A SYSTEMS SCIENCE PERSPECTIVE FOR SUPPLY CHAIN MANAGEMENT

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ABSTRACT

The Supply Chain Management (SCM) is a socio-technical system designed and managed to deliver products and services from raw materials to end customers through a logistic network of physical, information, financial and human resources.

The physical components of a typical supply chain include several production facilities, inventory warehouses, modes of transportation and distribution channels.

In order to synchronize demand of end products or services with supply of raw materials cash flow and human resources, it is necessary to have an information system like the popular Enterprise Resources Planning System (ERP) improved with some additional specific modules to strategic planning and corporate management of the Supply Chain.

Of course the Supply Chain Management requires an especial organization different from the traditional hierarchy. The paper will describe a recursive special organization for the Supply Chains Management based on the Viable Systems Model (VSM). This model of organization takes in consideration several feedback cycles of the production systems the local future and vital interaction between the market and the supply chain.

Incidentally, the inventory system in a supply chain has a special attribute that needs too much attention. It is called bullwhip effect (quite similar to the butterfly effect) because small changes in the demand downstream the supply chain; generate extreme changes in the supply positions upstream. It means that the inventories can quickly move from being backordered to being in excess.

Keywords: SCM, ERP, VSM, bullwhip effect, resilience, variety

INTRODUCTION

Supply chain management (SCM) is going to be the main management process for production systems in the XXI Century. This management process will take care of the flow of materials, information, purchased parts, personnel and financial needs supplied from different vendors, sometimes geographically too far from the main production plant. The industry of domestic appliances is a good example of the supply chain management. Before SCM a production systems designed their products itself and manufacture all the subassemblies and components and gave after sale service during and after warranty period.

Systems Science Perspective for SCM

After SCM the new production systems "comakership" several aspects of the production process, for example hermetic compressors for fridges, plastic parts and motors for washing machines, electrical components, etc. SCM provides different management principles to help in the designed planning and controlling the network of suppliers in order to synchronize the variability of customer's demand with the variability of capacity of suppliers. One management principle is called Ashby's law:" the variability of the manager system should be more than or equal to the variability of the managed system".

In order to speak correctly about SCM let see how is the official definition expressed by the Association for Operations Management in their APICS Dictionary (Blackstone, 2008): SCM is "The design, planning, execution, control, and monitoring of supply chain activities with the objective of creating net value, building a competitive infrastructure, leveraging world-wide logistics, synchronizing supply with demand, and measurement performance globally". The previous definition emphasizing the main functions of production systems management as follows: the design of the supply chain when it is going to be a new corporation, the **planning** of operational and strategic activities, the scheduling and **execution** of the production planning, the **control** and solution of conflicts and the monitoring and auditing of the production processes . The financial management to create **net value** to all stakeholders: owners, employers, employees, society and environment. In the following section of this paper, it is going to be described in more detail each one of the manufacturing functions of Supply Chain (SC), considering a systems approach based on the five components of the Viable System Model (VSM) by Beer (1985). Supported by the popular business/industrial information system called Enterprise Resources Planning (ERP).

After the theoretical description of the SCM via a systemic approach, it will be presented an application of fractal theory to improve inventory management synchronization of supply with demand considering a frequent phenomenon in sequential processes of SCM, called bullwhip effect. The financial management to create net value to all stakeholders: owners, employees, society and environment. An actual example of SCM implementation was reported by Proctor (2010) in the case Dupont, a multinational company with headquarters in Willington, Delaware. The company has operations in more than 70 countries and diverse product lines including agriculture, nutrition, electronics, communications, home products, etc. DuPont managers "credit the corporate survival and success during the recession to their employees's strong SCM knowledge which has given them visibility across business units. DuPont started in this area with kaisen, Lean and Six sigma. Once low cost sourcing was added SCM was a natural segue" (Proctor, 2010:12). Dupont management started to rely on demand planning (Customer Relationship Management, CRM), raw-material planning (Material Requirement Planning, MRP), finish-to-stock (FTS), package-to-order (PTO) and make-to-order (MTO) strategies, tightened delivered schedules (Master Production Schedule, MPS) logistic flexibility (Distribution Requirement Planning DRP) and effective sales and operation planning (S&OP); all of this functions belong to the management of SCM via ERP. I this paper it is used the terms Manufacturing Systems and Production Systems as synonymous.

