The Bullwhip Effect: Concretization of Entropic Information Dissipation in Supply Chain Systems

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ABSTRACT

Supply chains represent complex and dynamic systems that incorporate autonomous firms interacting with one another to fulfill a common goal, while insuring their own ones. These firms' behaviors are considered to be non-linear and sometimes unpredictable. This makes information transfer in the supply chain complex and causes instability when information transferred is incomplete or incorrect. This instability is characterized by the Bullwhip Effect that represents concretization of entropy, namely the degree of disorder within a system. In this paper we develop a new analytical approach assuming that the bullwhip effect is a consequence of the entropy of the supply chain system that is represented by information dissipation.

Keywords: Supply chain system, entropy, information dissipation, bullwhip effect.

1. INTRODUCTION

In this last century, firms evolve in an extremely complex environment, constituted by open markets, globalization of sourcing, advancements in and intensive use of information technologies, decreasing product lifecycles, and increased demand. This complexity is intensified by consumers who are becoming increasingly demanding in terms of product quality and service. These pressures have led companies to focus on their core business, resulting in outsourcing of less profitable activities. Most of these companies have opted for specialization and differentiation strategies, resulting in rapid new market growth and intensified flow between all actors. The intensity and ever increasing complexity of these flows has further destabilized the environment in which companies evolve. Globally the system has become extremely volatile, making planning and predicting quite difficult for all actors concerned. Streamlining processes and flows through the value creation system has also become rather problematic as a result. To cope with this complexity, firms have adopted new business models around the concept of networks.

According to systems theory, supply chains can be considered as dynamic and complex systems composed of autonomous firms that interact with one another contributing to fulfilling a common goal. These firms' behaviors are actually non-linear, varying between cooperation and conflict. Firms create value by cooperation and capture it by competition. Zouaghi and Spalanzani [13] characterized this type of system as ago-antagonistic, in which bipolar strategies can be considered constructive, even if conflicting. One of the most important characteristics of this kind of system is its dissipative structure meaning that a supply chain is subject to information loss over time [2]. Dissipations in supply chain systems are due to several non-linearities emerging from different activities, such as demand forecasting, inventory management, transport management, production management, replenishment, warehousing, to mention but a few.

2. SUPPLY CHAIN SYSTEMS, ENTROPY AND INFORMATION DISSIPATION

Changing dynamics between the supply chain and its environment challenges management approaches inherited from Cartesian linear analytical thought. Linear thinking concerning demand forecasting and local optimization is no longer adequate when faced with increasing complexity of supply chains due to the factors seen above such as globalization, information technologies, etc. Unlike the Cartesian reductionist view, system thinking sees the supply chain as a whole, representing more than the sum of its parts. Put simply, the supply chain has been defined by David et al. [4] as "a system of people, activities, information, and resources involved in creating a product and then moving it to the customer". Stevens [11] defines it as "a system whose constituent parts include material suppliers, production facilities, distribution services and customers linked together via the feed-forward flow of materials and the feed-backward flow of information". Put otherwise, we can say that a supply chain is a system composed of a set of companies that interact with each other by way of different kinds of flows (material, financial, information, knowledge and relational) to serve a common goal, which is customer satisfaction, within an uncertain environment.

Walker et al. [12], define uncertainty as "any deviation from the unachievable ideal of completely deterministic knowledge of the relevant system". This uncertainty can be materialized in a supply chain by demand uncertainty, production uncertainty and delivery uncertainty [3]. This uncertainty renders difficult supply chain system behavior predictability and thus lucid decision making. If we broaden our vision, we can say that a company's decision-making is a process requiring availability of reliable, exhaustive and real-time information and knowledge. The lack of these elements often results in decisions being made locally, without a global vision, and not taking into account the majority of potential knowledge issues that could optimize supply chain operations. For example, Zouaghi [14] studied the issue of tacit knowledge generation and inter-organizational memory development in a supply chain context, and shows that developing distinctive competencies in a complex context comes from tacit knowledge learning, creation and memorization in a holistic approach that integrate individuals and companies within the supply chain system.

Moreover, supply chain dynamics oscillate between two main states: Order and Disorder. Basically, organization of the supply chain system is the ordering of existing disorder. Initially, the supply chain exists whether managed or not. So, the better a supply chain is managed, the less entropy subsists. Entropy is the effect of system disorder. For example, the more companies (as sub-systems) focus on local optimization at the expense of global optimization, the greater the entropy over the entire supply chain system. This entropy is principally generated by antagonistic subsystem behaviors due to nonlinear supply chain dynamics.

As we have seen above, the supply chain represents a complex system which is dynamic in nature. This is mainly due to complex, dynamic interactions undertaken between different subsystems which embody supply chain members. This complexity creates conditions conducive to the emergence and spread of different types of disturbances. These disturbances may have varying degrees of intensity depending on their causes and their initial conditions. While uncertainty remains the main cause, sources of disturbance in the supply chain system can be intrinsic or extrinsic. Extrinsic ones come from the environment in which the supply chain evolves, like for instance, the unpredictability of market demand. The second source of disturbance is intrinsic and derives from the supply chain itself, like planning or execution of logistics operations such as transportation, production and inventory management for example. Davis [5] distinguishes defines three categories of uncertainty in a supply chain, namely supply uncertainty, process uncertainty and demand uncertainty.

