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Applying Goldratt's Theory of Constraints to reduce the Bullwhip Effect through agent-based modeling

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ABSTRACT

In the current environment, Supply Chain Management (SCM) is a major concern for businesses. The Bullwhip Effect is a proven cause of significant inefficiencies in SCM. This paper applies Goldratt's Theory of Constraints (TOC) to reduce it. KAOS methodology has been used to devise the conceptual model for a multi-agent system, which is used to experiment with the well known 'Beer Game' supply chain exercise. Our work brings evidence that TOC, with its bottleneck management strategy through the Drum–Buffer–Rope (DBR) methodology, induces significant improvements. Opposed to traditional management policies, linked to the mass production paradigm, TOC systemic approach generates large operational and financial advantages for each node in the supply chain, without any undesirable collateral effect.

1. Introduction

The complexity and dynamism that characterize the context in which companies operate nowadays have drawn a new competitive environment. In it, the development of information technologies, the decrease in transport costs and the breaking down of barriers between markets, among other reasons, have led to the perception that competition between companies is no longer constrained to the product itself, but it goes much further. For this reason, the concept of Supply Chain Management (SCM) has gained a lot of strength to the point of having a strategic importance. The current global economic crisis, consequence of many relevant systemic factors due to the fact that globalization still has not been able to develop systemic dynamic properties to deal with a growing variety of requirements, is creating conditions which increase awareness to adopt new approaches to make business (among others, Schweitzer et al., 2009); hence, SCM is a boiling area for innovation.

Analyzing the supply chain, Forrester (1961) noted that changes in demand are significantly amplified along the system, as orders move away from the client. It was called the Bullwhip Effect. He studied the problem from the perspective of system dynamics. This amplification is also evidenced in the famous 'Beer Game' (Sterman, 1989), which shows the complexity of SCM. He concluded that the Bullwhip Effect is generated from local-optimal solutions adopted by supply chain members. This can be considered as a major cause of inefficiencies in the supply chain (Disney, Farasyn, Lambrecht, Towill, & Van de Velde, 2005), because it tends to increase storage, labor, inventory, shortage and transport costs. Lee, Padmanabhan, and Whang (1997) identified four root causes in the generation of Bullwhip Effect in supply chains: (1) wrong demand forecasting; (2) grouping of orders into batches; (3) fluctuation in the products prices; and (4) corporate policies regarding shortage. The same idea underlies behind all of them: the transmission of faulty information to the supply chain. Therefore, the first approaches in the search for a solution to this problem were based on trying to coordinate the supply chain. Some practices that have been successfully implemented in companies are Vendor Managed Inventory (Andel, 1996), Efficient Consumer Response (McKinsey, 1992) and Collaborative Planning, Forecasting and Replenishment (DesMarteu, 1998). Nevertheless, the Bullwhip Effect is still a major concern around operations management in the supply chain. Chen and Lee (2012) discussed the linkage between the bullwhip measure and the supply chain cost performance, capturing the essence of most-real world scenarios.

The Theory of Constraints (TOC) was introduced by Goldratt and Cox (1984) in his best seller 'The Goal', representing a major innovation in the production approach. The author alleges that the sole purpose of an organization is to make money now and in the future. Hereupon, the author defines six variables as organizational

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measures to approach that goal. Three of them are operational: throughput, inventory and operating expense. The other three are financial: net profit, return on investment and cash flow. All these metrics are bound together through relationships. According to TOC, the most important thing to improve the overall system performance is to concentrate the whole improvement effort on its bottleneck. Goldratt proposes the Drum–Buffer–Rope (DBR) methodology to manage the system. Once the bottleneck is identified, it becomes the drum of the system. A buffer is used to protect against variability in replenishment time, because we aim to exploit the full capacity in the bottleneck. A rope is used to subordinate the system to the bottleneck.

The major contribution of this paper is to provide evidence via a multi-agent simulation model about the sound impact of TOC application to reduce the Bullwhip Effect in supply chains. TOC is compared against a traditional management alternative, typical in mass production paradigm: the order-up-to inventory policy. Our aim is to demonstrate that supply chains have plenty of reasons to operate according to the TOC systemic approach. Fig. 1 depicts the structure of our work.

The conceptual multi-agent model has been worked out using KAOS methodology. Robust SW engineering and test driven development techniques have been applied to build and verify the model. A multi-agent system (MAS) is an optimal environment to address this issue, as it is a physically distributed problem, where each node has only a partial knowledge about the problem-world.