SYSTEMS SCIENCE

In order to be in accordance with the title of this paper, it is convenient to define some systems concepts:

- ✓ *Environment*. The context, within which a system exists, includes everything that may affect the system and may be affected by it at any given time.
- ✓ *Function*. Denotes actions that have to be carried out in order to meet system's requirement and attain the purposes of the system.
- ✓ *General System Theory*. The concepts, principles and models that is common to all kinds of systems and isomorphism among various types of systems.
- ✓ *Human activity system*. A system with purpose, that expresses some human activities of definite purpose; the activities belong to the real world.
- ✓ *Model building*. A disciplined inquiry by means of which a conceptual (abstract) system's representation is constructed or an expected outcome/output representation is portrayed. There are models of function structure (like a still picture) and models of processes (like a motion picture).
- ✓ *Resilience*. The ability to bounce back from large scale disruptions.
- ✓ *Subsystem*. A greater system's component is made up of two or more interacting and interdependent components. The subsystems of a system interact in order to attain their own purpose(s) and the purpose(s) of the systems in which they are embedded.
- ✓ *System*. A group of interacting components that keep some identifiable set of relationships with the sum of their components in addition to relationships (i.e. the systems themselves) to other entities.
- ✓ *Systems Science*. The field of scientific inquiry whose objects of study are systems (Klir, 1993:27 in Francoise, 2004) and its structure is composed of a domain, concepts, theories and methodologies.
- ✓ *Variety*. Number of possible states that a system is capable of exhibiting (Beer, 1979).
- ✓ *Viable System Model (VSM)*. It is a system able to maintain a separate existence, capable of maintaining its identity and transcend independently.

The System Science use models to represents real systems, for example the Viable System Model (VSM) was elaborated by Beer (1979) to represent manufacturing/productions systems like the SCM.

The VSM presents a new way of looking at an organizational structure. It is a recursive model in which each successive unit is nested within the next larger one. It is a pre-eminent way to manage variety. It is a logical structure which differs from a classical hierarchical organizational chart but helps management to organize effectively the Production System. According to the VSM in any viable system, there are five systems interactively involved in any organization that is capable of maintaining its identity and transcend independently of other organizations within a shared environment (Beer, 1989). If an organization survives in a particular sort of environment, it is viable. All manufacturing systems are embedded in a continuously changing environment of sociopolitical World Economy. Success in global and local markets with social satisfaction requires constant unrelenting efforts to develop more viable manufacturing systems, aware of quality and sustainability. The VSM is organized on five subsystems/elements that in this paper are designed as 1) operations management, 2) coordination, 3) auditing/monitoring, production management, 4) general management, and 5) board of directors. In a VSM, System 4 is concerned with the future (the outside and then: Budget of long range forecast and marketing) as opposed to system three's concern with the present (inside and now: the best integration and coordination of existing resources. production logistic such as master production schedule, resources requirement planning, materials & capacity). Sales and operation management (S&OP)is a typical system one function managed by System 3, monitored by System 3 (auditing/monitoring) and coordinated (avoiding conflicts) by System 2.

In order to interconnect the five subsystems of VSM, it is necessary to add an integrated information system like Enterprise Resources Planning Systems (ERP). The ERP have received considerable attention recently, not only in the management of manufacturing industry but also within the services industries and their financial management. The VSM is recursive and ERP supports the management of each recursion. For example, in each component of SC there are 5 recursions levels, starting from Warehouse Management (WM) to Material Requirement Planning (MRP), to Manufactory Requirement Planning (MRPII), to Enterprise Resources Planning (ERP), and to Supply Chain Management (SCM). In each recursion level, there are emergent properties like the two categories of demand: independent demand and dependent demand in MRP; the feedbacks in the closed cycles in MRPII; the local, future and total environments, the interactions between the market and the Production System in ERP and the Law of requisite variety helps to manage complexity of SCM.