Most companies configure their supply chain to achieve "regular operational conditions". However, this is not always possible because "regular operational conditions" are distorted by disturbances, consequently producing dissipations within the supply chain. As defined in hard sciences, dissipation is energy loss in dynamic systems over time resulting from phenomena creating a disturbance. When applied to non-linear or chaotic systems dynamics, Prigogine and Stangers [9], cited by Saint-Amand [10], state that dissipative structure "reflects the association between the idea of order and the idea of waste and was purposely chosen to express the new fundamental fact: the dissipation of energy and matter, usually associated with ideas of performance loss and evolution towards disorder, becomes, far from equilibrium, a source of order". So, when joining order and disorder, entropy is manifested in complexity [10].

There are two main dynamics in which flow evolves (Table1). In the first, a system is stable and disturbances can be controlled, so actions can be performed to reduce small perturbations which have arisen over time. Here, flows are laminar and their cadence is regular, and their evolution in time and space is linear and predictable. The second dynamic is only visible if disturbances exceed a certain threshold. Thus, the initially laminar flow suddenly becomes a turbulent one after a short transition period. The disturbances are amplified and give rise to instabilities that make flows nonlinear and dissipative. The dissipation of flow is manifested by the non-spatiotemporal predictability of its evolution. The transition from laminar flow to nonlinear or chaotic flow depends on the speed of shift and acceleration of disturbances. All this depends on the initial conditions which determine the transition from a laminar flow to a turbulent one.

Dynamics	Laminar	Transient	Turbulent
Disturbances	quasi non-existent	sparsely intense	considerable
Flow	quasi clocked	non linear	chaotic
Stability and regularity	stable and regular	stable and irregular	unstable and irregular
Dissipation	insignificant	substantial	very important

Table1: Systems dynamics and their characteristics

Supply chain stability mainly depends on flow dynamics. Making the analogy between flow dynamics in fluid mechanics and supply chains can be interesting as it helps one understand how these dynamics evolve over time. Thus, we can equate the supply chain to a pipe in which the fluid flow represents physical and information flows. So, as they are laminar, flows evolve in a stable, steady and linear way in time and space. When extrinsic and intrinsic disturbances caused by different sources of uncertainty (demand forecasting, planning and execution of business processes) appear and cannot be mitigated, the supply chain dissipates flows to maintain a certain level of stability. The Bullwhip effect illustrates this well by showing how uncertainty related to market demand amplifies disturbances in the supply chain by increasing inventory levels, disrupting production and distribution, and by creating a disjuncture between the information flow and the physical flow of products that become as a result asynchronous in the form of supply chain information system dissipations. We will now characterize these dissipations in greater detail.

3. THE BULLWHIP EFFECT: CONSEQUENCE OF INFORMATION DISSIPATION WITHIN THE SUPPLY CHAIN SYSTEM

When overlaying features seen above on a supply chain outlook, we find that most of them fit this organizational configuration. The first one deals about the definition of ago-antagonistic couples. The analysis of supply chain as hybrid governance structure permit to identify some ago-antagonistic strategies, like for example lean versus agile strategy; integration versus outsourcing or hierarchy versus market governance; reactive versus proactive strategy and cooperative versus competitive strategy.

To illustrate this point we can present some ago-antagonistic couples in the supply chain. Leanness and agility can be a good example. These two strategic positions are opposite, but their combination has constructive effects. Assimilating leanness and agility gives us what is called leagility which is a bipolar strategy. This one join the fact of having a schedule level by eliminating non-value added time and at the same time, best cope with changing demand by extra reduction of value-added time through production technology breakthroughs [8]. Another example concerns integration as opposed to outsourcing. Once articulated, these two contrasted strategies produce positive effect. Actually, the search of light integration by matching vertical integration and strategic outsourcing extends a company's product portfolio and success, which in turn allows the development of a competitive.

To understand supply chain system complexity and dynamics, we will focus on information and physical flow to better anticipate its behavior. To illustrate this, we will first refer to the case of Procter & Gamble (P&G) diapers [7], to show that the market is not volatile, and final consumer demand is stable and characterized by low uncertainty; and that supply variations subsist and are accented along the supply chain. Despite this stability, stock levels are amplified in the supply chain from downstream to upstream.

This amplification phenomenon, known as the Bullwhip Effect, represents supply chain system instability mainly due to information asymmetry between companies. This asymmetry emerges and grows as inequality in terms of availability, access and sharing of information increases between companies. The Bullwhip Effect is not always the consequence of extrinsic demand uncertainty, but it embodies the intrinsic information entropy of dynamic, complex systems. Entropy is a measure of the level of informational disorder between supply chain system actors. In other terms, it characterizes the information loss within the system. Generally, entropy grows if nothing is done. This means that information loss is a growing phenomenon but may be regulated by negative entropy, called negentropy. The more entropy is present, the more rigid and inflexible the system becomes. Information loss and system rigidity represent sources of instability. Consequently, information quality, quantity and the mode of sharing it constitute important elements that contribute to making the supply chain system more stable.

