Evolution of the Theory of Constraints: A Literature Review

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Abstract The presented article deals with the analysis of current literature, focusing on the issue of the theory of constraints (ToC). The literature review is arranged in the structure of long-term defined periods and offers an insight into the development of this discipline up to 2005. The authors propose the extension of the given classification according to the ToC application after 2005, when the given approach is extended most often to Supply Chain management and, together with Lean and Six Sigma, to small and medium-sized enterprises.

Keywords Theory of constraints, optimization, goal, management, drum-buffer-rope, operations research, review

JEL C44, C61, M11

1. Introduction

The goal of every company (as a business entity) is to gain a dominant position on the market, which will make it more efficient. To achieve this situation, the firm chooses a strategy and takes into account other competitors in the market and their activities. However, companies should focus primarily on themselves and correctly identify their own structure, setup processes, project management and other aspects, whether it is a manufacturing or service sector. The described situation is then an ideal state for the application of the Theory of Constraints (TOC), which serves to identify weak (vulnerable) points in the chain. The method does not look at the individual components of the process independently, but as an interdependent system in which the weakest part slows down the entire process.

The concept of TOC has been evolving since the late 1970s, when it was created as a tool to improve manufacturing processes by removing constraints. However, it soon proved to be much more complex and significantly influenced the field of cost accounting, project management, operations management, etc. In the last 30 years, the philosophical approach has been implemented by public and private sector organizations, every industry, small businesses and international corporations.

The aim of this research article is to conduct a literature search of professional publications in the years indicated and in accordance with the periods presented by Watson, Blackstone & Gardiner (2007) to identify the specifics of these works and eras. Based on the literature published after 2004, the authors will further try to propose other eras in a similar context, which will correspond to the following periods up to the present (year 2023).

2. Literature review

The philosophical discipline of management known by the name ToC first appeared in the literature in 1984, when the book by the Israeli physicist Eliyahu M. Goldratt was published under the name The Goal. It is appropriate to state that this book is not a professional publication, but a novel from a corporate environment. In this book, Goldratt describes an unsatisfactory situation in a fictitious company and at the same time comes up with a solution that leads to the achievement of the set goals. What is important is that it does not use any (known at the time) management procedures or techniques that would lead to the fulfillment of goals, but a system of continuous and clearly defined steps that could not be classified as among known techniques.

The literature review presents a generally known classification of individual ToC periods. At this time, a number of relevant literature was created, which enriched various scientific fields and directed this scientific discipline into its current form.

The mentioned ToC era classification was developed by the authors Watson, Blackstone & Gardiner (2007) and the 5 eras include: the optimized product technology era, the goal era, the haystack syndrome era, the it's not luck era and the

critical chain era. The listed period names are taken from selected books by E.M. Goldratt that are most relevant to the period. The mentioned period classification system was further presented by Panizzolo (2016), Ramasu, Sobiyi & Akinlabi (2017), Miguel et al. (2017), Lokhande (2021), Jadhav & Dhawale (2021) and also developed by Şimşit, Günay & Vayvay (2014) and Kumar, Siddiqui & Suhail (2020). Another system for classifying literature by period is presented by McCleskey (2020), who focuses more on the application part and looks for connections primarily between the literature listed in in the 21st century. Development of publications in the period after 2004 was also presented by Miguel et al. (2017).

2.1. The optimized production technology era (1979-1984)

The first "Optimized Production Technology Era" covers the period between 1979 and 1984. It was during this period that Goldratt first introduced his concept of optimized production plans, which he implemented on his friend's poultry farm to increase production with limited resources. Goldratt (1980) subsequently presented his findings at the APICS International Conference. The system achieved considerable success, especially on the American continent, and in the following years Goldratt carried out more than 100 similar implementations in various enterprises (Bylinsky, 1983).