THE VIABLE SYSTEM MODEL: DESCRIPTION

Human organizations are much more complex than we are usually prepared to admit. Organization charts do not show how the organization really works, and in fact, real-world systems have variety which is effectively mathematically infinite. Consider the system as a traditional production model. The Operation is the element which does things. The Management is the element which controls the doers. And the Environment is the surroundings in which they function. The variety in the surrounding Environment will always be greater than that in the Operation, which in turn will be greater than that in the Management of the Operation. In order to cope with its environment, the Operation needs to match its variety to that of the Environment. In order to manage the Operation, Management needs to match its variety to that of the Operation. The Operation can cope with its Environment, as long as it can successfully absorb the variety from it, by attenuating the incoming variety, and amplifying its own variety back to it. Likewise, Management can cope with the Operation as long as it can successfully absorb the variety from it, by attenuating the incoming variety, and amplifying its own variety back to it. Here it is very important to take into account the Ashby's Law of Requisite Variety, which stated that control can be obtained only if the variety of the controller is at least as great as the variety of the situation to be controlled (Ashby, 1957). If these requirements are met, the system can maintain itself in a state of dynamic equilibrium, which is called self-organized system. If these requirements are not met, the system will become unstable and eventually leading to its collapse.

What persists in self-organized systems is the relationship between the components, not the components themselves. They have the ability to continuously re-create themselves, while being recognizably the same. This ability to maintain identity is related to the fact that these systems have purposes. These purposes provide the framework for their maintenance of identity.

The Viable System Model (VSM) claims to reveal the underlying structures necessary for a system to meet the criterion of viability. The VSM methodology was developed by the cybernetician Stafford Beer (Beer, 1972). The criteria of viability require that organizations are or become ultra stable, i.e. capable of adapting appropriately to their chosen environment, or adapting their environment to suit themselves. The VSM models the structures of the organization and the relationships between them. This includes key processes, communications, and information flows. The VSM has been used as a diagnostic tool in different contexts (Espejo & Harnden, 1989). Not only in the management of the manufacturing industry e.g. the explanation of the general production management model of the Enterprise Resources Planning Systems (Tejeida et al, 2010), but also in the financial management and in the service industry. The model is composed of five interacting subsystems. Kinloch *et al* (2009) states in summary, that systems 1-3 are concerned with the “here and now" of the organization's operation, system 4 is concerned with the “there and then" - strategical responses to the effect of external, environmental and future demands of the organization and system 5 is concerned with identity, values, mission and polices directives which keep the organization as a viable entity.

Briefly: System 1 Produces the system refers to the fundamental operations within a viable system which enclosed several primary activities. Each primary activity is itself a VSM. System 2 consists of a regulatory center for each element of system 1 and allows system 3 to monitor and coordinate the activities of system 1.

System 3 is responsible for system 1 control and provides an interface with Systems 4/5. System 3* has an audit function to monitor various aspects of the accountability relationship between System 3 and System 1. System 3* might assure that the quality of service, safety standards, financial information, internal control, etc are in order. System 4 has the purpose to look outwards to the environment to monitor how the organization needs to adapt to remain viable and need a feed back through system 3. Strategic Planning plays a big roll into this system to pursue a well connection between System 5 and System 3. System 5 is responsible for policy decisions. The former role effectively defines the identity and ethos of the organization - its personality and purpose.

