shown cross-industry performances that they have experienced in practice.

The reasons of not having a uniform and common measurement practices are mainly the breadth and complex relations that lie among the partners in a multi-tier supply chain. Measuring the performances of a single business organization becomes comparatively easier. However, measuring and establishing standard practices becomes very complex and difficult when it encompasses all the partners resting in the upward and downward multi-tiered relation in a supply chain (Khare *et al.*, 2012). Although, it is problematic and there are no 100% common SC performance measurement practices, researchers took initiatives and wrote scholarly articles on this issue and some (Chan *et al.*, 2003) argued that measurements of business activities which are performed along the whole supply chain have to be measured and compared to adopt timely steps for maintaining and improving the performance of business. Scholars and academicians have published their works on SC performance measurement and some of the most cited are briefly explained in the following section.

2.0 Methodology of review:

The starting point of this review was searching in online journals and Google scholars. The key words for searching were "supply chain performance measurement and system dynamics modeling", "modeling supply chain performance in system dynamics", "modeling in system dynamics" and "measuring and modeling supply chain performance". We reviewed more than 50 articles from management and supply chain related journals. After careful reading and consideration, 10 were found to be the most relevant to integrate supply chain performance and system dynamics modeling. Thus, the basis and focal point of this review are 10 carefully selected articles. Table1 presents the list of the journals and respectively number of selected articles.

Table1: list of articles with related journals

Name of journal	Number of articles
Journal of Management and Strategy	1
Management Decision	2
Supply Chain Management: An International Journal	2
International Journal of Advanced Manufacturing Technology	1
International Transactions in Operational Research	1
The Journal of Supply Chain Management	1
Industrial Engineering & Management Systems	1
Management Science	1

3.1 Framework proposed by Gunasekaran (2004):

Gunasekaran (2004) introduced three distinguished levels based on the responsibilities and authorities of managers to measure and implement performances of supply chains. These measures are in strategic, operational and tactical levels. All these levels have different priority functions and policies as well as they require different levels of managerial involvements. This approach is basically placing emphasis “on measurement systems and approaches as opposed to specific measures” (Gunasekaran 2004).

Strategic level: This level deals with the measurements that are basically involved in manipulating the decisions taken by the top management including “broad based policies, corporate financial plans, competitiveness and level of adherence to organizational goals” (Gunasekaran 2004).

Tactical level: Similarly, tactical level involves the processes of monitoring how efficiently the resources are allocated, how closely the performances are achieving as compared to those were set in strategic level, how the feedback from mid-level management are influencing in decisions that are being taken (Gunasekaran 2004).

Operational Level: Operational level is involved in the processes where analysis of routine operations are carried out, evaluation of decisions are done which are carried out by the junior managers and where shop-floor workers and supervisors prepare their daily operational objectives (Gunasekaran 2004).

Gunasekaran (2004) further developed a set of metrics that will enable us to determine and compare SC performance and explained the metrics in detail (see table 2).

Table 2: Metrics to measure performances (source: Gunasekaran 2004)

Activities/processes	Strategic activities	Tactical activities	Operational activities
Plan	Perceived value of product by users	average time for queries by customers	Order entry method
	Variances against budget	Product development cycle time	Human resource productivity
	Order lead time	Accuracy of forecasting techniques	
	Information processing cost	Cycle time of planning process	
	Net profit Vs productivity ratio	Order entry methods	
	Total cycle time	Human resource productivity	
	Total cash flow time		
	Product development cycle time		
Source		Supplier delivery performance	Ordering cycle management for purchasing
		Lead time of suppliers against industry average	Pricing of suppliers' against industry average
		Pricing of suppliers' against industry average	
		Ordering cycle management for purchasing	
		Procedures of ordering to suppliers	
Make/ Assemble	What products and services are targeted for business	Defective products' ratio	Defective products' ratio
		Hourly operational cost	Hourly operational cost
		Capacity utilization	Indices to measure human resource output
Deliver	Ability of service system to meet fluctuating customer demand	Ability of service system to meet fluctuating customer demand	Quality of delivered goods
	Efficiency and effectiveness of whole distribution planning	Efficiency and effectiveness of whole distribution planning	On time delivery of goods
		Effectiveness of invoicing system for deliveries	Effectiveness of invoicing system for deliveries
		Reliability of deliveries	Reliability of deliveries

