

Forty Years and Still Evolving: The Theory of Constraints

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This manuscript presents a literature review of the Theory of Constraints. The literature is divided into three periods: the early (1980-1995), the expansion (1996-2014) and the past five years (2015-2019). The theory has been applied to production efficiency, supply chain management, cost accounting, product-mix decisions, and strategic decision-making. It has evolved into a more mature management philosophy and thinking process. The theory has become integrated with other related or competitive theories and has withstood the test of time as an effective and intuitive approach to thinking about a broad range of functional areas, problems, and methods of decision-making.

Keywords: Theory of Constraints, operations management theory, review, thinking process, drum-buffer-rope, DBR, TOC

ORIGIN OF THE THEORY OF CONSTRAINTS

The earliest mention of the Theory of Constraints (TOC) appears in the *APICS 23rd Annual International Conference Proceedings* (Goldratt, 1980). TOC was developed and later published by Goldratt and Cox (1984) based on their prior work on a software-based optimization of production systems (Goldratt, 1988). Since its initial publication, the TOC has been mentioned in more than 1000 academic journal articles covering topics in manufacturing, continuous process improvement, decision-making support for organizations, production, supply chain analysis, project management, accounting, distribution, retail, and managerial decision-making (Ikeziri, de Souza, Gupta, and Fiorini, 2019). A deeper understanding of the TOC requires an understanding of constraints.

A constraint is a factor that limits the performance of a system and if that factor could be utilized or exploited more efficiently, higher levels of performance or achievement would result (Cox, Boyd, Sullivan, Reid, & Cartier, 2012). The concept of a constraint should not be confused with a simple bottleneck, defined as a resource whose capacity is less than the demand for its use during the period (Cox et al., 2012; Cox & Schleier, 2010). As posited by Goldratt (2010), even though system performance may be improved by a wide variety of actions, organizations do not have sufficient resources to pursue them all. Accordingly, organizations should focus the application of resources toward exploiting bottlenecks and constraints in their systems and should not apply more resources beyond a certain point on the non-constraint elements. This approach runs counter to the cost-accounting concept that Goldratt (2010) claimed encouraged production even if the production were part of a non-bottleneck. The application of increased efficiency to non-constraints can build up work-in-process inventory and divert resources away from the real potential increases in efficiency (Blocher, Stout, Juras, & Smith, 2019). The TOC has evolved over time.

Since its introduction, TOC has become a rich and versatile formal operations management theory because it is generalizable, parsimonious, a rich source of hypothesis development, internally consistent, conceptually subject to disconfirmation, and prone to higher levels of abstraction based on additional research (Naor, Bernardes, & Coman, 2013). The extant literature on TOC can be divided into categories based on time frames and includes the early years (1980-1998), the middle years of expansion and application (1999-2014) and the recent work on TOC published in the last five years. First, the early years are examined.

TOC THE EARLY YEARS

From its introduction, TOC quickly evolved into an overall theory of how to successfully manage an organization (Goldratt, 1988). This evolution was driven in part by the recognition that the most important constraint in most organizations stems from managerial policy rather than from physical bottlenecks. To address these managerial policy constraints and implement a process of continuous improvement, organizations needed to develop a new process for thinking about these issues. This TOC thinking process was deliberately designed to have a lasting impact on the world of business (Rahman, 1998) and one group of scholars called the TOC thinking process the most important intellectual achievement since the invention of calculus (Noreen, Smith, & Mackay, 1995). Early publications featuring TOC cast it as a competitor for two of the existing approaches to achieving competitive advantage.

Early Attempts at Competitive Advantage

Two of the early attempts to help organizations achieve competitive advantage included materials requirements planning (MRPI and MRP II) and the just-in-time (JIT) operations management system. Benton and Shin (1998) defined MRP and JIT as systems of planning and controlling characteristics of material flow and as “powerful management tools that could determine the success or failure of an entire manufacturing system” (411). Several early scholars presented TOC, also known as Optimized Production Technology (OPT), as a competitor to these early approaches (Aggarwal, 1985; Cook, 1994; Fox 1982; Gelders & Van Wassenhove, 1985; Plenert & Best, 1986). Early work on OPT was criticized due to a lack of transparency with its algorithm and due to its claim of offering an optimal schedule (Rahman, 1988). Based on that criticism, TOC moved away from some of its earlier conceptual distinctions and its claim to support the implementation of an optimal schedule. Despite the initial criticisms, TOC became a more mature management philosophy.