In addition to the five subsystems, there are some principles to make the system viable (Beer, 1979): a) Managerial, operational and environmental varieties diffusing through an institutional system tend to equate; they should be designed to do so with minimum damage to people and cost. b) The four directional channels carrying information between the management unit, the operation, and the environment must each have a higher capacity to transmit a given amount of information relevant to variety selection in a given time than the originating subsystem has to generate it in that time. c) Wherever the information carried on a channel capable of distinguishing a given variety crosses a boundary, it undergoes transduction; the variety of the transducer must be at least equivalent to the variety of the channel. d) The operation of the first three principles must be cyclically maintained through time without hiatus or lags**.**

Modeling a General SCM with VSM and ERP

In fig. 1. It is presented an SCM according to the VSM interconnected with ERP

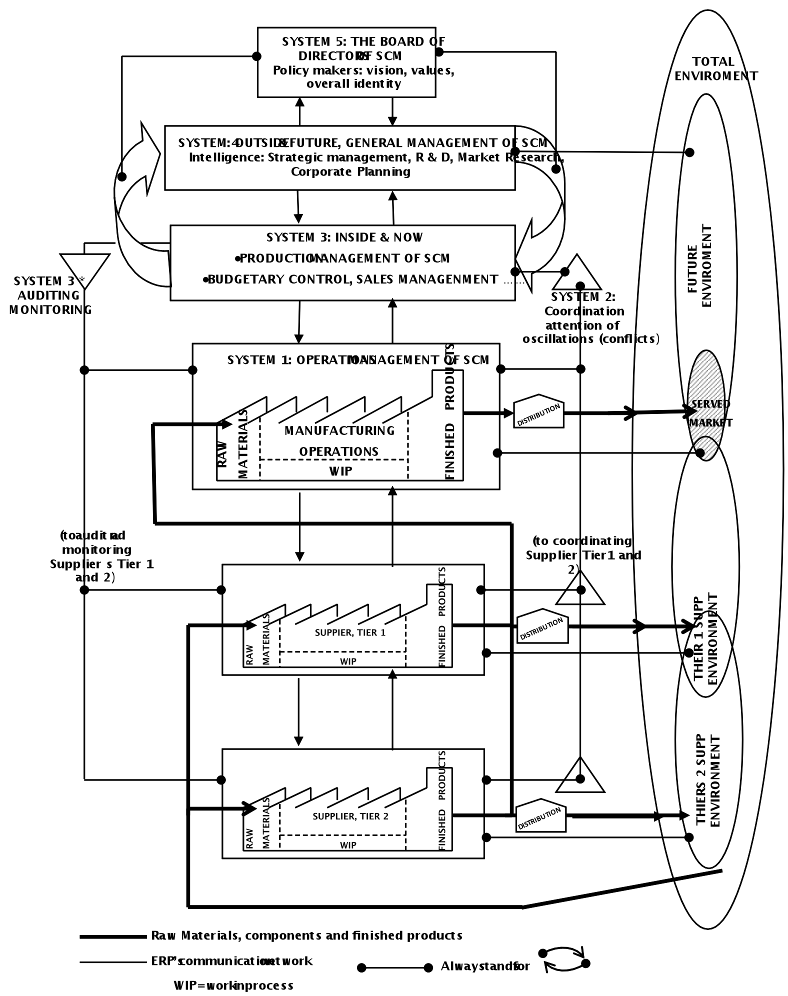

Fig. 1. A General Supply Chain Management Model based on VSM

System 1: The System 1 of a production system produces the system and consists of the various components directly concerned with carrying out the tasks that the production in a system is supposed to be doing, such as the tasks performed by some of the following ERP modules (See Table 1).

Each manufacturing department and or supplier is connected to the wider management system by the vertical communication channels to receive instructions and to report performance, preferable on standard electronic screens to manage variety. In order to be viable systems each manufacturing department or supplier should be autonomous and be able to make its own decisions according to the Master Production Schedule (MPS), shared thru ERP. The multiuser ERP system helps to reduce the bullwhip effect.

System 2: This system has a coordination function whose main task is to assure that the various manufacturing departments and or suppliers of a production system act in harmony, damping their oscillations so that common resources and support services are run smoothly avoiding the archetypical situation know as the "tragedy of the commons". Decisions of System 2 are based on what is best for the whole which is often different from the best for a particular manufacturing department (Leonard, 2008). It is the System 2's job to oversee the interaction between departments and to stabilize the situation to obtain a balance response from system 1. Normally this coordination function is located inside the Manufacturing Engineering office and uses some modules of ERP (see Table 2).