As shown in Fig. 1, our research method has been the following:

(1) Definition of problem world ('Beer Game' supply chain) and problem statement (Bullwhip Effect).
(2) Clarification of the process. The 'Beer Game' is modeled as it is widely described in literature (among others, Kaminsky & Simchi-Levi, 1998): the unique source of noise is the variability in demand; the Bullwhip Effect emerges as a consequence of the agents' behavior; the metrics considered are the shortage penalties and the inventory costs. Once the material and the information flows are implemented, two engines are added: TOC and the order-up-to inventory policy. The experimenter chooses what engine the agents in the supply chain will use to make their purchasing decisions.
(3) Devise the conceptual model using KAOS methodology.
(4) ABMS development of the model using NetLogo, followed by verification using statistical tests.
(5) Exploitation of the model: experimentation of different treatments.
(6) Problem analysis: descriptive and inferential statistics to derive conclusions.

2. Literature review

2.1. Theory of Constraints in Supply Chain Management

Elihayu M. Goldratt described in his book 'The Goal – A Process of Ongoing Improvement' (1984) his view about the best way to manage a company. He did it through fiction, telling how a troubled company managed to get over this situation. In a subsequent scientific work, Goldratt (1990) presented the Theory of Constraints (TOC) in more detail. This theory comprises three interrelated areas (Simatupang, Hurley, & Evans, 1997): logistics, logical thinking and performance measurement. In logistics, the methodology is based on the DBR scheduling method (Goldratt & Cox, 1984). The logical thinking is based on a continuous improvement cycle with five steps: (I) Identify the bottleneck; (II) Decide how to exploit the bottleneck; (III) Subordinate everything else in the system to the previous step; (IV) Elevate the bottleneck; and (V) Evaluate if the bottleneck has been broken, and return to the beginning. The performance measurement, which quantifies the application of this methodology, encompasses operational measures (throughput, inventory and operating expense) and financial measures (net profit, return on investment and cash flow), which obey to the same view: the only goal of the organization is to make money now and in the future.

Although TOC was initially oriented on the production system of the company, its application to other areas of the business has been proposed, such as marketing and sales (Goldratt, 1994), project management (Goldratt, 1997) or SCM (Goldratt, Schragenheim, & Ptak, 2000). In this latter area, several authors have researched the application of the TOC. As an example, Umble, Umble, and von Deylen (2001) described the application of TOC in the implementation of an ERP system to manage the supply chain. Cox and Spencer (1998) proposed a method for SCM through TOC, valid when one company directs the entire chain. However, when this

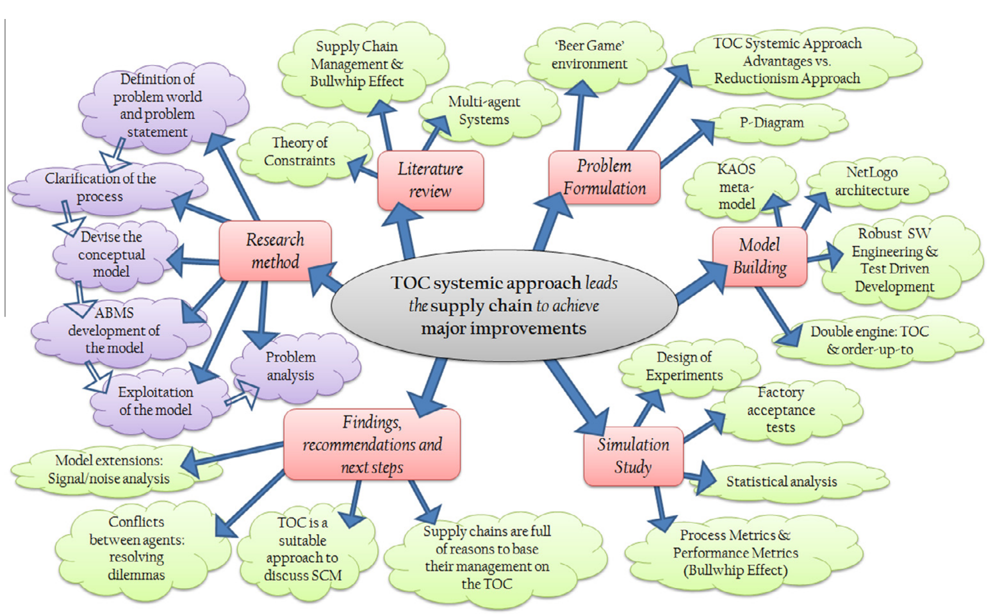

Fig. 1. Structure of this work.