A significant problem of the system was its non-transparency and the absence of a universal description, which would enable its greater popularity in the professional literature (Bylinsky, 1983). In this context, Aggarwal (1985) adds that the implementation of OPT into enterprise systems was technologically difficult and at the same time financially expensive. Jacobs (1983) points out that not all implementations have been successful and some have even led to litigation. It further states that it has never been proven that OPT provides an optimal schedule of work and activities. The algorithmization of the OPT system was attempted by Fox (1984), which was based on practical knowledge of identifying bottlenecks in a local factory.

Fox (1984) and Aggarwal (1985) further state that although OPT cannot be algorithmized, it represents significant competition for current operations management systems (eg JIT, MRP,...). Numerous researches have shown that OPT (then known as TOC) achieves better results than JIT, MRP, but also Lean or agile management approaches.

2.2. The goal era (1984-1990)

The new optimization system for manufacturing companies has created an extraordinary buzz and also a lot of questions. No one has been able to describe said tool, including the authors himself. Goldratt held several meetings with business representatives and attended conferences, but was unable to explain his procedures himself. Even the scientific community had a significant problem with the algorithmization of procedures. So Goldratt & Cox (1984) changed his strategy and published a new business novel called "The Goal".

It describes the process of identifying weak points as well as specific techniques suitable for application at given decision points. Heuristics based on TOC are also presented, and the authors present the so-called POOGI (Process of On-Going Improvement), which consists of the application of five steps of implementing the TOC concept in any process of any organization. As stated by Watson, Blackstone & Gardiner (2007), these five steps 5FS (Five Focusing Steps) includes (i) identifying system constraints, (ii) deciding how to use system constraints, (iii) subjecting all other decisions to the above, (iv) increasing system constraints, and (v) if there is a limitation in any of the previous steps, return to step 1. This system is based on the assumption that there is at least one constraint in every system (Goldratt, 1990). Scheinkopf (1999) and also Coman & Ronen (1994) tried to expand the conditions for system implementation, according to which the goal of the system, the purpose of the system and the method of measuring the system's performance must be identified.

Now, with the basic description of the system, research lawyers have begun to focus on procedures for maximizing the use of bottlenecks in corporate systems. Independent results (Lundrigan, 1986; Meleton, 1986; and Cook, 1994) point to the fact that the application of TOC has a positive economic effect on the enterprise, reducing inventory and operating costs and increasing system productivity. In the book, Goldratt (1984) further introduces the DBR (Drum-Buffer-Rope) concept, which a few years later will become the most important and fundamental planning technique in TOC. The system anticipates the errors of human workers and their slowdown is pumped into the buffer memory, thereby not jeopardizing the system as a whole.

2.3. The haystack syndrome era (1990-1994)

Already in the previous period, the public had the opportunity to familiarize themselves with the new TOC system and understand the main ideas of its operation. The problem was that many companies were not able to reflect the desired results (from a financial point of view) after implementing the steps, although it was objectively obvious that the system was working better and more efficiently. It was not possible to measure the performance of the system, and only companies that implemented similar types of changes in production could be compared relevantly. The whole problem had its origins in business cost accounting, as Goldratt (1990) explained in a new book, The Haystack Syndrome. This is because cost accounting distorts information about real costs, which mystifies decision-makers and gives them misleading information. Goldratt (1983) stated much earlier that cost accounting is the key enemy of TOC.

It is important to note that Goldratt was not the only one who despised cost accounting. The problematic nature of traditional accounting principles was mentioned by Johnson & Kaplan (1987) in highly flexible production systems, and Smith (2000) drew attention to the historical importance of information with insufficient explanatory value for future use. Fry & Cox (1989) with Goldratt and other experts worked on a new accounting model that would focus on processes and measure the performance of a business as its overall financial performance. This resulted in the Throughput Accounting

(abbreviated TA) system, which focuses less on operating costs, accounts for revenues after sales are completed and does not allocate added value to material stocks during the production process (Noreen, Smith & Mackey, 1995). Boyd & Cox (2002) subsequently compared both systems based on several years of observation. The mentioned setup led to the immediate ability to measure and compare the outputs of any business. Similar results were reached by Stefano, Antunes & Piran (2022), who, in the case of using the given system, draws attention to smaller fluctuations in demand and equalization of stocks, which subsequently positively affects business decisions.