British Journal of Business Design & Education
ISSN (Print): 2222-7426, ISSN (Online): 2222-8412
Vol 09 No 02

3.2 Framework proposed by Chan (2003):

Chan (2003) proposed the analytic hierarchy process (AHP) of SC performance management framework with the combination of both qualitative and quantitative metrics. Before proposing the structure, he mentioned that existing performance management systems (PMSs) have at least two major weaknesses and he tried to solve the shortcomings of the existing PMSs in his proposed AHP based method. These two existing shortcomings are:

- Lack of combination of both the financial and the non-financial measurement approaches, which are also named as balanced approaches, are not considered in most PMSs.
- The second most visible shortcoming according to Chan's (2003) opinion that present PMSs do not consider the supply chain from the system's point of view and do not encompass all the upward and downward partners in every single tier of relationships in the chain.

So, Chan (2003) included two variables from quantitative perspective such as cost and resource utilization. Then, he also included other five (5) measures from qualitative aspects. These qualitative measures are quality, flexibility, visibility, trust, innovativeness. Chan (2003) acknowledged the difficulty of measuring qualitative variables whereas quantitative variables like cost and resource utilization are comparatively easier to express in number. Finally, Chan (2003) proposed two levels of sub-criteria for each measurement parameters to express in some quantifiable number or ratios. For example, "trust" has four components in sub-criteria level 1 which are input, process, output and improvement.

And every of those have further components in sub-criteria level 2. For example, input has sub components of "labor" and "machine", process has "material handling", "routing" and "operation"; output has "volume", "mix" and "delivery"; and improvement has "modification", "new product" and "expansion" Chan (2003). Then, Chan (2003) further mentioned measurement criteria for every sub-criteria level 2. Thus, total 32 sub-criteria were suggested to measure SC performance in his proposed framework. Then AHP software can rank among the variables depending on the industry and importance of SC performances for that industry as well as can provide up-to-date ranking of performance by changing priority and variation.

3.3 Framework proposed by Beamon (1999):

Beamon (1999) first explained an overview of supply chain performance measures that were widely practiced and referred during 1990 to 1996. The common SC performance measures were cost minimization and sometimes a combined measurement of cost and responsiveness to customer demand. This simplicity and insufficiency led Beamon (1999) commenting that those performance measures were not complete and appropriate because some qualitative dimensions such as "customer satisfaction", "exchange of information" and "management of risk" were not yet incorporated in the SC performance systems and SC modeling up to 1999. After reviewing the shortcomings of the existing performance measurement systems, Beamon (1999) proposed a new framework that includes strategic goals of the company and intra-organizational relations and actions among supply chain partners.

The proposed supply chain measurement system consists of components that are aligned with strategic goals of a supply chain. These are measurements of resources, output and flexibility. These three measures help to attain desired efficiency, better customer service and satisfaction, and able to respond to changed environments in the market. Measures are inter-related and they consist of individual performance measures.