TOC as a Management Philosophy

Many of the early published articles on TOC addressed the philosophy of TOC and the concept as a broad management approach. Jacobs (1983, 1984) described the planning and scheduling concepts in TOC. Lundrigan (1986), Meleton (1986) and Cook (1994) described how TOC improved efficiencies including carrying less inventory, lower operating expenses, and higher productivity. Another aspect of the management philosophy of TOC was the drum-buffer-rope (DBR) analogy. Initially described by Goldratt and Fox (1986), DBR refers to a logistical system designed to manage the material flow of products during TOC implementations. Scholars writing about DBR after 1986 eventually combined the DBR concepts with other aspects of OPT into what became known as TOC (Guide & Ghishelli, 1995; Schragenheim & Ronen, 1990; 1991). The *drum* is the system of scheduling at a specific pace, the *buffer* is strategically placed inventory to protect against variations in output, and the *rope* provides communication between control points within the system (Goldratt & Fox, 1986). Goldratt (1990) described the philosophy of TOC using the five steps of focusing which included identifying the constraints in the system, deciding how to exploit them, subordinating everything to the exploitation of the constraints, elevating the constraints in the system, and continuously returning to the first step in order to continue to improve the system. Goldratt (1990) also espoused a key aspect of the philosophy by stating that every system has at least one constraint. More than a useful technique for analyzing

production systems, TOC became a true management philosophy based on the idea of continuous process improvement. TOC represents a concentrated process aimed at detecting existing constraints and restructuring the organization around them (Orouji, 2016). Some early work on TOC looked at its application in organizations.

Other Early Work

In addition to studies that compared TOC to MPR and JIT and papers that espoused TOC as a management philosophy, some early work examined the application of TOC in organizational settings, particularly in the application to production problems. Several studies examine the use of TOC in organizations and the benefits obtained by applying it (Aggarwal, 1985; Fry, Cox, & Blackstone, 1992; Gardiner, Blackstone, & Gardiner, 1994). Additional studies presented applications of TOC to production problems including inventory reduction, reduction of WIP, reduction of lead time, and improved delivery (Darlington, 1995; Guide & Ghiselli, 1995; Reimer, 1991; Wahlers & Cox, 1994). Through the study of its applications, TOC continued to evolve as later research expanded the reach and scope of industries and functions impacted by process improvement.

TOC THE EXPANSION YEARS

After its initial period of growth, the application of TOC to organizational improvement expanded rapidly. This included the application of TOC tools as well as an expansion of work related to the TOC thinking process (Kim, Mabin, & Davies, 2008). During the publication period from 1996 to 2014, TOC was applied to studies and cases in a variety of subject areas and utilizing an assortment of methodologies.

Literature From the Expansion Years

Scholars examined TOC as it related to supply chain optimization (Alber & Walker, 1998; Balakrishnan & Cheng, 2005; Rahman, 2002; Simatupang, Wright, & Sridharan, 2004; Watson & Polito, 2003; Wu, Huang, & Jen, 2012; Wu, Lee, & Tsai, 2014), project management (Cohen, Mandelbaum, & Shtub, 2004; Goldratt, 1997; Leach, 1999; Steyn, 2001; Umble & Umble, 2000), production and organizational performance improvement (Holt, 1999; Inman, Sale, & Green, 2009; Mabin & Balderstone, 2000), continuous process improvement (Gattiker & Boyd, 1999), the cost accounting framework (Cox, Draman, Boyd, & Spencer, 1998; Fritzsche, 2011; Lockamy & Spencer, 1998; Moisello, 2013; Smith, 2000; Zimmerman & Yahya-Zadeh, 2011), and throughput accounting calculations and approaches (Balderstone & Keef, 1999; Corbett, 1998; de Souza, Sobreiro, Nagano, & de Souza Manfrinato, 2013; Eden & Ronen, 2007; Foster, Sullivan, & Ward, 1998; Kee, 2001; Kee & Schmidt, 2000;). Other scholars examined TOC as applied to expense reduction (Cox, Howe, & Boyd, 1997), setting and evaluating market prices (Caspari & Caspari, 2004; Corbett, 1998; Smith, 2000), as well as business problem solving and process improvements (Button, 1999, 2000; Chaudhari & Mukhopadhyay, 2003; Chou, Lu, & Tang, 2012; Reid & Cormier, 2003; Scheinkopf, 1999; Schragenheim & Dettmer, 2000; Smith, 2000). Some studies examined medical claims processing (Taylor & Sheffield, 2002), corporate and business level strategy (Boyd, Gupta, & Sussman, 2001; Dettmer, 2003a; 2003b; Goldratt, Goldratt, & Abramov, 2002; Smith, 2000;), product mix decisions (Aryanezhad & Komijan, 2004; Ferencíková, 2012; Lee & Plenert, 1996; Onwubolu, 2001; Sobreiro & Nagano, 2012; Tulasi, Rao, & Tirupati, 2012), and the critical chain management concept, a.k.a CCPM (Elton & Roe, 1998; Cohen et al., 2004; Goldratt, 1997; Leach, 1999; 2000; Newbold, 1998; Raz, 2003; Steyn, 2001; Umble & Umble, 2000).

