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Abstract

Information transfer in the supply chain is complex and causes instability and unpredictable behavior, 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 assume that "complete" and "accurate" real-time information sharing concerning product and inventory levels through RFID reduces entropy and limits its effects on the supply chain. RFID can reduce information loss and increase accuracy. From the literature we show that RFID can improve visibility, reduce uncertainty and complexity of the supply chain permitting us to conclude that it represents a regulatory mechanism of informational entropy in the supply chain.

Key words: Supply chain system, entropy, Bullwhip Effect, RFID

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 [45] 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 [3]. 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.

Furthermore, the supply chain system oversees physical flows via information flows throughout the various processes by coordinating each company in the system. The efficiency of this management has a direct impact on corporate profitability, thus justifying infrastructure investment necessary to manage flows and stocks and to ensure traceability via RFID (Radio-Frequency IDentification), or communicating "tags" with the ability to dynamically store information and wirelessly communicate with their surrounding environment, bring a new dimension to supply chain management. Indeed, RFID provides supply chain management the ability to identify, track and trace a product flowing through the supply chain at every stage of processing. This technology can automatically and quickly capture information on a product and make it available for use and decision making at any stage of the product's journey in the supply chain. So, from these characteristics, how can RFID regulate the supply chain system?

To answer this question, we first present RFID applications. Then we elucidate supply chain systems dynamics, highlighting the concept of entropy and information dissipation that it engenders. Then we make a theoretical analogy between entropy and the Bullwhip Effect. We assume that the Bullwhip Effect is a consequence of supply chain system disorder that is embodied through information loss, and results in reduced visibility and increased system rigidity. In the third part, we put forward the idea that the use of RFID regulate or decreases entropy of the supply chain system by creating Order through negentropy.

2 The RFID applications in the supply chain

RFID applications in supply chains have not experienced broad use for various technological, organizational and financial reasons. Happily, this wasn't the case in a number of pilot projects undertaken by supply chain innovation pioneers like Wal-Mart and the American Department of Defense. Among the applications tested in these projects, RFID was used to monitor real-time logistics units (products, pallets, boxes ...) and it allowed better targeting the removal of suspected products. RFID can provide complete visibility of returned products to reduce reverse logistics fraud. The use of RFID in supply chain can generate value by allowing better inventory levels and visibility of various flows, and better knowledge of process status via electronic tracking. Indeed traceability allows tracking status and history of flows, can describe a product in real time, its origins, transformation processes it is undergoing and the materials used. "We cannot measure what we cannot detect; we cannot control what we cannot measure; we cannot manage what we cannot control" [9].

Table1: Applications of RFID in the supply chain system

Applications of RFID in the SCS	Results
Advanced Shipping Notice (ASN)	Automatically detect a pallet or shipment when it leaves the warehouse. Clients will be informed in real time [14]
Transport	Facilitates easy and quick localization of vehicles or means of shipping [22]
Supply chain efficiency	Improves service level between P&G and Wal-Mart from 96% to 99 % [39]
Improve stock management	Reduces inventory levels between P&G and Wal-Mart by 70% [39]
Reduction in labor cost (RLC)	RFID reduced misplaced products and inventory levels in the distribution center by 23 % [30]
Shrinkage or product loss	Represents 2 to 5% of stock. RFID increases the capability to identify where losses are occurring [25]. A 1% product shrinkage can cause a 17% stockouts, a 2.5% shrinkage can cause a 50%

stockout [26].

The use of RFID in supply chain management is a key step in performance research because good information is the basis for any supply chain improvement [21]. Implementation of this technology allows businesses to realize substantial savings through a multitude of applications. It helps improve the operational performance throughout the supply chain and all along the product life cycle from its production to its return passing by distribution and inventory management. In Table1, we mention some applications for RFID within the supply chain that can be levers for performance improvement. The real benefits of RFID will probably not be fully realized, however, until it is implemented at the unit level. The common thread among these applications is the speed and ease of access to accurate information that reflects the state of a process and/or the evolution of a product in a supply chain.

3 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, systems 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. [10] as “a system of people, activities, information, and resources involved in creating a product and then moving it to the customer”. Stevens [38] 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. [40], 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 [5]. 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.

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 [11] 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 [34], cited by Saint-Amand [33], 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 [33].

There are two main dynamics in which flow evolves (Table2). 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.

Table2: Systems dynamics and their characteristics

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

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.

4 The Bullwhip Effect: entropy evidence in the supply chain system

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 [28], 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) [24], 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 [2].

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.