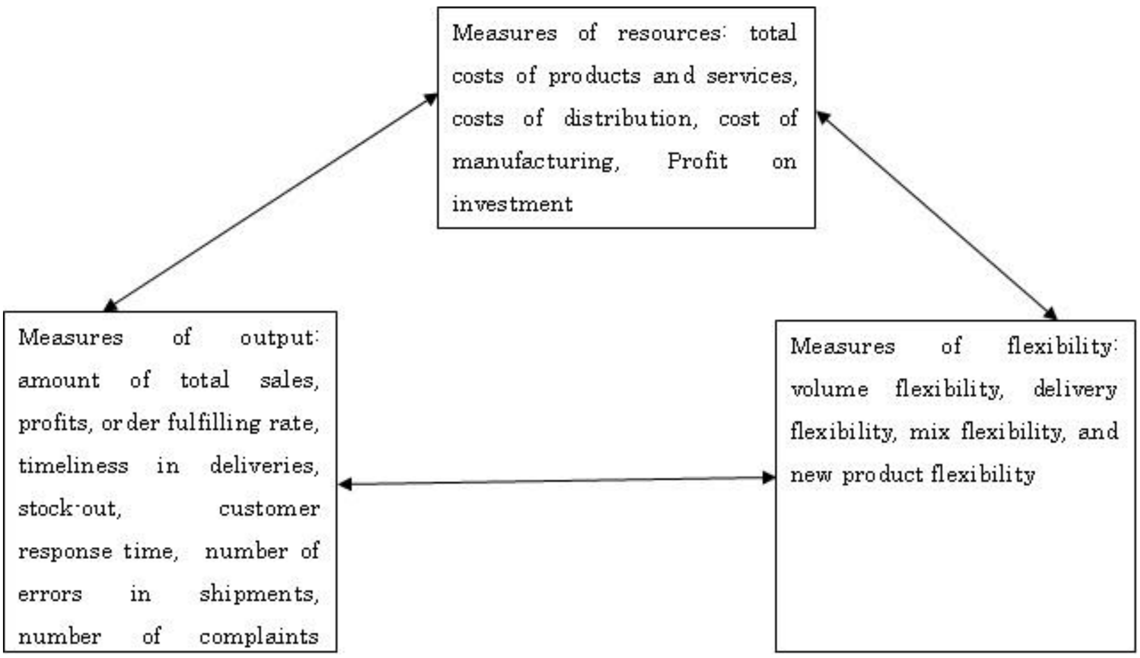


Figure1: System for measuring supply chain performance (source: Beamon, 1999)

As the system is illustrated in the figure 1; measures of resources include costs of resources that are used in the supply chain are "distribution costs including transportation and handling, manufacturing costs including labor, maintenance, re-work; inventory costs of materials, obsolescence, work-in-process, finished goods" (Beamon, 1999). Measures of output include customer responsiveness as well as quality and quantity of products that are produced within a supply chain. Total revenues, the percent of requested orders that are filled, on-time deliveries, stock-out probability, etc., are considered as measures of output in the model. Flexibility pertains to how the supply chain is capable of being maintained if the volume of final products is changed, planned delivery is fluctuated, product mix is changed and new product introduction and modification of existing products are needed.

3.4 Framework proposed by Felix (2003):

According Felix et al. (2003), they have proposed an innovative PMS that overcomes the shortcomings of existing systems including the systems proposed by Beamon (1999) and Gunasekaran (2004). Supply chain (SC) performance is divided into qualitative and quantitative categories where "customer satisfaction, flexibility, information and material flow information, effective risk management and supplier performance" (Felix 2003) are categorized as qualitative performance measures. However, "cost minimization, sales, profit, investment on inventory, return on investment, fill-rate, customer response time, lead time and capacity utilization" (Felix 2003) are categorized as quantitative SC performances because these metrics can somehow be expressed in numbers. Felix (2003) also developed a fuzzy set model to measure SC performances of any complex supply chains. This system is termed as an innovative system (Felix 2003). The system does not only look into a company or some parts of the supply chain, but it also considers performances of the whole supply chain network starting from the suppliers of supplier up to the end customer. Thus it is also called a system-thinking approach. First, appropriate performance measures are selected from each process and then, a "performance measurement team (PMT)" (Felix 2003) is formed to measure and evaluate the metrics. Finally, weighted average score is given and index for every measure is calculated using a fuzzy set algorithm. As a result, it is called both a system-thinking and a process-based approach to PMS.

3.5 Framework proposed by Theeranuphattana and others (2012):

Theeranuphattana (2012) developed a new model to overcome the shortcomings of existing good models, (Chan and Qi, 2009; Felix 2003) which are complex because they use fuzzy set models. This new model employs the level 1 of SCOR model and evaluates SC performances using the three approaches Multi-attribute Value Theory (MAVT), Swing Weight, and Eigenvector method. The proposed model is

British Journal of Business Design & Education
ISSN (Print): 2222-7426, ISSN (Online): 2222-8412
Vol 09 No 02

advantageous because it can convert the preference of managers to a 5-point or a 7-point likert scale into numerical scores. Finally, all SC performance measures can be expressed into a single index through integration process. Thus this model is very helpful and easier than other methods that use fuzzy sets and complex algorithms.

