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Systemic Approach to Supply Chain Management through the Viable System Model and the Theory of Constraints

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In today's environment, Supply Chain Management (SCM) takes a key role in business strategy. A major challenge is achieving high customer service level under a reasonable operating expense and investment. The traditional approach to SCM, based on local optimization, is a proven cause of meaningful inefficiencies –e.g. the Bullwhip Effect– that obstruct the throughput. The systemic (holistic) approach, based on global optimization, has been shown to perform significantly better. Nevertheless, it is not widely expanded, since the implementation of an efficient solution requires a suitable scheme. Under these circumstances, this paper proposes an integrative framework for supply chain collaboration aimed at increasing its efficiency. This is based on the combined application of the Beer's Viable System Model (VSM) and the Goldratt's Theory of Constraints (TOC). VSM defines the systemic structure of the supply chain and orchestrates the collaboration, while TOC implements the systemic behaviour –i.e. integrate processes– and define performance measures. To support this proposal, we detail its application to the widely used Beer Game scenario. In addition, we discuss its implementation in real supply chains, highlighting the key points that must be considered.

Keywords: supply chain management; systems thinking; viable system model; theory of constraints; supply chain collaboration

1. Introduction

The revolution of information and communications technologies, the decrease of transportation costs, the geopolitical restructuring that took place as a result of the Cold War, and the liberalization of capital markets have drawn a new competitive business context marked by its complexity and dynamism. Competition must manage efficiently convoluted worldwide networks being able to agilely react to the frequent changes in customer requirements. By way of illustration, Figure 1 shows the dramatic increase of the international trade of products in the eurozone over the last decade (from 2003 to 2014, exports and imports grew by 97.57% and 79.74% respectively), even in a recessive economic context. In this regard, competition between firms is no longer limited to the product itself, but goes much further. For this reason, the concept of Supply Chain Management (SCM) has gained strength to the point of having a strategic importance for companies, which has encouraged researchers to deepen its study and the development of proposals to increase the yield of companies involved.

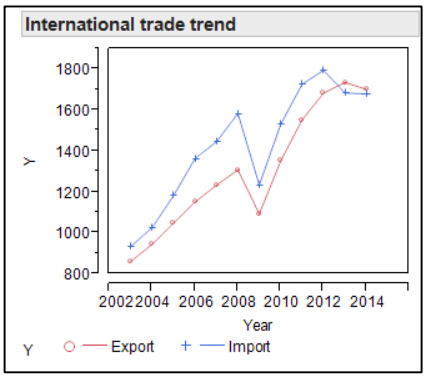

Figure 1. International trade in the eurozone (in millions of euros). Data from Eurostat.

One of the main challenges regarding SCM is to improve the customer service level without capital outlay (CGI Group, 2013). The delivery of products on the right time and lowest cost enables a company to differentiate from its counterparts and enhances future profitability (Chopra and Meindl, 2007). Given the current complexity

and dynamism, real supply chains usually exploit the throughput inappropriately, which leads to poor service levels. This issue, which can be considered as the problem statement of this research work, is especially relevant when lead times are long or the product experiences short life cycles (De Treville, Shapiro, and Hameri, 2004).

Sterman (1989) concluded that large inefficiencies occur within supply chains due to the individual adoption of local optima solutions by the various participants. This reductionist approach to SCM (the overall strategy is obtained as a sum of individual strategies), based on mass production paradigm, leads to increasing storage, shortage, labor, obsolescence, and shipping costs through the well-known Bullwhip Effect[1]. That is, this reductionist approach has shown to present several problems in terms of throughput management.

Thus, a premium has been placed on collaboration (Lehoux, D'Amours, and Langevin, 2014) as a key source of competitive advantages. This holistic or systemic approach –the overall strategy determines the individual strategies– to SCM, has been shown to outperform the traditional reductionist alternative –the overall strategy is obtained as a sum of individual strategies– (e.g. Disney and Towill, 2003; Kollberg, Dahlgaard, and Brehmer, 2006; Costas et al., 2015). However, although the improvement in operational and (consequently) financial terms is widely accepted by academics and practitioners, supply chain collaboration faces high hurdles, such as the menace of opportunistic behaviors (Simatupang, Wright, and Sridharan, 2004), which stresses the importance of defining an appropriate framework.

It should highlight that the recent economic crisis has been understood as a consequence of the fact that globalization still has not been able to develop systemic

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[1] The Bullwhip Effect refers to the amplification of the variability of orders along the supply chain.

dynamic properties to deal with a growing variety of requirements (Schweitzer et al., 2009). This fact has increased the interest for new approaches to business based on holistic paradigms. Hence, supply chains must be underscored as boiling areas for innovation.

The main contribution of this research article is the proposal of a systemic approach to SCM, where to take advantage of the benefits derived from collaboration. Within the framework proposed by Simatupang and Sridharan (2005), the Theory of Constraints (TOC) (Goldratt, 1990) is the mechanism used to improve supply chain efficiency, while the Viable System Model (VSM) (Beer, 1979; 1981; 1985) orchestrates the implementation of the collaborative solution.

Our research method has followed guidelines from A3 Thinking (Sobek II et al., 2011). A3 Thinking provides researchers and practitioners with an efficient way of studying and tackling business problems. Its effectiveness has been widely demonstrated within the TPS (Toyota Production System) paradigm. This Lean's tool for problem solving allows us to provide a complete structure to implement successful moves toward organizational improvement through a deeper understanding of the issue. This structure can be observed along this article: (*section 1*) Problem statement, background and setting goals; (*section 2*) Clarifying the problem after reviewing the literature; (*section 3*) Developing the conceptual model, through the proposal of an integrative framework for supply chain collaboration; (*section 4*) Detailing the application of the proposed model on the well-known Beer Game scenario; and (*section 5*) Discussing its applicability in real supply chains.

