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Theory of Constraints and the product mix problem: literature review, underlying theories and research opportunities

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DEDICATION

I dedicate this work to my family and friends. Thank you for all the warmth and support I have had during my long journey in the bachelor and the incentives for me to pursue my dreams and work hard for them come true. This final project is also especially dedicated *in memoriam* to my loved brother, Murilo, who supported me since my childhood. You believed in me even when I doubted about myself. Thanks for being my safe harbor and for all advice you gave me. You are never going to be out of my thoughts or out of my heart.

To my family, which has never given up on me and always has supported unconditionally my dreams

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EPIGRAPH

“Do. Or do not. There is no try”

Yoda - Star Wars

RESUMO

SILVA, M. C. R. **Teoria das Restrições e o Problema do Mix de Produtos**: revisão de literatura, teorias subjacentes e oportunidades de pesquisa. 2019. 198 f. Monografia (Trabalho de Conclusão de Curso) – Escola de Engenharia de São Carlos, Universidade de São Paulo, São Carlos, 2019.

A Teoria das restrições é considerada uma filosofia de gestão, não se restringindo apenas a regras e algoritmos analíticos (MABIN, 2001). O conceito central da TOC é que existem um ou mais recursos que limitam o desempenho organizacional (HUANG; CHEN, 2007; SHEU; CHEN; KOVAR, 2003). Além disso, um problema de mix de produtos consiste em definir quais produtos (e suas respectivas quantidades) serão produzidos (GHAZINOORY; FATTAHI; SAMOUEI, 2013). A TOC e o problema do mix de produtos interagem, pois as decisões do mix de produtos dependem das restrições do sistema (HADDOCK; RODRIGUEZ, 1985). Este projeto teve como objetivo fornecer respostas à literatura atual para as seguintes questões de pesquisa: “1) Quais são os principais conceitos e definições relacionados ao problema do mix de produtos? 2) Quais são as teorias subjacentes que contribuíram para o desenvolvimento de soluções propostas ao longo do tempo? 3) Quais são as possibilidades de pesquisa que precisam de atenção ou que poderiam ser desenvolvidas em pesquisas futuras?”. Este trabalho empregou uma revisão de literatura e análise bibliométrica e estudou 11 dimensões de cada artigo. Em uma revisão de literatura, para reunir todos os dados necessários e dispor de informações suficientes para constituir um resumo dos *findings*, é obrigatório ler a totalidade dos trabalhos publicados (WINCHESTER; SALJI, 2016). Ademais, o presente projeto desenvolveu um escopo bem estruturado e questões de pesquisa com o objetivo de mitigar a parcialidade (WINCHESTER; SALJI, 2016). Logo, havia critérios claros para a seleção de palavras-chaves e artigos. Este trabalho estudou profundamente 67 artigos, que estavam disponíveis na base de dados Scopus de 1985 até o final de agosto de 2019. Nesse ínterim, o número de publicações desde 1985 foi estabilizado. Essa pequena variação pode ser uma indicação de que o tópico está consolidado, possibilitando que a academia avance para outros tópicos. Fatores externos que podem influenciar no problema do mix de produtos devem ser alinhados ao mix de produtos ideal, próximo ao ideal ou viável. Além disso, é inegável que algoritmos heurísticos, meta-heurísticos e de busca inteligente contribuem para a tomada de decisão. Todavia, eles não podem ser considerados "verdades absolutas", porque outros fatores também interferem na escolha do mix de produtos. Desse modo, existe uma ampla gama de variáveis que devem ser estudadas. Por fim, pode ser proveitosa a aplicação de algoritmos a ambientes do mundo real, a fim de considerar problemas com maior complexidade.

Palavras-chaves: Teoria das Restrições. TOC. Mix de produtos. Revisão de Literatura.