Table 1. ERP's Modules for System 1 of VSM.

1. Sales and operation management (SOP) to develop tactical and strategical plans to achieve competitive advantage	2. Customer Relationship Management (CRM) to understand and support existing and potential customers needs
3. Quality Function Deployment (QFD) to ensure that all major requirements of the "voice of the customer" are incorporated in the product or service	4. Master Production Schedule (MPS) to reflect the anticipated production schudule
5. Material Requirement Planning (MRP) and informatics algorithm that processes data from BOM, IM and MPS	6. Capacity Requirement Planning (CRP) to determine in detail the amount of labor and machine resources required to accomplish the MPS
7. Bill of Material (BOM), a file of the product structure	8. Bill of Processes (BOP)
9. Shop floor Control (SFC)	10. Production Activity Control (PAC)
11. Suppliers Relationship Management (SRM)	12. Total Quality Control (TQM)
13. Maintenance Management (MM)	13 Distribution Requirement Planning (DRP)

Table 2. ERP's Modules for System 2 of VSM

- Production Scheduling (MPS)	- Quality control of major Raw Materials
- Work procedures / Bill of processes (BOP)	- Maintenance Management (MM)

- Supply Chain Event Management (SCEM)	- Manufacturing Auditing (MA)

*Systems 3 and 3**: System 3 is a command control function. It interprets policy in the light of internal data from System 2 and monitoring or auditing reports from System 3*. The task of the last one is to give system 3 direct access to the state of affairs in the operations of System 1 including Total Quality Management (TQM), Total Productive Maintenance (TPM), of each manufacturing department and or suppliers.

Through this channel, System 3 can get immediate information, rather than hinged on information passed to it by the localized management of manufacturing departments and or suppliers. For example to check directly on quality, maintenance procedures, employee comfort, etc.

The ERP modules that help System 3 to command and accomplish its management and control functions are shown on table 3.

From the accounting and financial perspective, there should be one of two fundamental objectives in a production system. One is to obtain the capability to produce a product or service that can be sold at a profit represented by A/R, A/P, F/A, etc. The second is to improve an existing product or service so as to improve performance and customer acceptance, or reduce cost with the help of "Activity Basic Costs" (ABC) without sacrificing customer acceptance either of which would lead to higher profits. From the information processing point of view, the capacity of managers in System 3, of carrying out the control function, needs to be in balance with the current information flowing through the three incoming channels: 1) Coordination from system, 2) auditing / monitoring from system 3*, and 3) command from System 1.

Table 3. ERP' Modules for System 3 and System 3* of VSM.

Shop Floor Control (SFC)	Financial Business Modules like:
Manufacturing Execution System (MES) (to control and monitoring of plant-floor machines and electromechanical systems)	Activity Based Costing (ABC) to get real cost of finished products or services
Input – Output control and Production Activity Control (PAC) (to control details of production flow)	Accounts Payable (AP)
Human Resource Management (HRM) (for payroll, time management benefits administration, etc.)	Accounts Receivable (AR)
Plant and Equipment Management (FA) (Fixed assets management)	General Ledger (GL)
Shop Floor Control (SFC)	Fixed Assets (FA)
Manufacturing Execution System (MES) (to control and monitoring of plant-floor machines and electromechanical systems)	Payroll (PR) for salary administration

Total Quality Management (TQM) Total Productive Maintenance (TPM)	Profit and cost center accounting, etc.

*Systems 2 (coordination), System 3** (Auditing & monitoring) and System3 (production management) are highly dependent on timely and accurate reporting of what is happening in System 1 (operation management, manufacturing operations and its environment). It makes no sense to install an expensive data collection subsystem of ERP if the data are not close to real time as possible (Turbide, 2007). The big dream of accountants is not to be faced with the "month end" syndrome and real time data approach to a solution because the ERP systems are updated all the time (Currant & Keller, 1998). ERP changes the accountants´ role in System 3 because they have more time to assist management in System 3 as general advisors who can use the numbers to reduce variety and improve management of System 1. Real time data are subject to statistical filters of variety and processes to help achieving a better management of the System 1's variety.