2.4. The it's not luck era (1994 – 1997)

The fourth period of TOC development is defined by the emergence of a tool for searching for solutions in sophisticated processes, which is the Thinking Processes (TP). When publishing the book "It's not Luck" (Goldratt, 1994), the goal was not to respond to deficiencies or social demand as in previous cases. The main goal was to implement new knowledge within the continuous improvement of cognitive systems. Goldratt (1994) states that in order to achieve improvement, it is necessary to answer the questions: "What to change?" What to change it into? How to cause the change?" Kim, Mabin & Davies (2008) dealt with the implementation of the procedure in other scientific disciplines.

The connection of TP with the application part was noticed by Şimşit, Günay & Vayvay (2014), who state that if TOC is a philosophical tool for managing production and other processes in the company, then TP is a system for its implementation. Gattiker & Boyd (1999) drew attention to the advantages of TP, according to which the system has a great ability to work on continuous improvement of customer services. Scheinkopf (1999) or Chaudhari & Mukhopadhyay (2003) further dealt with the application of TP in solving business problems.

2.5. The critical chain era (1997 – 2004)

The complex of methods for project management CCPM (Critical Chain Project Management) is one of the most important applications of TOC techniques, which was already presented at the International Jonah Conference in 1990. The given concept was not accepted at the time and it received greater development only after the presentation of another business novel "Critical Chain" in 1997. The basic idea of CCPM is to manage projects using resources and their availability in the implementation of tasks. It differs from traditional project management methods in the system of assigning duration to activities, the use of buffers for the purpose of drawing time reserves, and the elimination of resource conflicts in activities. The most visible adjustment compared to other project methods is the procedure applied when determining the duration of individual activities and the project as a whole. Instead of a normal duration estimate that reflects a 95% certainty of completion, CCPM durations are based on 50% estimates, resulting in shorter activity durations. If this duration is exceeded, a buffer is placed at the end of the project, from which the mentioned deficiencies are drawn. From

this idea, it is clear that CCPM never works with an exact project completion date, however, the method makes it possible to determine when it will be completed at the latest.

Goldratt (1997) states that many traditionally managed projects fail due to the unpredictable behavior of human resources, as aspects of human behavior are difficult to influence, let alone plan. Other sources cite frequent project failures as a result of inefficient multitasking, i.e. working on multiple activities at the same time. Other negative influences include the student syndrome, Murphy's project law or Parkinson's law (Robinson & Richards, 2010). He further states the suitability of the application of the given method in completely new and never-realized projects. Even so, studies on successful applications of the CCPM method can be found (Anastasiu, Campian & Roman, 2023).

3. Literature after 2004

It is interesting to see how the individual periods appropriately delimit development, and with his novels Goldratt was able to partially guide the scientific sphere in the use of individual approaches to the TOC, although often he did not directly create a description of more sophisticated approaches.

Now, based on the knowledge gained, it is appropriate to propose further development and classification of TOC activity in the periods from 2005 to 2022, which represent new ideas or the application of methods in new areas. It should be noted that it is not easy to clearly determine (and time-bound) what the professional public is most concerned with in the TOC. Just the fifth era itself is difficult to specify in this way, because the conceptual boom of the CCPM project method came only with its wide use around 2010 and continues to this day.