A set of metrics of numerous performance variables from SCOR model consisting of "Perfect Order Fulfillment (POF), Order Fulfillment Cycle Time (OFCT), Upside Supply Chain Flexibility (USCF), Upside Supply Chain Adaptability (USCA), Downside Supply Chain Adaptability (DSCA), Supply Chain Management Cost (SCMC), Cost of Goods Sold (COGS), Cash-to-Cash Cycle Time (C2C), Return on Supply Chain Fixed Assets (ROSCFA), Return on Working Capital (ROWC)" (Theeranuphattana 2012) included in the model. The major drawback of this method is that it does not include parameters such as "customer satisfaction, trust, information flow" (Felix 2003) which are also important in a supply chain; rather, it mostly deals with cost and financial measurements.

3.6 Supply chain operations reference (SCOR) model:

SCOR is one of the few approaches that deal with the designing of strategic issues in a supply chain (Huang 2004). The schematic diagram (see figure 2) of SCOR model shows that it encompasses "the five management processes plan, source, make, deliver, and return" in a supply chain (supply chain organization, 2013).

Figure2: Supply chain framework proposed by SCOR (source: www.supply-chain.org, 2013)

SCOR has integrated three major processes that are process redesign or business process re-engineering (BPR), bench marking and determining best practices in an industry. As the figure shows, SCOR model considers all phases from the stages of a supplier's supplier to a customer's customer. Thus, it is an integrated approach. SCOR uses five attributes that are reliability, responsibility, agility, cost and assets to set measurement metrics for any supply chain. Then SCOR sub-divides the metrics into three levels. Level 1 metrics are usually called key performance indicators (KPI) of the supply chain and these KPIs basically help to determine strategic objectives of an organization. Level 2 is a diagnostic of level 1 to identify causes of poor performances. Similarly, level 3 helps to diagnose and identify poor performances of level 2 metrics.

4.0 What is System Dynamics?

System Dynamics is evolved mainly from industrial dynamics that was first written by Jay W. Forrester in 1961. Forrester (Industrial Dynamics, 1961: 13) explained industrial dynamics as a complex system of inter-dependent industrial organizations; this interdependence changes over time as information feed-back changes and is thus called a dynamic system. Sterman (2000) used industrial dynamics for analyzing business systems depending upon changing information and time. Thus system dynamics is very useful to craft future policies for running businesses in a complex environment as time changes. In addition to tangible factors, it can also be used to model intangible factors that are not easily measureable such as human behavior, customer satisfaction, and employee skills. Simulation of intangible factors is sometimes called strategic simulation because it does not actually quantify the exact numerical value, but shows a pattern of the likely outcome for intangible factors when they are acting in various feedback loops with inter-relations, change over time, or demonstrate a dynamic behavior.

There are two structural ways to analyze any dynamic systems: ‘causal loop diagram’ (CLD) and ‘stock and flow diagram’. CLD diagrams can be used to show the governing inter-relations among a number of different variables using feedback loops. A positive feedback loop means the dependent variable moves in the same direction as that of the independent variable; as such, the polarities are assigned as a plus (+) sign on the arrowhead of feedback loops. In the case of negative feedback loops, if the independent variable increases, the dependent variable decreases and vice versa. Thus a minus (–) sign is assigned to the arrowhead of the feedback loop.