2. Literature review

This section reviews the main collaborative approaches to SCM and introduces the two philosophies that are combined in this research work.

2.1 Supply chain collaboration

Supply chain collaboration can be easily defined as several companies creating competitive advantage, and hence obtaining higher profits, by working together in a production and distribution system (Simatupang and Sridharan, 2002). From that point on, collaboration has been understood in very different ways by researchers and managers. In this regard, Simatupang and Sridharan (2005) propose an outstanding framework, defined by five features: (1) Information sharing; (2) Collaborative performance system; (3) Decision synchronization; (4) Incentive alignment; and (5) Integrated processes. This integrative rather than sequential approach (the output of each feature acts as an input for the others) is supported by empirical evidence –if some of the features are ignored, intrinsic barriers could derail the collaborative process.

Supply chain integration encompasses the coordination of resources, decisions and methods among the different stakeholders and is the skeleton of the overall process. Decision synchronization covers devising joint decision-making processes (includes re-allocating decision rights) with the aim of synchronizing planning and execution levels. This includes forecasts, safety stocks, order placement, order delivery, target customer service level, and pricing. In this regard, a wide variety of solutions have been proposed in the last two decades to improve the performance of the supply chain, such as Vendor Managed Inventory (Andel, 1996) and Collaborative Planning, Forecast and Replenishment (Ji and Yang, 2005). Moreover, some systemic philosophies like Lean Production (Womack and Jones, 1996) proposed methods to manage the production

flow, e.g. Kanban and CONWIP control –see Takahashi and Nakamura (2002) for a comparison, and Jasti and Kodali (2015) for a review of existing Lean SCM frameworks.

Information sharing, the main enabler of collaboration, refers to the access to private data of all members, which covers dissemination of demand conditions, inventory and order status (and locations), cost-related data, and performance indicators. With this goal, the use of information and communications technologies has shown to improve supply chain efficiency (Gunasekaran and Ngai, 2004). Measuring this efficiency through systemic performance metrics (which must be devised to guide the participants to improve overall performance) is another key feature of supply chain collaboration. Companies require different types of metrics that span the supply chain (Kaplan and Cooper, 1997). For example, Li and O'Brien (1999) use four main criteria to measure supply chain efficiency: profit, lead time performance, delivery promptness, and waste elimination. Najmi and Makui (2012) propose a conceptual model for evaluating supply chain performance that we recommend looking at.

Lastly, incentive alignment requires to share costs, risks, and benefits among the participants. That is, aligning incentives aims to motivate them to act consistent with the overall strategy, and hence eliminating the incentives to deviate. Kaplan and Narayanan (2001) propose the use of expert systems, activity-based costing, and web-based technology to trace, calculate and display the incentive scores. To implement it, the use of linear contracts (e.g. pay-for-effort and pay-for-performance schemes) is common.

2.2 Viable System Model (VSM)

The VSM (Beer, 1979; 1981; 1985) offers the possibility to scientifically design an organization as a system with regulatory, learning and adaptive capabilities necessaries to ensure its survival (viability) when facing changes that may occur in its environment

over time, even though they were not foreseen in its design. To achieve this viability, the VSM proposes an invariant systemic structure based on the definition of five functions, called Systems One to Five, that are considered necessary and sufficient conditions to deal with the environment complexity[2] in which the system operates.

System One represents the operational (autonomous) units managing the different production elements. Since conflicts between processes and responsibilities of these operational units might appear, System Two –with an essential role in coordination– is essential. Controlling the performance level of the operational units is assumed by System Three, which is also responsible for defining directives, allocating resources and corresponding accountability to each operational unit, as well as identifying potential synergies that might arise. Next to System Three, System Three* is responsible for performing audit activities to operational units. Since System Three is unable to predict the future and recognize potential risks, a structural function is required to solve this problem. This function is represented by System Four. Changes in the environment are detected and analyzed with regard to the system's main objectives, leading to possible recommendations for action. Finally, System Five formulates the principles and goals of the system, playing a key role in preserving its identity.

Supplementing these five functions, the VSM is supported by instruments for unfolding variety both horizontally and vertically. The horizontal unfolding aims to balance variety through the design of mechanisms to reduce (attenuators) and amplify (amplifiers) it. Thus, each connection (with four components: transmitter, transducer, channel, and receiver), which represents communication relationships among the functions of the model and between them and the environment, considers variety

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2. The complexity is measured by the concept of variety, i.e. the number of possible states or behaviour modes that a system can adopt (Ashby, 1956).

attenuation and amplification mechanisms in both senses (from the environment to operations and from operations to management). On the other hand, the vertical unfolding supports the recursion of operational units to smaller subsystems. The purpose is to reduce the variety faced by each part of the system (complexity reduction).

Although this socio-cybernetic theory has got increasingly greater recognition for their plausibility, Jackson and Flood (1988) criticized: (1) their purely theoretical design and abstract nature; (2) the questionable analogy between the human brain and other organizations; and (3) their hierarchical arrangement and lack of flexibility. Nonetheless, different authors show concrete VSM applications to diagnose or design viable organizations in a multitude of sectors (Beer, 1981; Puche Regaliza, 2014; 2015). These resulted in the discovery of pathologies and, after their treatment, the VSM led to a tangible improvement in such organizations.