Watson, Blackstone & Gardiner (2007), who determined the current classification of individual periods (eras), also thought about the future development of TOC and its importance in the world. At the beginning of the 21st century, TOC experienced a significant boom in professional literature (McCleskey, 2020) accompanied by an increase in publications, and TOC ideas also began to be applied in completely different industries. According to Watson, Blackstone & Gardiner (2007), the method entered the 6th era, when instead of an alternative way of management, the technique began to become mainstream. It is therefore difficult to keep track of all the streams in which TOC is developing, how much and how fast. Symbolically, this change is completed by the retirement of a number of current academics and experts, who are being replaced by a new open-minded generation.

3.1. TOC in supply chain management

However, if we focus purely on new publications and what the professional public has been dealing with immediately after the end of the 5th Era, we notice a significant increase in publications in the field of supply chain optimization using TOC techniques. Alber & Walker (1998) were among the first to draws attention to the benefits of strategic cooperation

and directly mentions the increase in income and the reduction of unexpected costs in the long run. The idea was further developed by Rahman (2002), who applied TA to the supply chain not only to identify critical success factors in supply chain management, but also to understand causal relationships.

The real foundation of TOC in supply chains was laid by Watson, Polito (2003) who created a simulation model. This served as a basis for the comparison of multi-echelon distribution models. While the original model used partial centralization of stocks with orders planned by Distribution Resource Planning, the other two models used the Theory of Constraints-based heuristic for buffering and inventory replenishment. The actual application of the method in a real environment was then dealt with by Simatupang, Wright, Sridharan (2004), who presented several recommendations for further research - quantification of replenishment and emergency levels, the evaluation of the selfenforcing property of collaborative metrics, and the inclusion of reverse logistics.

The issue of TOC in the supply chain was further addressed by Balakrishnan, Cheng (2005) or Wu, Huang and Jen (2012), who followed the strengths and pitfalls of the TOC supply chain replenishment system (TOC-SCRS) method implemented in a number of companies. The practical application in the form of a case study was further dealt with by Simchi-Levi et al. (2008), Wang, Lai & Shi (2011), Al Amin, Rahman & Shahriar (2020), Opoku (2022), Orue et al. (2021) or Mason-Jones, Davied & Thomas (2022). Current publications testify to the fact that the topic of TOC implementation in the supply chain is still relevant. Gupta & Andersen (2018) or Singh & Misra (2018) dealt with the measurement of efficiency within the supply chain. An interesting way to avoid problems during the implementation of the technique was proposed by Lizarralde, Mediavilla & Apaolaza (2020), who have designed and created a systematic process for the first two steps of TOC.

3.2. TOC as a sales and marketing tool

At the turn of the millennium, TOC still appeared as an alternative but quite universal tool applicable to a wide range of industries. In addition to successful implementations in production processes and projects, articles began to appear dealing with the possibility of using TOC for the purpose of setting and evaluating market prices and using it for product mix decisions. Fredendall & Lea (1997) even created the first product mix heuristic for these purposes, where they implemented two of the five steps of the TOC process. These were: (1) Identify the system's constraint(s) and (2) Decide how to exploit the system's constraint(s). The load on the resource is calculated after the production of all products is completed, with the bottleneck being the resource whose capacity is less than the market demand. Throughput is then the difference between the selling price and the cost of raw materials. The authors also introduce the term contribution margin.

Onwubolu (2001) states that the product mix decision is one application of TOC that involves determination of the quantity and the identification of each product to produce. Relatively contradictory findings are presented by

Aryanezhad, Komijan (2004), according to which the current TOC model is ineffective and unusable for the purpose of determining the product mix. They then draw attention to its weaknesses and propose their own solution based on the use of integer linear programming methods. Another constructive heuristic based on the knapsack problem was introduced by Sobreiro & Nagano (2012). Another version of the model, which was based on TOC and branch and bound product-mix calculation decisions, was then created by Mehdizadeh, Jalili (2018).

Due to the proximity of the given topic, it is advisable to also focus on the use of TOC for setting and evaluating market prices. Corbett (1998), Smith (2000) and Caspari, Caspari (2004) dealt with this issue marginally in their books. Since these theories have never been elaborated in a limited number of publication outputs in recent years, it cannot be argued that the development of TOC for sales and marketing has been meaningful and effective.