Since the emergence and development of information technologies, companies have heavily invested in Electronic Data Interchange (EDI) solutions and extranets to coordinate their activities and create effective collaboration mechanisms within the supply chain. These solutions can ensure information transfer; however, they cannot certify the qualitative and quantitative accuracy of the information transferred. Indeed, sources of inaccuracy in the shared information are multiple. We can invoke human error while inputting data in a store, potentially leading to asynchrony in physical and accounting inventories, which are often transferred through EDI.

We can also add to this inaccuracy due to synchronization delays between inventory movements, database updates and the time between receiving and recording goods. Other sources of instability are product "losses" in stores (loosing track of merchandise) [6], that lead to asynchrony between inventory information transmitted to partners and real inventory status. Companies regularly inventory merchandise in an effort to cope with information quality and quantity loss (two key factors in supply chain management), even though this technique remains ineffective [1].

Information loss is a source of uncertainty in the supply chain system and is characterized by a lack of upstream and downstream process visibility. In an effort to protect themselves against stock-outs, companies in the supply chain produce in "batch" with fairly long and quite variable lead times thus increasing the level of local stocks due to a localized optimization orientation, amplifying thereby the Bullwhip Effect.

Throughout the rest of the article we will make the assumption that demand is known and stable. We do this to isolate the environment effect on the supply system and focus only on entropy that characterizes the intrinsic complexity of the supply chain system. As said earlier, entropy is a measure of the informational disorder within a system. In the case of a supply chain, this entropy takes the form of informational disorder which is amplified as one moves along the chain from downstream to upstream. Indeed, entropy measures the probability of loosing information during transfer within the supply chain information system. This can manifest as missing information, lost wealth or accuracy, or speed of availability.

In Figure1 we show that entropy exists in all complex systems. It is responsible for disorder and the loss of informational quality and quantity that is contained in a system existing between actors. Entropy reduces inventory evolution visibility and negatively impacts all production, distribution and warehousing activities in the system, increasing uncertainty. Lack of visibility leads to significant intrinsic uncertainty, and as a result the system loses its flexibility and increases its rigidity. Companies generally use mass production (batch) to cope with situational risks, and therefore increase their inventory levels. The rigidity of the system results from the loss of visibility that increases from upstream to downstream in direct proportion to the overall system dynamic. This explains inventory fluctuation levels that increase as one goes up the supply chain.

Figure1 represents supply chain system entropy in its current state. We show that loss of information causes system rigidity.

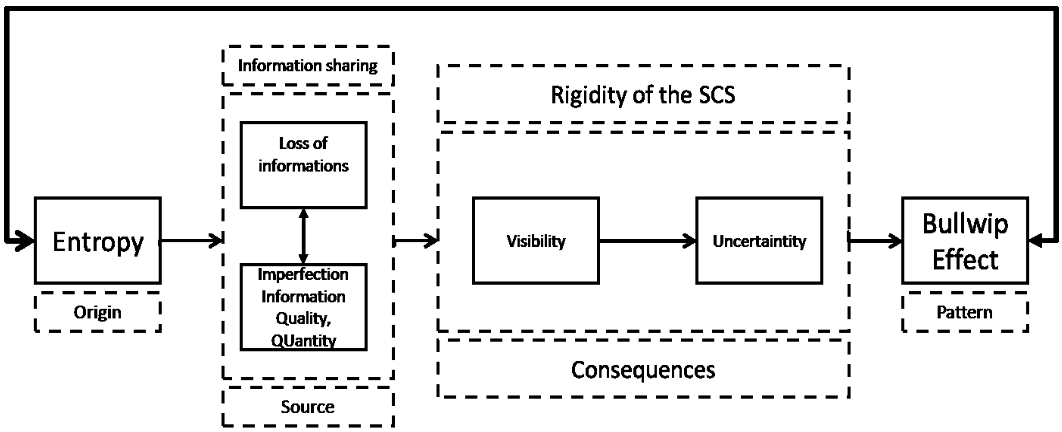

Figure1: Concretization of entropy in the supply chain system

4. CONCLUSION

As we have seen in this paper, supply chains represent complex, dynamic systems mainly due to the interactions carried out between diverse subsystems aka: supply chain members. We have seen that the dynamics fluctuate between order and disorder. Fundamentally, organization of a supply chain system is the creation of order out of current disorder by effective management.

Admittedly, supply chains exist whether managed or not. So, the better a supply chain is organized, the lower the levels of subsisting entropy. This entropy is manifested in supply chain system disorder, and is principally generated by incompatible subsystem behaviors due to non-global management orientation. It is concretized by information dissipation or loss. The impact of this information loss remains a source of uncertainty inherent in the supply chain system. It is characterized by a lack of upstream and downstream process visibility, the amplification of which is described in the Bullwhip Effect.

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