Its systemic and multilevel nature, its ability to handle the dynamic complexity enclosed when managing an organization, and its interaction with the environment makes us consider the advantages offered by the VSM regarding SCM. In this subject, Chronéer and Mirijamdotter (2009) proposed its utilization for shortening a product development process by better connecting the information flows and Badillo et al. (2015) used VSM to better understand the supply chain of a telecommunications firm.

2.3 Theory of Constraints (TOC)

The TOC (Goldratt, 1990), a major innovation in the production field, is a management philosophy that views any system as being limited in reaching a higher performance level only by its bottleneck. Thus, it aims to achieve breakthrough

improvements by only focusing on it[3]. The TOC encompasses three main areas: logical thinking, performance measurement, and operations management.

Its logical thinking focuses on the bottleneck through a continuous improvement philosophy (Goldratt, 1992). In order to increase the overall performance, all efforts must be concentrated on the system's constraint –that is, any improvement away from the bottleneck means a waste of resources. The cycle is split into five stages: (1) Identifying the bottleneck; (2) Deciding how to exploit it; (3) Subordinating everything else in the system to the previous decision; (4) Implementing measures to elevate the constraint; and (5) Assessing whether the bottleneck has been broken, and re-starting the cycle to avoid that inertia limits the system.

The performance measurement is based on a simple idea: the only purpose of a business is to make money now and in the future. To quantify the success in achieving this goal, TOC uses three financial indicators: net income (absolute terms), return-on-investment (relative terms), and cash flow (survival terms). This theory highlights the simultaneous consideration of the three –it is not about increasing one at the expense of the others. To determine these metrics, the Throughput Accounting (Goldratt, 1994) is proposed, which considers three operational indicators: throughput (how much money does the system generate?), investment (how much money does the system need to generate throughput?), and operating expenses (how much money is required to operate?). Unlike the traditional cost accounting (aimed at cost reduction), this accounting seeks to maximize the throughput, i.e. to optimize the efficiency of the value stream. Thus, it enables managers to analyze the link between process constraints and

[3] Unlike Lean Production that shares the effort throughout the whole system.

financial performance in decision making. Consequently, it allows them to determine the real impact of their decisions.

The logistic function applies the Drum-Buffer-Rope (DBR) method (Goldratt, 1990), which aims to manage properly the bottleneck through suitable coordination (ensuring its steady supply). It is named for its three main components. The *drum* is a system pacemaker and is placed at the node that limits system performance. The other nodes follow its beat (production rate) so the drum is protected against variability by the *buffer*, whose size plays a key role (Ye and Han, 2008; Kuo-Jung, Sheng-Hung, and Rong-Kwei, 2003) –the full capacity of the bottleneck must be exploited. The *rope* is the release mechanism, which subordinates the entire system (upstream and downstream) to the drum. That is, orders must be released according to the buffer time before they are due. The planning stage, or DBR configuration, is complemented with the monitoring stage, which implies managing the buffer along the different nodes to tune the system for peak performance.

Although TOC was initially oriented to production systems, its application to other business areas has been further studied, such as Marketing (Goldratt, 1994) and Project Management (Goldratt, 1997). In SCM (Goldratt, Schragenheim, and Ptak, 2000), the early works deal with managing the system from a single company perspective (Cox and Spencer, 1998). Later studies used TOC to promote supply chain collaboration. Simatupang, Wright, and Sridharan (2004) provide a conceptual framework for using TOC in supply chains. Wu et al. (2010) developed a DBR-based replenishment model under capacity constraints. Costas et al. (2015) showed that the DBR method induces large operational improvements in the supply chain without any collateral damage. According to their practical experience, the TOC Center reports that

firms adopting TOC typically gain 25-100% of additional output without significant increase in expenditure (Mabin and Balderstone, 2003).

3. Conceptual model: Integrative framework for supply chain collaboration

The top performer paradigm for production systems is the well-known Lean Production. Thus, proposing the Lean implementation seems to be the natural step to tackle the problem that consists on closing the gap in terms of throughput in the supply chain. Lean is a brilliant systemic philosophy, and we have no doubts in recommending it in each supply chain member. Nonetheless, two key points in Lean are focusing on the flow of value to customers and, simultaneously, reducing the overall MUDA (Lean's term for waste) in a systematic and continuous way. These points remain extremely important in supply chains, as these are multi-agent systems –and this makes a difference.

In our proposal, VSM is used as a framework for system design and diagnosis. According to it, when the supply chain is considered as system-in-focus and apply recursion to the subsystems (organizations that belong to the supply chain), it becomes clear that most of the reported common issues in collaborative supply chains are linked to the alignment of System Five (values, culture, principles, rules, and the overall policy) for all nodes. Hence, by taking TOC as the general paradigm for the supply chain, we strongly attenuate the variety (simplify) such a big issue. The reason is that TOC works by putting the system bottleneck in the center of attention for everyone. By means of that, the system-in-focus has a natural representative node, which is the one where the bottleneck is placed –nonetheless TOC also manages the change of the bottleneck.

Applying TOC across the supply chain, through the DBR method, warranties to concentrate all agents to what matters for the system as a whole: the throughput, the operational expense, and the investment. These indicators act as a balance scorecard to monitor the system. However, the implementation of TOC in supply chains does not come without very important challenges. Watson, Blackstone, and Gardiner (2007) can be consulted for a review on the evolution of this management philosophy, including the problems impeding greater acceptance. Here the Simatupang and Sridharan's schema is introduced.