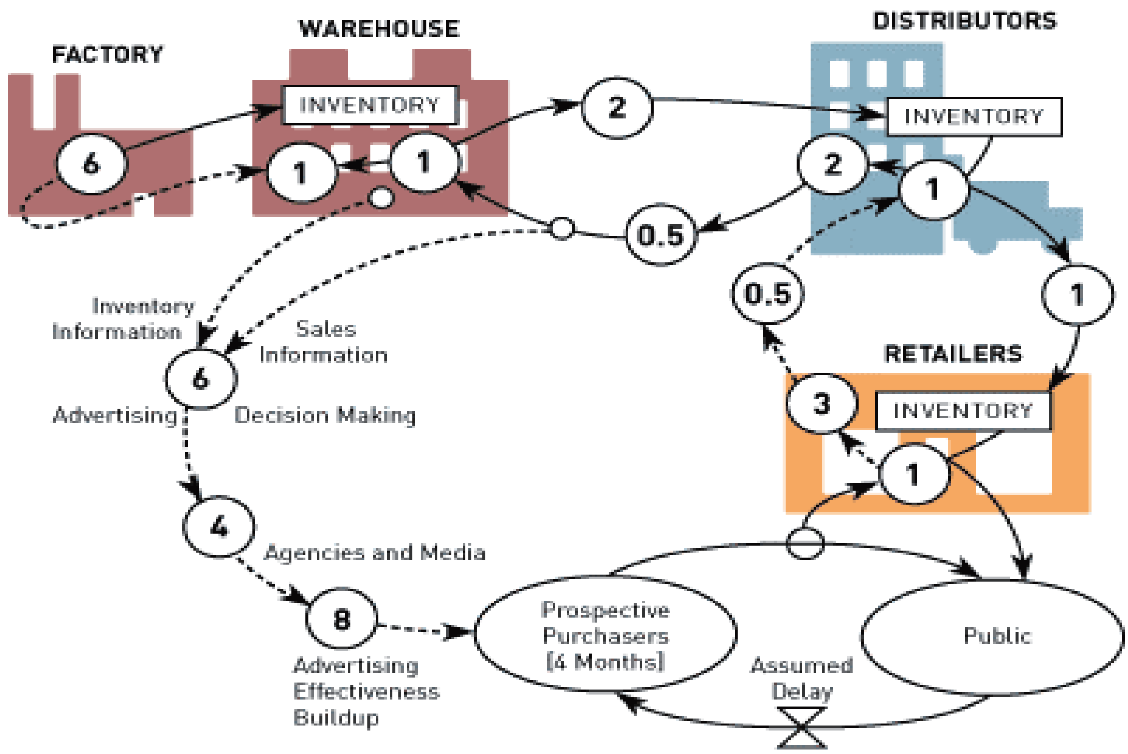
The other structure of system dynamics is a stock and flow diagram that is used to explain both variables, i.e. the stocks and flows. Stocks refer to the status of variables at a point/moment of time while flows exist during a period of time. Stocks are accumulated over time through inflows and outflows. Apart from stock and flow variables, another kind of variable called an ‘auxiliary variable’ has been used here.

British Journal of Business Design & Education
ISSN (Print): 2222-7426, ISSN (Online): 2222-8412
Vol 09 No 02

Auxiliary variables are used to connect stocks and flows to each other as well as to themselves. By using all these three kinds of variables, we can explain dynamic systems more appropriately. Many researchers and authors have used stock and flow diagrams to model and describe supply chain performance variables (Agarwal and Shankar 2005; Campuzano and Mula 2011).

4.1 Model proposed by Forrester (1961):

The first supply chain modeling based on system dynamics was proposed by Forrester in 1958, and then he expanded the basic model in 1961 in his book "industrial dynamics". Thus system dynamics is originated from industrial dynamics in 1958. The "Forrester-Model" interacts with "the flows of materials, orders, money, personnel, capital equipment, and information" (Forrester, 1961). The model included supply chain partners in a four-tier relationship consisting of "factory, warehouse, distributor and retailer" (Forrester, 1961). Thus, Forrester's model was clearly a step toward introducing integrated supply chain since it included stages from suppliers to customers.



Source: Adapted from "Industrial Dynamics: A Major Breakthrough for Decision Makers," *Harvard Business Review*, July–August 1958

Figure3: The Forrester production-distribution system

Then, Forrester (1961) carried out simulations using Dynamo assuming different policy implications. Of the analyses carried out by Forrester, the bullwhip effect or demand amplification, delay in decision making, inventory fluctuations, centralized and decentralized controls, and information flow were considered as focal points to simulate forecasted future scenarios that are still the most confronted issues in modern and international supply chains. Forrester (1961) also identified and prescribed some basic rules of system dynamics ranges from problem identification to model building which are also valid till date.