ABSTRACT

SILVA, M. C. R. **Theory of Constraints and the product mix problem:** literature review, underlying theories and research opportunities. 2019. 198 f. Monograph (Senior Project) – São Carlos School of Engineering, University of São Paulo, São Carlos, 2019

The Theory of Constraints is considered as a management philosophy, not being restricted only to analytical rules and algorithms (MABIN, 2001). The core concept of the TOC is that there are one or more resources which limit the organizational performance (HUANG; CHEN, 2007; SHEU; CHEN; KOVAR, 2003). In addition, a product mix problem consists of defining which products and their respective amounts are going to be produced (GHAZINOORY; FATTAHI; SAMOUEI, 2013). The TOC and product mix problem interact, because the product mix decisions rely on the system restrictions (HADDOCK; RODRIGUEZ, 1985). This project aimed at supplying the current literature with answers for the following research questions: "1) What are the main concepts and definitions related to the product mix problem? 2) What are the underlying theories that have contributed to the development of solutions proposed over time? 3) What are the possibilities of research that need attention or could be developed in future research?". This work employed literature review and bibliometric analysis and studied 11 dimensions of each paper. In a literature review, in order to gather all the required data and have enough information to constitute a summary of findings, it is mandatory to read the entire published works (WINCHESTER; SALJI, 2016). Besides, the present project developed a well-structured scope and research questions aiming to mitigate bias (WINCHESTER; SALJI, 2016). Thus, there were clear criteria to the selection of keywords and articles. This work studied deeply 67 articles, which were available on Scopus database from 1985 up to the end of August 2019. Meanwhile, the number of publications since 1985 has been stabilized. This small variation could be an indication that the topic is consolidated. It enables the academia to advance studies on other issues. External factors that may influence on product mix problem should be aligned to the optimal, near optimal or feasible product mix. Furthermore, it is undeniable that heuristic, metaheuristic and intelligent search algorithms contribute to the decision making. Nonetheless, they may not be considered as "absolute truths" since other factors come into play. Thus, there is a wide range of variables that must be studied. Lastly, it could be fruitful the application of algorithms to real-world environments, in order to consider problems with higher complexity.

Keywords: Theory of Constraints. TOC. Product mix. Literature review.

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LIST OF ABBREVIATION AND ACRONYM

ABC	–	Activity-Based Costing
ABTM	–	Activity-Based Throughput Management
AHP	–	Analytic Hierarchy Process
AI	–	Artificial Immunity
ANFIS	–	Adaptive Neuro-Fuzzy Inference System
BN	–	Bottleneck
CLPFR	–	Compromise Linear Programming having Fuzzy Resources
COLOMAPS	–	Complexity and Load driven Master Production Scheduling
DM	–	Decision Maker
FLP	–	Fuzzified Linear Programming
FRTOC	–	Fuzzy Revised Theory of Constraints
FRTOC-SA	–	Fuzzy Revised Theory of Constraints - Simulated Annealing
GA	–	Genetic Algorithm
GMT	–	Green Manufacturing Technology
HMI	–	Human-Machine Intelligent
IA	–	Immune Algorithm
IA-TOC	–	Immune Algorithm – Theory of Constraints
ICA	–	Imperialist Competitive Algorithm
ILP	–	Integer Linear Programming
IPMPS	–	Integrated model for Product Mix Problem and Scheduling
LP	–	Linear Programming
MIP	–	Mixed-Integer Programming
MRP	–	Manufacturing Resource Planning
PSO	–	Particle Swarm Optimization
QI	–	Quality Improvement
RTOC	–	Revised Theory of Constraints
SA	–	Simulated Annealing
SD	–	System Dynamics
TDABC	–	Time-Driven Activity-Based Costing
THM	–	Threshold-based Heuristic Method

TOC	–	Theory of Constraints
TOCh	–	Theory of Constraints Heuristics
TS	–	Tabu Search
TS-SA	–	Tabu Search – Simulated Annealing
VOC	–	Volatile Organic Compound
WIP	–	Work in Process

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1 INTRODUCTION

Goldratt and Cox (1984) and Goldratt (1990) introduced the concept of Theory of Constraints (TOC) as an approach in the context of production planning and control. The TOC is considered as a management philosophy, not being restricted only to analytical rules and algorithms (MABIN, 2001). The core concept of the TOC is that there are one or more resources which limit the organizational performance (HUANG; CHEN, 2007; SHEU; CHEN; KOVAR, 2003). In addition, a major importance of TOC philosophy is that it contributes to the Master Production Schedule (MPS) definition (LEA, 2007). Lastly, the TOC has several applications, such as the drum-buffer-rope (DBR) approach (MIGUEL et al., 2010).