3.3. TOC, lean and six sigma as support systems

Subject of investigation by new experts in TOC in recent years is a completely new area. Just as it was possible to combine TOC procedures with project management methods (which created the CCPM method), TOC procedures can be combined with other scientific disciplines or industries. In this context, Lean management and the Six Sigma management strategy are most often talked about recently. Although the professional public is sometimes inclined to this idea, it cannot be said that these procedures are interchangeable.

Lean is a technique that pursues added value for the customer while reducing costs and maintaining quality; Six Sigma performs statistical analysis of a wide volume of data in order to improve business, production and logistics processes and consistently meet customer expectations; TOC aims to improve system performance by removing bottlenecks and increasing throughput. From the point of view of logic, the mentioned techniques are not substitutes, but complement each other.

One of the first to deal with the issue of comparing these three approaches (TOC, Lean, Six Sigma) was Nave (2002). He tried to create a manual according to which a company in a selected situation and with set goals should choose the optimal tool for achieving them. The integration of Six Sigma methods into the TOC system for continuous improvement to improve production system performance is presented in a case study by Ehie, Sheu (2005). Soni (2011) further drew attention to the four possibilities of combining Six Sigma and TOC, which include - identification of a significant opportunity, analysis of the problem, development of solutions, and continuous improvement.

Although these initial studies had a pioneering character, the given combination of methods regularly began to appear in the professional literature only after 2015. Jesus Pacheco et al. (2015) tried to analyze the points of convergence and divergence between TOC, Lean and Six Sigma in the framework of continuous improvement of production systems. The conclusions of the research conducted on 28 evaluation criteria confirmed that all three methods overlap with each other.

Bostan (2018) dealt with a similar analysis of the interdependencies of these three approaches. Ekles & Turkmen (2022) proposes an updated integration model for ToC and Six Sigma. Aripin, Nawanir & Lee (2023) deals with the possibility of combining Lean and ToC. A model integrating TOC, Lean and Six Sigma procedures of the production process was presented by Dias, Silva & Tenera (2019), and their work was followed by Jesus Pacheco et al. (2019), who proposed several procedures for mutual integration of TOC and Lean in order to further improve processes. The proposal of a complex integrated framework under the name TLS (ToC, Lean, Six Sigma) is presented by Gupta, Digalwar & Goyal (2022).

It should be noted that there are not only ideas to link TOC with Lean and Six Sigma in the professional literature - Cieśla, Kolny (2019) propose the integration of TOC into the Business Intelligence System (BIS) in order to solve problems and improve the performance of organizations. Puche et al. (2019) then presented a comparison and the possibilities of mutual integration of Kanban and Drum-Buffer-Rope methods in TOC.

4. Discussion

It is worth noting that a number of authors have already dealt with the analysis of literature reviews in the area of the TOC. It is now appropriate to confront their ideas with the views and findings of the authors of this study.

The first thing to mention is the literature review presented by Watson, Blackstone & Gardiner (2007), who established the classification of individual TOC periods that is used until today and which is based on the problems solved in five eras. The very concept of the contribution draws attention to the detailed approach of the authors, who devote themselves significantly to the description of all techniques and contexts. In extent of knowledge this work has never been surpassed. As a negative aspect, it should be noted that the study is a bit stingy with the number of sources and real applications presented, while the reflections and theses of some authors in the given period were completely omitted. Nevertheless, this is a suitable and ideal publication, presenting an insight into the first quarter of a century of TOC.

The literature review presented by Şimşit, Günay & Vayvay (2014) is significantly based on the classification created by Watson, Blackstone & Gardiner (2007). The authors quite inexplicably completely neglects the last era, concerning the CCPM, which she explains by the lack of contemporary literature. The limitation of the theory in The Haystack Syndrome Era to the issue of "Throughput Accounting", which is mentioned only marginally, is a bit incomprehensible. However, the authors appropriately draws attention to a large number of other methods (JIT, MRP, FMS,...) in the beginnings of TOC, which represented an obstacle to greater advancement. She also describes The Goal Era in detail.