4.2 Model proposed by Barlas and Aksogan (1999):

This is one of the very few system dynamics models that deals with apparel industry. The model basically developed various inventory policies to reduce costs for retailers and distributors in apparel business. Barlas and Aksogan (1999) included four levels of the tiered relationship: “manufacturer, wholesaler, retailer and end customer” in their model, which is similar to the model proposed by Forrester (1961) except that supplier is excluded. They (Barlas and Aksogan, 1999) actually developed a simulation model by using system dynamics so that the model can suggest reducing costs and maximizing retailers’ sales volume of apparel goods. The second objective of the model was to test different policies that could be adopted to forecast the scenarios.

A stock and flow diagram was made for the model and, then, many simulations were run under changing conditions such as different order policies, market demands or fluctuations, various inventory positions. After running numerous simulations, they found a new result from the model that the same order policies cannot be effective both in continuous and discrete/periodic inventory management systems. Finally, Barlas and Aksogan (1999) proposed new ordering policies for apparel retailers, which is a “partially continuous and partially discrete inventory system”.

4.3 Model proposed by Towill (1996):

In the paper, Towill did not build a model specific for supply chain management; rather, he had discussed different methodologies and ways to develop system dynamics models to redesign and re-engineer parameters in a supply chain. The paper concluded with the comment that “best results are most likely to be obtained by adopting a holistic approach in which the basic disciplines of industrial engineering

British Journal of Business Design & Education
ISSN (Print): 2222-7426, ISSN (Online): 2222-8412
Vol 09 No 02

and business process re-engineering are integrated into a comprehensive methodology which starts with modeling a real-world situation and outputs an updated supply chain with enhanced competitive performance" (Towill, 1996). Towill presented an input-output framework for building SD models that are primarily based on the "Cardiff Industrial Systems Dynamics Group Re-engineering Methodology" (Towill, 1996). This methodology was successfully implemented for planning and implementing supply chains. Towill (1996) suggested that the knowledge of four inputs (see figure 4) is necessary to build effective models for supply chains.

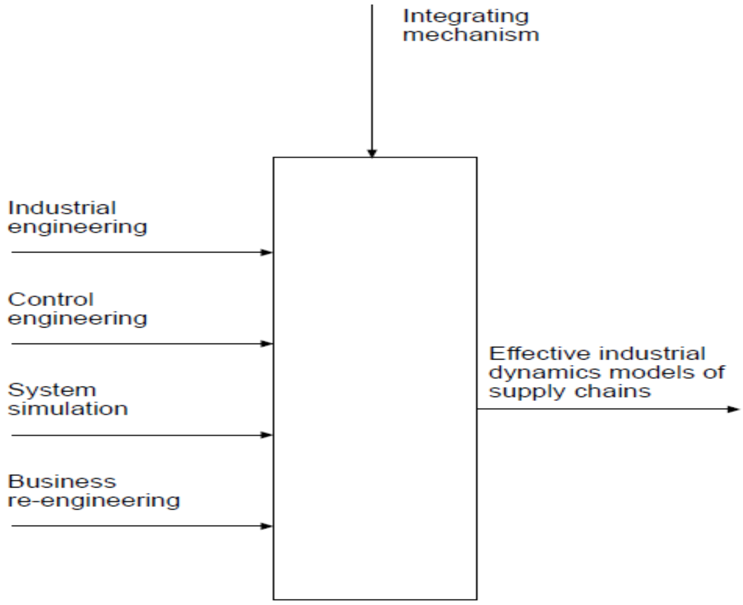


Figure4: input-output diagram for building system dynamics model for supply chains (Source: Towill, 1996)

4.4 Model proposed by Ge and others (2004):

Ge (2004) developed a system dynamics model for supermarket chain in UK using MATLAB. This model basically deals with demand amplification or bullwhip effect. And the effect of information sharing, information distortion, information delays and forecasting methods were tested on demand amplification of supermarket chains in UK. Therefore, this system dynamics model is mainly about information feedback and the bullwhip effect with causal relationship. Ge (2004) built the model using five subsystems or tiers in the supply chain; these are "the end consumers, the retailer's store, the retailer's distribution centre, the manufacturer's factory, and its procurement system" (Ge 2004). The simulation results of this model show that mutually sharing of necessary information among suppliers and buyers within every tier relationship in a supply chain is very important to enhance supply chain performance.