Results of the Application of TOC

As the previous inexhaustive list helps demonstrate, TOC was applied to a wide variety of organizational challenges and functional areas during these years of conceptual expansion. In addition to the wide variety of applications of TOC and its related tools and techniques, Mabin and Balderstone

(2000) conducted a review of publicly announced benefits of TOC in the literature. Based on mean calculations, Mabin and Balderstone (2000) found a 70% reduction in order to delivery time (based on 32 implementations), a 65% reduction in manufacturing cycle time (based on 14 implementations), a 49% reduction in inventory carrying (based on 32 implementations), a 63% increase in productivity (based on 22 implementations), and a 44% improvement in due date performance (based on 13 implementations).

The Efficacy of TOC Interventions

This demonstrates strong evidence of the efficacy of TOC philosophy, tools, and techniques for improving organizational efficiency and performance. Many of the realized improvements in implementations of TOC at the organizational level resulted in an “order of magnitude” improvement in performance (Watson, Blackstone, & Gardiner, 2007, p. 400). As these benefits were realized and began to be publicized, an increasingly large number of scholars and practitioners became interested in TOC and applied its philosophy and techniques to an ever-larger set of problems and contexts.

Future Plans for TOC Applications

During these years, scholars also noted that TOC was viewed as an operations strategy and many top-level managers delegated implementation and application of TOC to mid-level management roles (Watson et al., 2007). During these years of rapid expansion of TOC, some scholars (Tulasi & Rao, 2012) posited that TOC should be combined with other tools and techniques in operations management and as the next section demonstrates, recent literature has taken a more integrated approach to TOC. The most recent five years of publications in TOC help illuminate where TOC stands today and where it might be headed in the future.

TOC IN THE PAST FIVE YEARS

The recently published extant literature on TOC provides valuable insight into how the theory is being applied today. While some authors examine TOC as a method to increase speed in avenues such as manufacturing cycle time or the product life cycle (Blocher et al., 2019), wider applications exist and continue to expand the application of TOC. One key trend is the integration of TOC with other tools, techniques, and philosophies. Additional applications continue in the traditional TOC arenas of increased productivity, supply chain and critical chain management, product-mix decisions, and the TOC thinking process.

TOC Integration With Other Tools and Techniques

A recent article describes TOC as an important approach for utilizing problem-solving in a Business Intelligence System (BIS) using tools such as Power BI (Cieśla & Kolny, 2019). These authors suggest integrating a forty-year-old management philosophy with some of the most recent BIS tools to improve the performance of organizations. Dias, Silva, and Tenera (2019) presented a model that integrated TOC, Lean, and Six Sigma practices at a manufacturer. Telles, Lacerda, Morandi, and Piran (in-press) studied the integration of DBR with data envelopment analysis (DEA) at an aerospace manufacturing firm. In another case, de Jesus Pacheco, Pergher, Antunes, and Roehe Vaccaro (2019) picked up the thread of previous literature and proposed multiple methods of integrating TOC with Lean approaches to production and process improvement to minimize the inherent tradeoffs in operations management. While de Jesus Pacheco et al. (2019) looked at the integration of TOC with Lean principles, Puche, Costas, Ponte, Pino, and de la Fuente (2019) offered a side by side comparison between a Lean technique (Kanban) and a TOC tool (DBR). This approach harkens back to the early days of TOC literature comparing different productivity approaches.