Real time data contribute to auditing/monitoring coordination and control of System 1 through some additional ERP´s modules and functions such as: 1)Advanced Planning System (APS), 2)Available to promise and capable to promise functions (ATP), 3)Production Activity Control (PAC), and 4)Inventory Management (IM).

System 4: System 4 performs the research and development function of a manufacturing SC system, it has two main tasks:

1) Translate Instructions and reports between System 5 Board of Directors and the lower – level systems.
2) To capture all relevant information for the production system, about its total environment.

If the manufacturing SC system is to be viable and effective it has to, somehow, match the variety of the environment in which it finds itself. To do this it must have a model of the environment that enables predictions to be made about the likely future state of the environment and allow the production system to respond in time to threats and opportunities.

System 4 is the point where internal and external information can be brought together for the Strategic Business Units (SBU's). A company's products are typically grouped into Strategic Business Units with each SBU evaluated in terms of strengths and weaknesses vis-á-vis similar business units made and marketed by competitors. Activities such as Strategic Planning, Market Research, Research and Development and public relations should be located there.

The ERP modules that can help perform the tasks of system 4 are shown on table 4:

Table 4. ERP's modules for System 4 of VSM.

Human Resource HR	Advanced Planning System (APS)

Product Life Cycle (PLC)	Long Range Forecasts (LRF)
Legal and Fiscal Planning	Business Planning under various scenarios

The data base of the Human Resources module (HR) helps to build a portfolio of human resources, evaluated with high potential, for HR Requirements planning in order to have the right managers and employers in the right amount and in the right time.

The Advanced Planning System/Master Production Schedule (APS/MPS) are feed forward systems which processes current information of operations with future ideals and adjust the output model accordingly.

One of the most important responsibilities of system 4 is to keep adaptation mechanisms of the production systems with its future environment, represented by groups of investors, shareholders, governments, unions, communities, etc.

System 5: System 5 is responsible for the direction of the whole production system; it is where identity and coherence are focused by the board of directors. System 5 activities include formulating policy on the basis of all information passed to it by system 4 and communicating the policy downward to system 3 for implementation by the manufacturing departments and or suppliers. System 5 must ensure that the production system adapts to the external environment while maintaining an appropriate degree of internal stability. It is the thinking part of the production system. There are no modules of ERP to help activities of system 5. It is recommended for developers of ERP systems to design modules for consensual agreements, strategies and policies based on methodologies such as Syntegrity from S. Beer, (1994) Interactive Management from J. Warfield (1994) or CogniScope from Christakis (2007) Algedonic information coming directly from system 1 to system 5 helps to manage critical situations and to improve resilience: the ability to bounce back from large scale disruptions, such as random, events, accidents, negligence or intentional disruptions.

BULLWHIP EFFECT IN SUPPLY CHAIN MANAGEMENT

General Description

The "bullwhip effect" is a variation of Ashby's Law only variety can absorb variety (Beer,1985) it refers to the phenomenon that experienced supply chains when replenishment orders generated by a stage exhibit more variability than the demand the stage faces. For instance, by examining the demand of Pampers disposal diapers, management people in Procter & Gamble realized that retail sales were fairly uniform, however the distributor's orders issued to the factory fluctuated much more than retail sales (Lee, 1997a). Because all variability is typically attenuated by buffered, the bullwhip effect has important consequences for the system wide efficiency of the supply chain. Hence, it is necessary to understand what cause this phenomenon. Lee, Padmanabhan and Whang (1998b), identified four factors that lead to the bullwhip effect: batching, forecasting, pricing and gaming behavior, which suggested some options for mitigate it. Bullwhip effect has been analyzed in academic for some time. This phenomenon suggests that demand variability increases as one move upstream in a supply chain. Forrester (1961) observed that factory production rate often fluctuates more widely than does the actual consumer purchase rate and stated that this was consequence of industrial dynamics. Sterman (1989) reported an experiment of a simulated inventory distribution system played by four people who make independent inventory decision without consultation with other chain members, just relying on orders from the other players instead. This experiment was call “Beer Distribution Game” and shows that the variance of orders amplify as one moves up in the supply chain i.e. bullwhip effect. Sterman attributes this phenomenon as misperceptions of feedback of the players.