The center of this integrative schema underscores the information sharing. Poor information sharing is a general problem, but with TOC it becomes more harmful because of the fact of applying an inventory managed policy as a need to manage the rope –the key artefact used to manage the flow. VSM cares about potential issues of this type with System Three*, which is what we propose as an element to ensure that the adequate degree of transparency and validity of the information (in terms of availability, opportunity, and cost) is surveilled.

Like Lean, TOC requires the orchestration of all processes, namely core and enablers. Core process is anyone that delivers value to customers, while enabler processes are focused on providing services inside the system. Hence, the feature regarding integrated supply chain processes in Simatupang and Sridharan's schema provide guidelines to address this issue. For core processes, TOC is self-sufficient, but not for enablers. Such orchestration is examined at the light of VSM. System Two provides the context to keep at the lowest possible place in the organization the everyday decisions to keep the system running smoothly.

Every participant takes many decisions that have an impact across the whole supply chain. For instance, launching promotions may need most of the times

coordination, approvals, and other activities that must be properly synchronized. Such decision-making with the focus on the whole system is shaped using Systems Three, Four and Five (the meta-system) in order to early detect poorly structured constructions for the decision support system.

Last but not least, the issue of redistributing the overall economic profit obtained by the system must be considered. Implementing TOC means that many decisions with strong economic impact must be done according to general rules and, consequently, this can (and does) generate conflicts for the agents if the system does not take care about it. Incentive alignment and overall performance metrics are a must.

To sum up our approach, the key component to solve the problem regarding throughput in supply chains is TOC, which implements the most that system needs for the core processes through the DBR method and the Throughput Accounting. Then, once this necessity has been created, the Simatupang and Sridharan's scheme provides an appropriate framework for collaboration based on five blocks. Finally, VSM acts as a guideline for initial and permanent regular design and diagnosis about structural weaknesses of the system, caring about the five VSM functions as well as the channels properties, and making judgements in terms of the laws of requisite variety. Figure 2 highlights and summarizes the conceptual model proposed. In section 5, we introduce some of the challenges that must be taken into account so to prevent major errors.

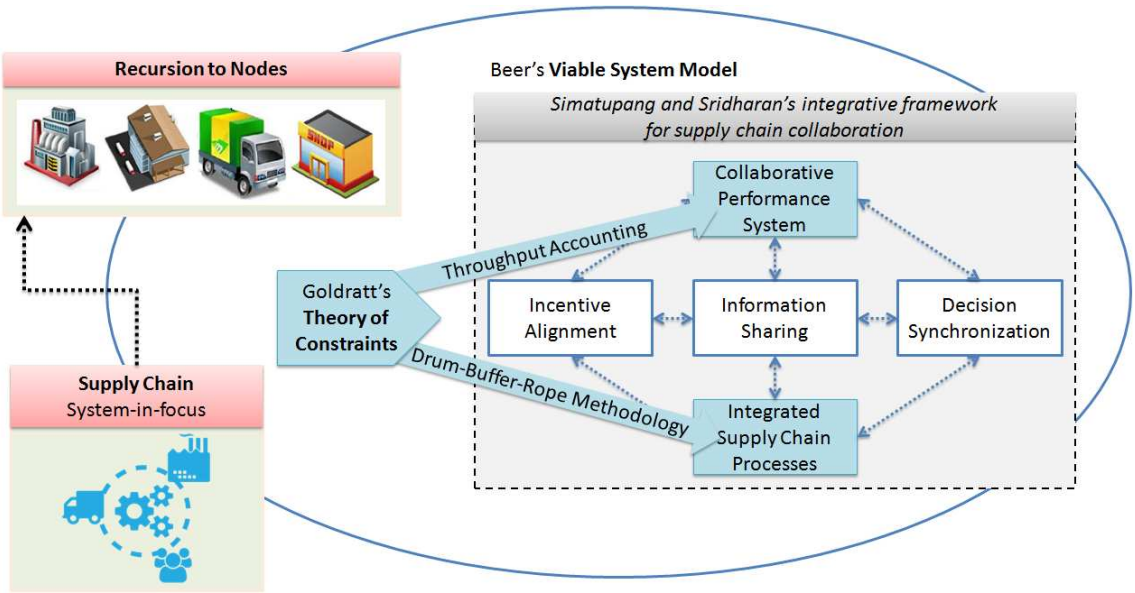

Figure 2. Collaborative model for SCM based on VSM and TOC.

4. Hypothetical case study

The Beer Game is a role-playing exercise aimed at teaching the main SCM principles that has been used in countless management courses over the last 50 years. Its experimental and counterintuitive nature has proved to be very effective in helping managers to understand the causal relationships between decision-making and supply chain behavior (Goodwin and Franklin, 1994), showing the generation of large inefficiencies (Sterman, 1989). This way, the Beer Game scenario, a single-product linear supply chain, composed of four echelons, has been widely used in literature to emphasize, investigate and analyze supply chain dynamics (Macdonald, Frommer, and Karaesmen, 2013).

Under these circumstances, the Beer Game supply chain is a suitable fit to show how our proposal can be implemented, as it: (1) covers the two main flows of the system along a significant length; (2) incorporates all commonly available sources of information within supply chains; (3) brings a rich enough sequence of events so that the belief-desire-intention of the participants can be analyzed in front of different event

algebras; and (4) has widely shown in literature the problems of the reductionist approach, i.e. that the interaction of individual decisions produces a solution that is far from the optimal.

In this section, we describe the application of our systemic proposal for SCM to the Beer Game scenario. We first define the system-in-focus. Subsequently, the five VSM functions are designed pointing out where each Simatupang and Sridharan's feature must be considered.