Traditional TOC Applications in Recent Literature

TOC continues to be studied in connection with its original and most common applications aimed at increasing production and other operational efficiencies. Work in this area includes studies in production efficiency (Panizzolo, 2016; Trojanowska, Kolinski, Varela, & Machado, 2018), throughput per hour as a

measure of entrepreneurial efficiency (García-Vidal, Pérez-Campdesuñer, Sánchez-Rodríguez, & Martínez-Vivar, 2019) or developing a throughput scale (Sahi, Gupta, & Patel, 2017), as well as supply chain effectiveness (Gupta & Andersen, 2018; Rossi Filho, Pacheco, Pergher, Vaccaro, & Antunes, 2016; Singh & Misra, 2018), implementation of TOC in diverse product manufacturing and the impact on strategic manufacturing decisions (Urban, 2019), and the production of an algorithm based on TOC and branch and bound product-mix calculation decisions (Mehdizadeh & Jalili, 2018). Other scholars examined TOC and critical chain project management from the standpoint of the role of knowledge intermediaries (Balakrishnan & Cheng, 2019) and using a design structure matrix to measure information flow rather than simply examining resource constraints (Zhang, Song, Chen, & Shi, 2015).

TOC Thinking Process

TOC also continues to be examined based on its philosophy including its thinking process. A complete review of the TOC thinking process is beyond the scope of this manuscript however, a prior review has been published (see Kim, Mabin, & Davies, 2008). Mabin (2015) compared the TOC thinking process to the Rational Model of decision-making. Bauer, Vargas, Sellitto, Sousa, and Vaccaro (2019) specifically applied the TOC thinking process to the study of decision-making in healthcare systems and Modi, Lowalekar, and Bhatta (2019) conducted a longitudinal study of the TOC thinking process in an Indian manufacturing company supply chain over seven years. The TOC concepts have even been applied to technical problems such as solving memory allocation in cloud storage systems (Chang, Chang, & Chang, 2017) and the process of software development (Ribeiro, Schmitz, Alencar, & Silva, 2018).

TOC and Accounting Methods

TOC has a long history of application to and comparison with accounting methodologies. Reynolds, Fourie, and Erasmus (2018) put a new spin on a traditional idea by examining TOC and time-driven activity-based costing (TDABC) using implementation by subject matter experts in a variety of industries and found support for the combination. Zhuang and Chang (2017) examined activity-based-costing using mixed-integer programming and applying it along with TOC to the product-mix decision.

TOC IN THE FUTURE

Given the impressive breadth and depth of the admittedly inexhaustive list of literature described above, TOC has made a clear impact on the academy in the areas of operations management, supply chain, accounting, and product-mix just to name a few. Some scholars suggested that based on its versatility, TOC could be applied in virtually any sector and to almost any size organization (Şimşit, Günay, & Vayvay, 2014). Recent work combining TOC with other methodologies, tools, and techniques is opening up new avenues for both additional research and greater applications to practice. TOC continues to mature as both a management theory and thinking process. Ikeziri et al. (2019) noted that a “positive evolutionary trend” exists in the extant literature on TOC and its related tools and techniques (5094). However, additional empirical work in organizations with large sample sizes and longitudinal designs is needed. Further, some clear subject matter areas for additional research exist including capacity management in diverse environments, more empirical work on critical chain methodologies, additional practical studies on the TOC thinking process, and further study of TOC as a structured approach to continuous process improvement (Ikeziri et al., 2019).

It is not uncommon in the social sciences to discard older theories in favor of newer ideas, revised conceptual models, or repackaged thinking. TOC is one theory that has withstood the test of time for nearly forty years and continues to gather momentum, interest, and converts across a wide variety of functional areas and applications.

This manuscript presented a review of the extant literature published on the Theory of Constraints (TOC). The literature was presented based on three periods: the early years (1980-1995), the expansion (1996-2014), and the past five years of literature (2015-2019). The continued movement toward an integration of TOC tools and techniques with other approaches and concepts was presented. Suggestions for additional avenues for TOC research were also provided.

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