Interesting research is also presented by Kumar, Siddiqui & Suhail (2020), who narrows down the classification of Watson, Blackstone & Gardiner (2007) by the period to only very general developments with a minimum of references to the literature of the time and thus presents the basic, but organized and balanced facts. However, the significant added value of their study is the catalogue of TOC applications in the environment of business companies incl. a brief description of the outputs realized following the implementation of the TOC. Kumar, Siddiqui & Suhail (2020) also draws attention to the attitude of sceptics, according to whom TOC does not offer optimal solutions, but feasible solutions. He also adds that the TOC implementation has helped to improve already efficient systems such as Ford or NASA.

A completely different approach was taken by McCleskey (2020), who, as one of the few authors, does not stick to the set classification and presents his own. These are: (1) TOC in The Early Years; (2) TOC in expansion years; (3) TOC for the last 5 years. Its main goal is to provide a comprehensive list of authors who dealt with the issue of TOC in various sectors and in given periods. Overall, this is a high-quality summary of the literature, which is sometimes too detailed, while some cited sources deal with the issue too marginally. McCleskey, as one of the few authors, also states future expectations from TOC. Specifically, the authors believes that suitable areas for further research include capacity management, empirical work on CCPM, and practical studies on the TOC thinking process.

The authors of this study is most in favour of the concepts of Watson, Blackstone & Gardiner (2007) and McCleskey (2020), which are most consistent with this research article. Watson offers a detailed description of the problem, while McCleskey focuses more on analysis of published studies. Watson focuses on the classification of TOC periods, while McCleskey classifies the use of TOC in individual industries. Watson deals with the older period (up to 2005), McCleskey concentrates on the period in the 21st century. It can be said that these two publications together form a strong informational and universal base focused on the current concept of TOC.

Dozens of different literature reviews have already been published that dealt with the issue of the TOC, and only a part of them use different classification options. Among them, the classification proposed by Watson, Blackstone & Gardiner (2007) is most often used. In them, however, very few authors addressed the idea: "What happens after the 5th era, which ended in 2005?" and suggested further development. In the case of this contribution, the authors tried to explore and describe this development (between 2005 and 2022).

As a result of the extraordinary increase in publications dealing with TOC after 2000, it is very difficult to navigate current trends. Around the same time when (for example) the CCPM method was created and TOC became an important part of project management, many publications were also created about the use of TOC in Supply Chain Management, and the method also had benefits in other industries. While previously specialists and academics focused on TOC as a whole and were guided by published trends, today many of them are much more specialized and overall trends can be very difficult to track and analyse.

In total, three selected areas were listed in which TOC significantly developed further after 2005, which are (1) TOC

in Supply Chain management; (2) TOC as a sales and marketing tool; and (3) TOC, Lean and Six Sigma as support systems. Especially the last-mentioned area is extremely current, as many new models were presented after 2019. It should be emphasized that these are not the only trends, because the importance of TOC has been manifested in the last 20 years also in healthcare, storage, accounting, education and many other areas (McCleskey, 2020).

5. Conclusions

Many years have passed since the TOC system could be simply classified and written about in individual periods. Today, TOC is part of the mainstream and is appearing in businesses in all industries, small and large. While previously it was possible to classify TOC according to the observed horizon of years, today it is more appropriate to perform this classification by sector.

However, it is worth emphasizing that TOC is a system designed primarily for medium and large manufacturing companies. The authors thus believes that there are potential opportunities for TOC use by small businesses, especially in the service sector. However, the implementation of this system is usually very expensive, and for these companies, the implementation of the given system may not be financially effective. FPEDAS Productions has tried its best efforts to ensure that the templates have the same appearance.

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