4.1 System-in-focus

From a TOC-based perspective, only satisfying customer requirements generates throughput for the global supply chain. Therefore, the nodes (factory, wholesaler, distributor, retailer, using the common notation in the Beer Game) must be aimed at maximizing it. Taking the supply chain itself as system-in-focus, each node represents a System One operational unit (see Figure 3). If we enter each one of them, we find a structural replica of VSM (structural invariant), i.e. a set of nodes representing the operational units. From that point on, the next level of recursion is represented for each (system-in-focus) operational unit. Likewise, in the previous level of recursion we find all the industry. Each supply chain of it is an operational unit –we focus on one of them. We can further define previous (countries, continents, etc.) and next (departments, production lines, etc.) levels of recursion (vertical variety unfolding).

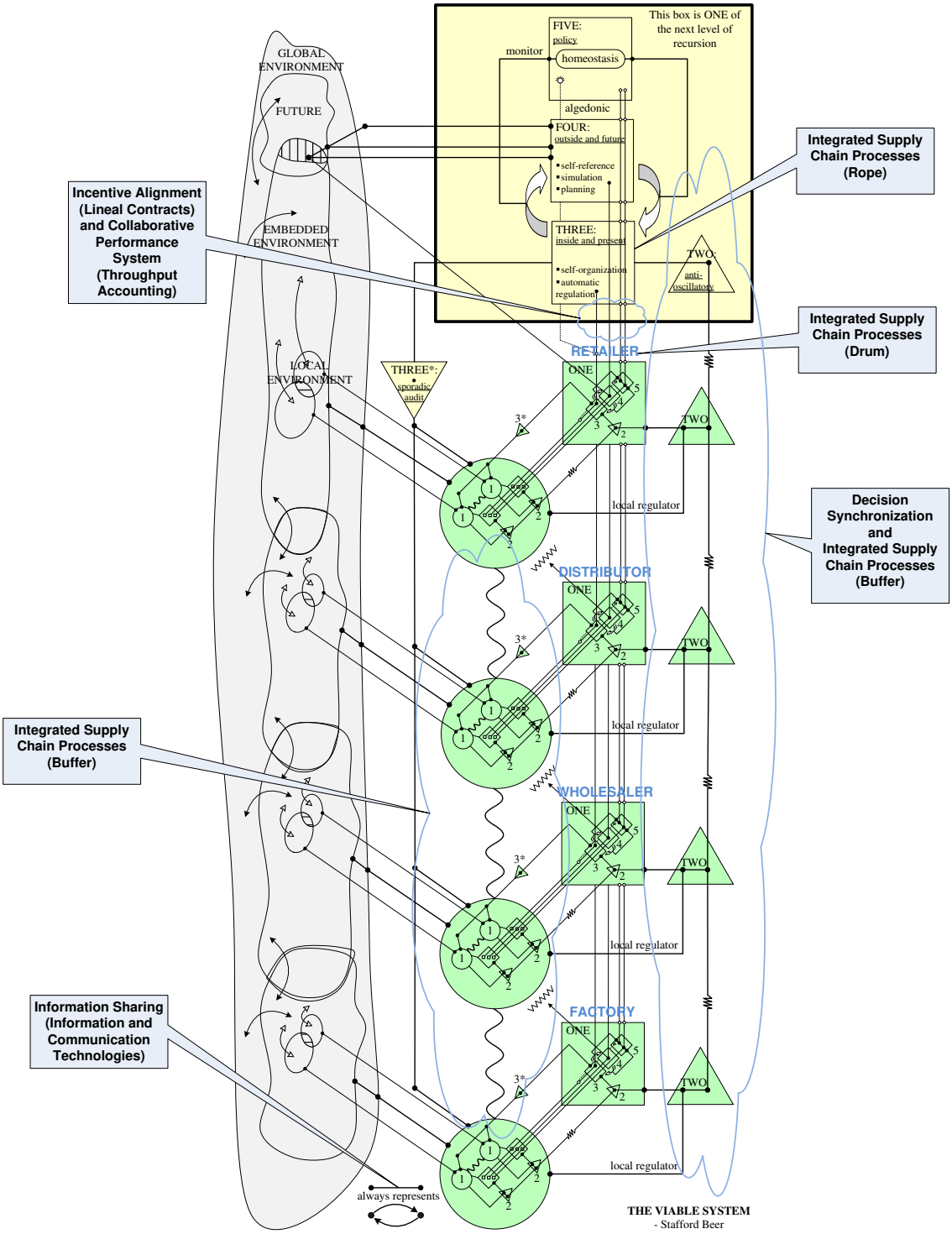

Figure 3. Systemic approach to SCM. Adapted from Beer (1985).

The supply chain overall function is threatened by a number of noise sources, which can be classified into four kinds[4]: (1) surrogate noise (geographical point of view,

[4] According to the p-diagram classification, a widely-used technique in robust engineering.

use of space, etc), (2) temporal noise (progressive deterioration, mutations in the environment, legislation, etc), (3) system noise (latencies, faults, defects, errors, etc), and (4) external noise (demand variability, raw materials, etc). The third kind is related to the System One typical functioning, while the others are related to the supply chain environment. Note that the last one refers to the upper and lower nodes of the system – retailer to customers (final product) and factory to suppliers (raw materials).

4.2 System One

Once reviewed the perspective of taking as system-in-focus the operational nodes, the systemic behaviour must be shaped according to TOC. The bottom right of Figure 3 displays the four operational elements representing the four supply chain nodes. Each one is composed of: (1) a management unit (square shape); (2) operations (circular shape) responsible for interacting with the environment to offer their products and services (left amoeba); and (3) a system of local coordination (triangular shape).