British Journal of Business Design & Education
ISSN (Print): 2222-7426, ISSN (Online): 2222-8412
Vol 09 No 02

4.5 Model proposed by Sterman (1989):

Sterman built a system dynamics model for managing stocks (see figure 5), which can be applicable "in many situations such as raw material handling, production control, or at a macroeconomic level, the control of the stock of money". Sterman (1989) further explained that, "*in most realistic stock management situations the complexity of the feedbacks among the variables precludes the determination of the optimal strategy*". After building the model, Sterman (1989) conducted a "Beer Game" production-distribution system in a simulated environment and all the actors were asked to minimize costs as their primary objective. However, actors could not behave rationally to minimize costs by managing inventories due to time delays in multiple feedbacks along the supply lines and the decision making process was not perfect for global optimization but the actors were rational for local optimization.

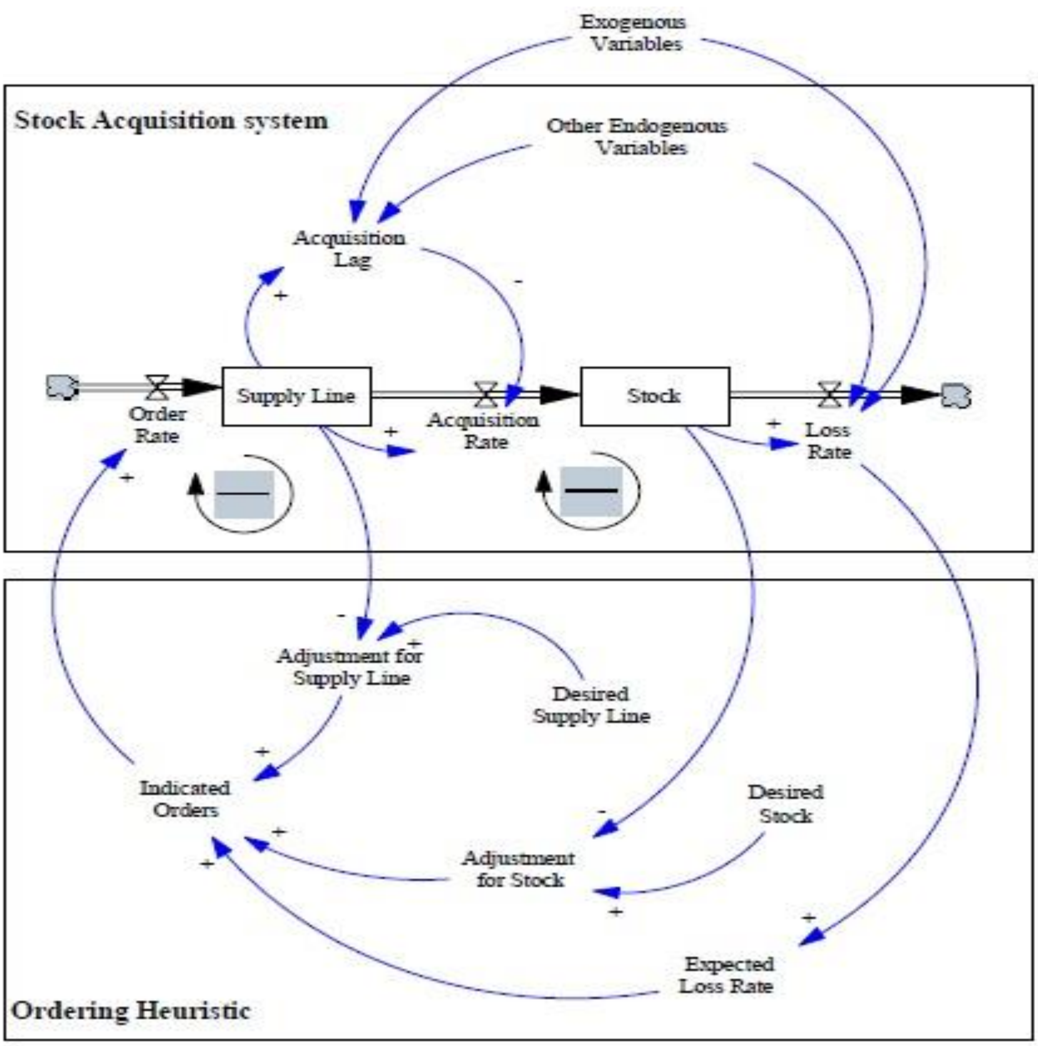


Figure5: System dynamic model for stock management (Source: Sterman, 1989)

5.0 Conclusion:

This paper is intended to provide an overview of useful measurement approaches and system dynamics modeling in any supply chain. There are multiple researches that have measured and modeled SC performances in previous decades, but all the concepts of measurements and models are not widely accepted both in academia and industries. We have discussed some of the SC performance measuring frameworks that are either combining in terms of both quantitative and qualitative measuring metrics or widely referred in scholarly articles. System dynamics modeling has become popular in SC management in last two decades although it was first coined by Forrester in 1961. Our research shows that SD modeling in inventory and stock management is quite abundant, but it has few modeling on fashion or apparel industry specifically in terms of lead time management and combining all the qualitative and quantitative variables. Therefore, these are the important scopes of further research in SC with system dynamics modeling. Thus, we believe that this article will help researchers to find a quick and brief overview on both supply chain management and system dynamics modeling as well as their interactions. Finally, further research should be carried out on supply chain modeling in apparel industry focusing on lead time, cost, quality and delivery simultaneously.