Lee et. al. (1997b) analyzed the demand information flow in a supply chain and identified four causes of the bullwhip effect: demand signal processing, rationing game, order batching and price variations. By identifying these causes, the authors concluded that the “combination of sell through data, exchange of inventory status information, order coordination and simplified pricing schemes can help mitigate the bullwhip effect". Chen et. al. (2000) quantified the bullwhip effect in a simple supply chain of two stages. The model includes the demand forecasting and order lead time, which are commonly factors that cause the phenomenon. The work is extended to multiple stage centralized and decentralized supply chains. The study demonstrates that the bullwhip effect can be mitigate but not eliminated. Daganzo (2003, 2004) has been studied the bullwhip effect in the frequency domain. He argued that the bullwhip effect is trigger with all operational inventory control policies, independent of demand process but showed that advance demand information in future order commitments can eliminate the bullwhip effect without giving up efficiency under a family of order up-to policies. Dejonckheere et. al. (2003) used control theory to analyze and illustrate the bullwhip effect for a generalized family of order-up-to policies.

The study of supply chain from the point of view of complex dynamical systems theory has started only recently (Helbing, 2008). Concepts from statistical physics and nonlinear dynamics have recently been used for the investigation of supply networks (Radons and Neugebauer (ed.), (2004)). Helbing (2003) generalized concepts from traffic flow to describe instabilities of supply chains. This work remark how small changes in the supply network topology can have enormous impact on the dynamics and stability of supply chains. In order to stabilize the supply chain, some strategies are mention on Radons and Neugebauer (ed.) (2004).

By simulation a supply chain model, Larsen et al (1999) showed a wide range of nonlinear dynamic phenomena that produce an exceedingly complex behavior in the production distribution chain model. Hwarng and Xie (2008) used chaos theory through the Lyapunov exponent across all levels of a specific supply chain. They showed that chaotic behaviors in supply chain systems can be generated by deterministic exogenous and endogenous factors. They also discovered the phenomenon “chaos amplification”, i.e. the inventory becomes more chaotic at the upper levels of the supply chain.

Two causes of bullwhip effect are: a) the serial nature of communicating replenishment orders up to the supply chain b) the inherent transportation delays of moving product down the supply chain.

Fortunately, the bullwhip effect can be attenuated or eliminated by engineering such as synchronizing the supply chain by mean of an effective Enterprise Resources Planning System (ERP) and a Viable System of organization. Both systems of information and organization technology facilitate to company partners the necessary collaborative business planning, forecasting and replenishment processes.

CONCLUSIONS AND RECOMMENDATIONS

The Systems Science perspective provides a framework to better comprehend the Supply Chain Management System. This approach described how to adequate the VSM and ERP to the case of Manufacturing SC. Each subsystem of the VSM represents several functions from the shop operations up to Board of Directors. The idea of this work is to provide also the ability to balance both internally and externally factors, making the SCM adaptable to changes of its environment.

Bullwhip effect is a phenomenon experienced by supply chains when demand at the top tends to exhibit more variability than demand at the bottom. This work provides new insights to develop a new model of the supply chain management which capture the characterization of the supply chain in order to attenuate its current upstream variety.

Some recommendations Follows:

1) Avoid barriers due to lack of trust between suppliers and manufacturers
2) Collaborate with suppliers to interface the ERP modules to their production systems
3) Integrate ERP with all Tiers of critical Suppliers
4) Educate a train suppliers in operation of specifics ERP modules such as: MPS, MRP, BOM, IM,CRP, DRP and S&OP
5) Other concepts from systems theory, systems dynamics, knowledge management, complex systems, etc. can also be analyzed in a future research to incorporate methodologies or concepts that help better understand the dynamics of the supply chain management system; however, this initial proposal can be use as a guide for diagnosing SCM's.

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