Since TOC is based on managing the supply chain through its bottleneck, the first step is to detect it. Where is the bottleneck in a supply chain? It is not a static but a continuous question. The factory could be the bottleneck if its production rate cannot cover customer demand. Intermediate echelons could be bottlenecks if their transport or storage capacities significantly limit the customer service level. Nonetheless, the supply chain bottleneck tends to be related to customer demand (Youngman, 2009). In order to maximize the flow, lost sales in the retailer must be minimized. Therefore, following the DBR method, the drum should be placed on the retailer, see figure 3. Nonetheless, its allocation could be displaced to other node over time.

In a supply chain, there are two main flows: the material flow (downstream product shipping) and the information flow (to monitor and control the system, and to coordinate actors for decision-making; e.g. upstream flow of orders and downstream

flow of shipping notes). These flows are represented by the different connections between nodes, between them and the environment, between them and the VSM functions, between functions, and between functions and the environment. Each connection, simplified in Figure 3, represents an information or material exchange in both senses, serving also as variety amplifiers or attenuators (horizontal unfolding). The Simatupang and Sridharan's feature related to information sharing through information and communication technologies is allocated in this point. Also, it can be extended to all other connections in the VSM.

4.3 System Two

In the upper right area of Figure 3, a triangle representing the global System Two can be observed. This is responsible for the coordination of the four operational elements through its interaction with their locals Systems Two. When the demand arrives at the system, the drum makes signals to the rest of operational units or supply chain nodes. They remain subordinated to the drum through a rope, so that the customer demand estimation is linked directly to the factory. Each node calculates the length of its rope until the drum position and orders material movements on the basis of its buffer downstream until reaching the bottleneck. The drum node issues orders directly to the factory. The buffer management consists of moving the flow so that arrivals occur in time in the bottleneck[5]. The buffer represents the material release duration while the rope corresponds to the release synchronization[6].

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5. Instead of a traditional safety stock based on material quantities, TOC-based buffers depends upon the lead time.

6. To deepen into TOC implementation, the exceptional guide developed by Youngman (2009) is highly recommended.

As mentioned, the factory uses customer demand (time slot defined by rope, which is the time slot to protect) to decide the production orders that must be placed in the channel. Manufacturing time is equal to the shipping lead time in the remaining levels. Subsequently, each node except the retailer (since there are no downstream nodes) manages the buffer, which represents both time and material flow. Managing it means to compensate the downstream dissipated flow after shipment in each slot. Orders are dosed in the buffer and, consequently, are dissipative. They have not lead time, since each node decides how much to dose subordinate to the bottleneck. In addition, backorders are not generated as the new dose also obey the bottleneck. The DBR method applied to the Beer Game scenario is schematically shown in Figure 4. Although the usual case is to place the bottleneck on the retailer, we have placed it on the distributor with the aim of illustrating a more complex example, where to observe two ropes and two buffers. It should be clarified that to plot the graph, we have considered the lead time to be 3 time units, hence the control point buffer is 9 time units and the shipping buffer is 3 time units.

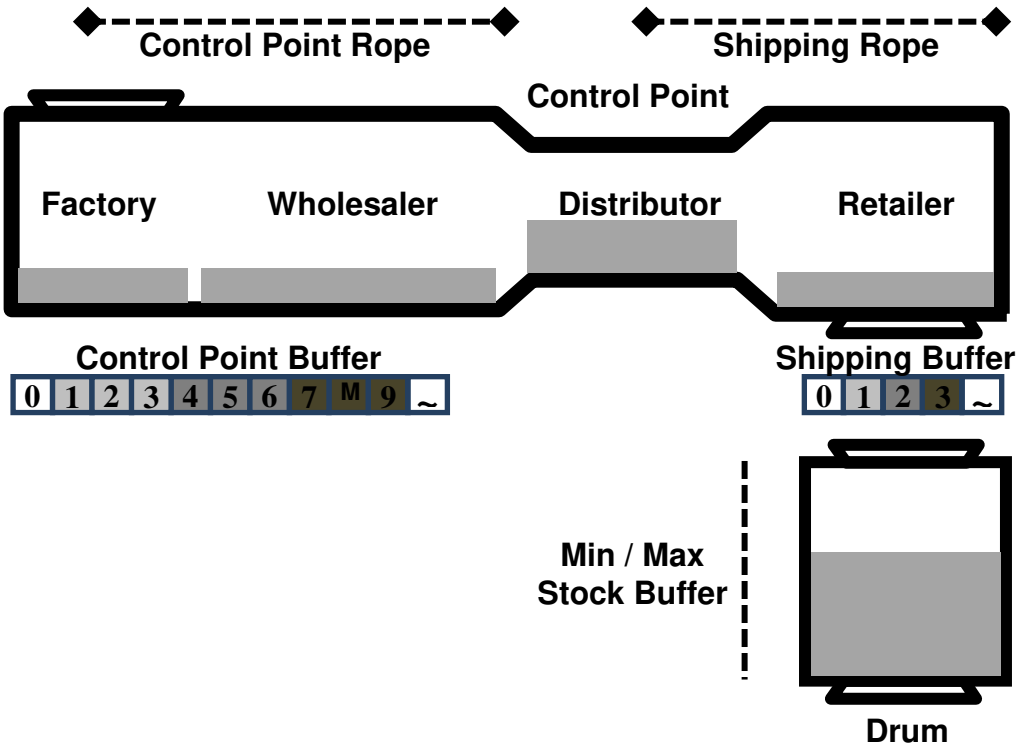

Figure 4. DBR method applied to the Beer Game supply chain. Adapted from Youngman (2009).