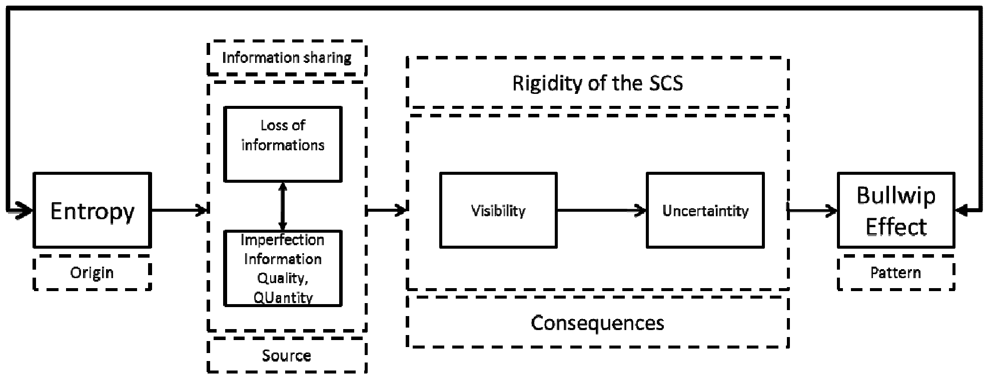

Fig. 1. Concretization of entropy in the supply chain system

Figure1 represents supply chain system entropy in its current state. We show that loss of information causes system rigidity. We will now examine how RFID systems can create a "negentropic" dynamic as outline by Brillouin [6]. Negentropy is a factor in organizational systems, measuring the degree of order in the system and permitting the system to self-regulate. Figure2 shows how RFID systems can be mechanisms for creating informational order and self-control, thus decreasing entropy or the Bullwhip Effect in a supply chain context.

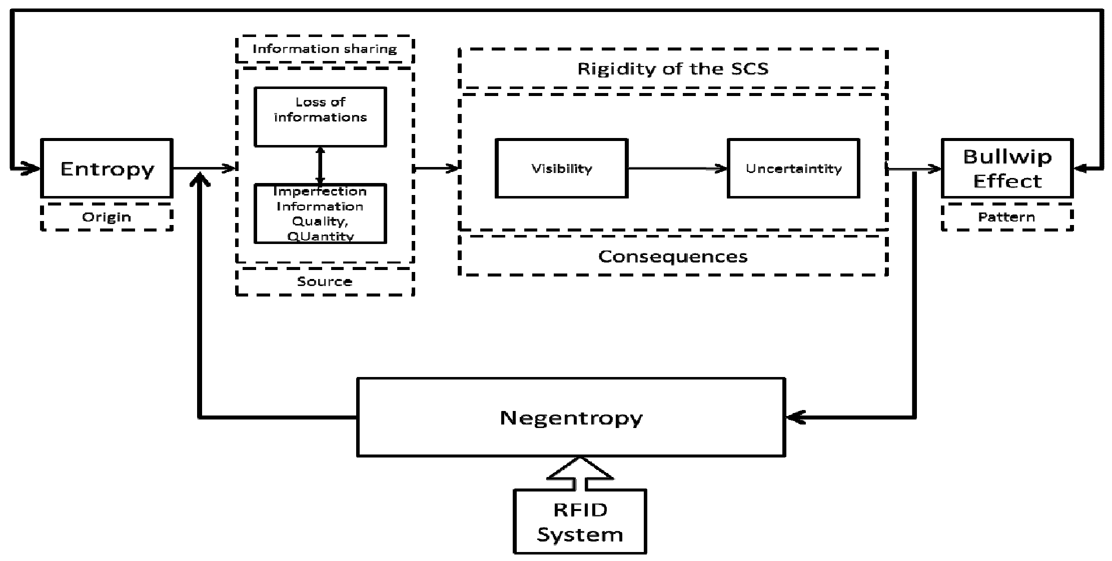

Fig. 2. RFID regulation of supply chain system entropy

5 RFID-based supply chain system regulation

As we have seen above, the Bullwhip Effect is a phenomenon that characterizes the complexity of the supply chain. It was introduced by Forrester [12] who had observed a fluctuation and amplification of demand from downstream to upstream in the supply chain. This variability of demand increases at each step of the chain (retailer, distributor, manufacturer and supplier). Forrester (1958) concluded that this supply chain behavior is due to difficulties in sharing information between supply chain partners. Sterman [37] introduced a method called “beer game” as an educational tool to show via game theory that a small change in demand can generate the Bullwhip Effect. This game application clearly shows that the main cause of this effect is lack of information sharing. Finally, Agrawal et al. [1] show that in a two-tier supply chain, reducing the lead time has a more significant impact on the bullwhip effect than information sharing.