References:

1. Ambuj Khare and Anurag Saxsena (2012) ‘Supply Chain Performance Measures for gaining Competitive Advantage: A Review’, *Journal of Management and Strategy,* 3(2), 25-32.
2. Barlas, Y. and A. Aksogan (1999), ‘Product diversification and quick response order strategies in supply chain management’, (available at: http://www.ie.boun.edu.tr/~barlas/wwwpape2.html)
3. Chan, F. T. S., Qi, H. J., Chan, H. K., Lau, H. C. W. and Ip, R. W. L. (2003), ‘A conceptual model of performance measurement for supply chains’, *Management Decision, 41(7), 635-642.*
4. Chan, F. T. S. and Qi, H. J. (2003), ‘An innovative performance measurement method for supply chain management’, *Supply Chain Management: An International Journal,* 8, 209-223.
5. Chan, T. T. S. (2003), ‘performance measurement in a supply chain’, *International Journal of Advanced Manufacturing Technology,* 21, 534-548
6. Felix, C. H., Q. Chan., H. Chan., Henry, C. W., Lau, R., and Ip, W. L. (2003), ‘A conceptual model of performance measurement for supply chains’, *Management Decision,* 41(7), 635-642.

7. Ge, Y., Yang, J. B., Proudlove, N. and Spring M. (2004), 'System dynamics modeling for supply-chain management: A case study on a supermarket chain in the UK', *International Transactions in Operational Research,* 11, 495-509
8. Huang, S. H., Sheoran, S. K. and Wang, G. (2004), 'A review of supply chain reference (SCOR) model', *Supply chain management: An international Journal*, 9(1), 23-29.
9. Sterman, J. D. (1989), 'Modeling Managerial Behavior: Misperceptions of Feedback in a Dynamic Decision Making Experiment', *Management Science,* 35 (3):321-339
10. Theeranuphattana, A., Tang, J. C. S., Khang, D. B. (2012), **'**An Integrated Approach to Measuring Supply Chain Performance', *Industrial Engineering & Management Systems*, 11(1), 54-69
11. Tan, K. C. (2002), 'supply chain management: practices, concerns and performance issues', *The Journal of Supply Chain Management,* winter, 42-43