As previously mentioned, System One is represented by nodes that compose the supply chain, one of which is the drum. In System One, one part of the buffer can be observed, namely the squiggly lines that link supply chain nodes and that represent the material flow among them. The rest of the buffer is represented by System Two, which enables the coordination between all operational units. Regarding Simatupang and Sridharan's framework, the buffer (from the integrated supply chain processes feature) is allocated on these two points, while decision synchronization is located on the last point, see Figure 3. Synchronization mechanisms, as those mentioned in section 3, must be used to force the nodes follow the downstream material flow and upstream orders flow sequences. Thus, purchase orders, sales orders and backorders of the all different nodes are coordinated.

4.4 System Three

In Figure 3, System Three is identified in a square next to global System Two. The rope is represented by System Three. It takes care of finding synergies between nodes, assigning appropriate resources to each one, accountability of using these resources (agreement contract), and transmitting the system-in-focus rules to each node. The incentive alignment feature (from Simatupang and Sridharan's scheme), which can be implemented through linear contracts, is allocated on this point, see Figure 3. System Three* (inverted triangle) allows managers to audit the nodes performance without relying on the information they sent through System Two and central channels connecting with System Three (which forms the information flow). To deploy System

Three*, audits are carried out, which enables monitoring and makes the information (shared through the overall framework) reliable.

In this point, the collaborative performance system is allocated, see Figure 3. We propose its implementation through the Throughput Accounting that is based on three main operational indicators. Firstly, the throughput expresses the rate at which money is generated, and is obtained through the difference between the revenue (sales at the retailer) and variable costs related to purchases (raw materials at the factory). Note that internal sources damage the throughput, e.g. defective products. Secondly, the operating expense refers to all that costs spent in turning inventory into throughput. It is the sum of storage, transport, labor and order costs. It should be highlighted that system thinking requires considering only overall rather than local (per echelon) indicators. Hence in the holistic approach, it would have no sense to consider (the common in the Beer Game) backlog costs among the different participants, as it is not money entering or leaving the system. Thirdly, the inventory is calculated by estimating the economical value of the products that are inventory in the system, both on-hand (net stock) and on-order (in transport), as well as all other invested money, e.g. equipment, machinery, and facilities.

Through the concept of "cost bridge", the improvement in the aforementioned metrics leads to an increase in the financial indicators, which can be easily obtained. The net profit is the difference between throughput and operating expense. The cash flow considers, besides the above difference, the change of investment in the time horizon to analysis. The return-on-investment is the ratio of the net profit to the inventory. Figure 5 outlines the implementation of the Throughput Accounting in the Beer Game scenario. By means of this collaborative accounting, we aim to quantify the impact of the decisions, through analyzing the relationship between process constraints and financial performance in decision making. We think the Throughput Accounting

proposes a suitable structure where to tackle the problem of exploiting throughput within supply chains.

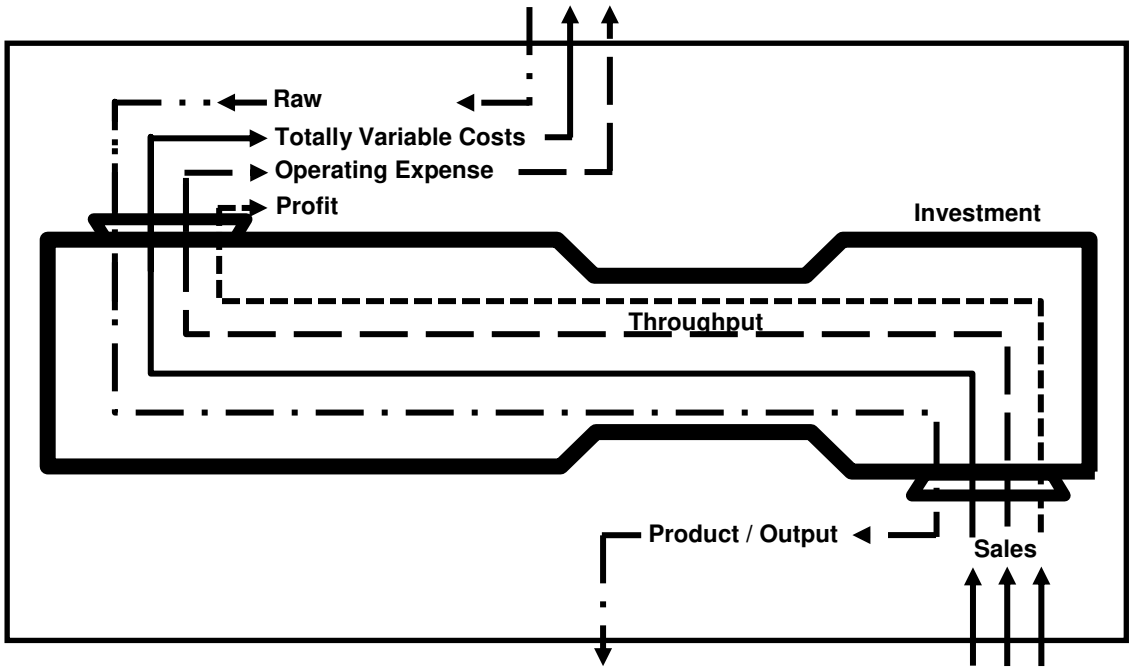

Figure 5. Implementation of the Throughput Accounting within the Beer Game supply chain. Adapted from Youngman (2009).