According to a recent literature review concerning this phenomenon, Sarac et al. [35] stipulate that several authors examined the root causes of the Bullwhip Effect as well as key factors to reduce it. Lee et al. [28] consider that the causes of the Bullwhip Effect are the difficulty in demand forecasting, planning for economic batch production quantity and price fluctuations. Wang et al. [41] consider that lead time can also be a source of the Bullwhip Effect. Likewise, Gaukler [16] conclude after performing a literature review that the main cause of the Bullwhip

Effect is poor material flow. Chen et al. [8] show that the level of information sharing within the supply chain can also be a source of the Bullwhip Effect. Nevertheless, Holweg [20] show that collaboration within the supply chain and visibility in information flows can reduce the Bullwhip Effect and improve the quality of service, reduce inventory levels and stock-outs.

RFID technology can be used to reduce the Bullwhip effect limiting informational dissipation, which is a source of instability and lack of performance of the supply chain. Joshi [23] shows, using a simulation of a simple supply chain with different scenarios, that RFID provides better visibility and reduces inventory levels by 40% -70%. In the following tables we will present the various sources and consequences of the Bullwhip Effect and the role of RFID. To determine the value of using RFID as a mechanism for regulating the Bullwhip Effect, we will present a first table, which presents the link between the different causes of demand amplification in supply chain and the positive impact that RFID technology can provide to reduce or eliminate sources of information fluctuation.

Table3: RFID positive impact on Bullwhip Effect sources

Bullwhip Effect source	RFID Impact	Authors
Information loss	Improved information integrity RFID as the sole channel of information sharing	[13], [43].
Information imperfection	Track inventory precisely and improve information accuracy Improve inventories accuracy	[30], [29], [19], [7].
Lack information flow and inventory level visibility	Improves the level of visibility (and stock information) within the supply chain Improves visibility in real time (providing an effective management tool)	[13], [44], [41], [17], [36].
High uncertainty	Helps decrease uncertainty in the supply chain Improves decision making	[32], [7], [31], [44].
Information sharing	Enhances information sharing between companies	[13].
Activity synchronization	Synchronizes the activities of different actors, providing a real time view of the chain	[13].
Lead time	Reduces lead time	[42].
Lack of coordination in the supply chain	Improves coordination in the supply chain	[19].
Forecasting accuracy	Improves quality of forecasting	[27].

The Table3 below shows the link between the consequences of demand amplification along the supply chain and the positive impact that RFID systems may have in limiting the adverse effects of this phenomenon. The benefits for the supply chain and the direct impact on service quality are key elements in the performance of an effective supply chain system.

Table 4: RFID impact on reducing Bullwhip Effect consequences

Bullwhip Effect consequences	*RFID impact*	*Authors*
Important inventory management costs	Lowers the cost of inventory management and replenishment decisions Reduces stocktaking	[2], [15], [30], [41].
High inventory levels	Reduces inventory levels and safety stocks (from 40 to 70%)	[2], [4],[23].
Sales loss/stock-outs	Reduces stock-outs (16% for Wal-Mart) and increases product availability Triples replenishment speed (According to the findings of a study carried out by the University of Arkansas on RFID applications on Wal-Mart distribution channel; RFID Journal. October 14, 2005).	[2], [18], [4].
Customer service	Improves customer service	[23].
Demand fluctuation	Reduces demand fluctuation	[4], [13], [41].

6 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.

We have seen that RFID systems can be used to reduce the Bullwhip Effect by limiting informational dissipation which is a source of instability and poor supply chain performance. Furthermore, RFID technology allows for reduced lead time, better visibility along the supply chain, improved demand forecasting, better and more accurately controlled inventory, and reduced robbery and losses. It also increases customer satisfaction.

The role of the RFID system is to capture all available data in the various supply chain processes and then transform it into actionable information for the supply chain system. Once accomplished, the RFID system provides information to improve decision making. We can present the RFID system as a sort of “pipeline” for business value creation through effective information handling, characterized by four performance indicators. The length of the pipe represents the Lead Time (1): it is the delay between the need for information and obtaining this information. The speed with which information is obtained is important for effective decision making. Throughput (2): The amount of information that a company can have in a time unit and its impact on decision making. Leakage (3): this represents information dissipation and manifests in imperfection of the information obtained, its technical quality, its structure, its business value. The greater the dissipation, the less relevant the information. Pipeline thickness and diameter of usable passage (4): The cost of RFID system operations is the cost of obtaining information, if the cost is excessively high, it is equivalent to having a pipe with extremely thick walls and almost no room left for the flow to move through. Once these four elements are harmonized, it will be possible to develop a single informational performance indicator measuring the negentropy in the supply chain system.

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