4.5 System Four

In Figure 3, System Four is represented by a square shape just above System Three. In addition, it can be observed the interaction between System Four and the environment (left amoeba), allowing its inspection. The arrows between System Three and System Four enable exchanging information on what is happening in the organization and in the environment now and what will happen in the future. This last interaction is of special importance since, on the one hand, System Three adapts the organization based on the indications identified by System Four and, on the other hand, System Four inspects the environment based on what the organization is currently doing. System Four is responsible for preparing the supply chain against the possible changes that may arise in the future (prediction), providing the whole system with the necessary adaptability to maintain its viability over time. In this systemic approach,

System Four is more relevant than in a reductionist approach in order to try to eliminate redundancies and minimize local Systems Four in favour of promoting the need for monitoring the environment of the supply chain as a whole. In addition, the bottleneck should acquire special importance, which can be manifested in managing demand and markets development of the supply chain and its competitors.

4.6 System Five

Finally, System Five can be identified in Figure 3 by a square shape above System Four. It is connected with the interaction between System Three and System Four interaction, which allows practitioners to solve the problems encountered when System Three and System Four do not agree on the basis of the principles defined by System Five. In addition, Figure 3 highlights the algedonic channel that connects directly (and unidirectionally) the operational elements with System Five, allowing them to alert System Five in case of serious risk. System Five defines the philosophy to be followed by the overall supply chain, which according to TOC principles is to make money now and in the future. In this case, the need for transparency of information (Simatupang and Sridharan's framework for application of TOC) and the enforcement of the Goldratt's principles as management principles for all nodes (everything is subordinated to the bottleneck) must be highlighted as key points.

5. Implementation in real supply chains: discussion and future work

One of the main challenges facing supply chains currently is to improve efficiency by increasing simultaneously the net profit, the return-on-investment and the cash flow. In other words, the throughput must be appropriately exploited along the system. Supply chain collaboration has shown to be effective to deal with this issue.

Nonetheless, this systemic approach is not totally widespread within real supply chains, as some high barriers emerge.

Supply chain participants must understand that the implementation of compelling solutions based on collaboration is a complex process that requires an appropriate scheme, such as the one proposed by Simatupang and Sridharan (2005). Based on this, we propose an integrative framework to achieve an holistic SCM. The DBR method, from Goldratt's TOC, is used to integrate processes –and hence to improve supply chain efficiency, measured through the systemic Throughput Accounting. The VSM also plays a crucial role in the overall process, as it orchestrates the framework so to define the systemic structure of the supply chain. In this reciprocal approach, the interaction of different connecting features of collaboration is being addressed.

To support this proposal, we detail its application to the hypothetical and widely used Beer Game scenario, although it can be easily adapted to other supply chain topologies. This case study aims at providing managers with insight to evolve from a reductionist approach, where the global strategy is obtained as the sum of individual strategies, to a holistic approach, where the individual strategies arise from the global strategy.

Concerning the application of this framework in real supply chains, the main catalyst is the overall improvement potential for the whole group of supply chain participants induced by TOC. Mabin and Balderstone (2003) reviewed several TOC applications in practice and calculated an average increase in the throughput by 63% without a significant increase in operational expense. On the other hand, the major hurdle to overcome is the dilemma of the predatory relationships among supply chain agents, since they are not expected to be in conflict in this new paradigm, but to behave as powerful partners –i.e. their incentives to deviate must be completely removed.

According to the personal experience of the authors of this article, in order to implement the proposed framework, one relevant opportunity to capture is the central purchasing unit. If a central purchasing unit does exist in the supply chain, it can develop towards a kind of headquarter to host the VSM System Five, System Four, and System Three* –and will also play a big role in System Two.

System Five, and its recursion to every node, can be fostered by a central unit by developing task force encounters and other group techniques, where the goodwill of the supply chain is worked by groups and activities. In addition, rules derived from the TOC philosophy can be established so to reinforce the vision of the whole system and the way members are expected and required to contribute in specific manners.

System Four will take a much more effective instantiation from the supply chain as a whole rather than the intelligence generated by each node. The reason is made evident at the light of the VSM; once the system-in-focus is the whole supply chain a new SWOT analysis[7] starts. Thereby, the horizontal unfolding of variety enters to work, and generates huge value to the supply chain (applying the Forces of Porter, the Delta Hax analysis, etc). Actually, in supply chains in which there is a "lion", this function is usually taken by this node, who forces the others to follow some roadmap; if the "lion" do not convince, activity is deployed by huge effort and energy rather than smoothly.

System Three* takes place by Lean's *genchi genbutsu*, i.e. going to the place and observe critically. Cross visits, blitz events (activities lasting a few consecutive days to produce a tangible alteration, generally deploying best demonstrated practices outside) and other activities are placed by the central unit after discussion to achieve *nemawashi* (i.e. consensus obtained by applying a scientist schema) in order to fuel continuous

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[7] SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis: a tool in risk analysis and business strategy.

improvement to raise common standards shared in the system, namely to protect the image that the supply chain projects to the environ (customers, public, suppliers, etc).

Regarding possible extensions of this research work, some areas require further investigation in the VSM application in supply chains, e.g. to detail how to shape all VSM components (functions, different recursion levels, etc) and variety amplifiers and attenuators. Moreover, we would like to research why the systemic approach is not widely used yet, being extensively verified that this mature theory outperforms classical approaches. We know that moving each node away from their selfish natural behaviour needs some education phases. For this reason, we also aim to focus on the transition process: from reductionism to holism in SCM. Nonetheless, and in conclusion, the good news is that a mature state for moving towards this direction is available, and as previously highlighted the literature brings evidences that expectations for success are quite high for most supply chains.

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