A product mix problem consists of defining which products and their respective amount are going to be produced (GHAZINOORY; FATTAHI; SAMOUEI, 2013; REZAIE; NAZARI-SHIRKOUHI; GHODSI, 2010). Aryanezhad, Badri and Komijan (2010) stated that the product mix problem is an essential application of process improvement employing the TOC concept. Moreover, the product mix is regarded as one of the major decisions in a production system (BADRI; GHAZANFARI; MAKUI, 2014). Finally, the product mix problem is crucial for several issues, such as profit and throughput maximization (LUEBBE; FINCH, 1992; SOBREIRO; NAGANO, 2012).

The TOC and product mix problem interact, because the product mix decisions rely on the system restrictions (HADDOCK; RODRIGUEZ, 1985). In addition, the product mix aims to improve the constraint resource utilization (LUEBBE; FINCH, 1992; SOBREIRO; NAGANO, 2012).

This senior project aimed at supplying the current literature with answers for the following research questions:

1. What are the main concepts and definitions related to the product mix problem?
2. What are the underlying theories that have contributed to the development of solutions proposed over time?
3. What are the possibilities of research that need attention or could be developed in future research?

Despite recent published literature review papers (IKEZIRI et al., 2018; MIGUEL et al., 2010; URBAN; ROGOWSKA, 2019), the employed database (Scopus) is a considerable difference between this work and the performed on Urban and Rogowska (2019). Moreover, Miguel et al. (2010) scrutinized the tools associated with TOC philosophy, which were not the focus of this work, albeit they were mentioned briefly on some topics of this project. Finally, Ikeziri et al. (2018) and this work utilized Scopus database. Nevertheless, the literature review paper focused on strategic level (due to the large number of studied works – approximately 1,000), whereas this final project investigated deeply all the papers, proceedings and book chapters.

The methods employed on this work were literature review, bibliometric analysis and studied dimensions of each publication. The studied works included conference proceedings, articles and book chapters. The bibliometric analysis contained the most important authors and their indexes, most used keywords, timeline, contribution per country and so forth. Besides, the eleven examined dimensions enabled a systematic analysis and classification of each work. Lastly, all the works were downloaded from Scopus database, which provided scientific articles, conference proceedings and book chapters.

The following five sections comprises the research methods, literature review, results and discussions, research opportunities and conclusion. The "research methods" exploits the literature review, bibliometric analysis and so forth. Moreover, the "theory of constraints and product mix problem" provides a wider perspective about the theory of constraints, product mix problem, their relation, and methods that are associated with the TOC and product mix problem. In addition, the "results and discussions" contains the bibliometric analysis, main outcomes of this work, the analyzed works on the perspective of the chosen dimensions and remarks. Besides, the "research opportunities" focuses on five aspects to enhance and support further research and discussions: "focus", "environmental concern", "external factors analysis", "production planning and scheduling", "variability and uncertainties", "accounting", "new and modified algorithms" and "business and management". Finally, the "conclusion" summarizes the key findings, further research and the objective achievement.

2 RESEARCH METHOD

This section comprises an explanation about the methods employed on this final project to obtain the main outcomes and findings. The content includes literature review, bibliometric analysis and description of the 11 dimensions.

2.1 Literature review – Definition, importance and methods

Literature review is a detailed scrutiny of the existing works about a specific topic (BAKER, 2016; WINCHESTER; SALJI, 2016). Nevertheless, this sort of review is not only a long list of published works and a superficial analysis, a literature review

> […] should be an informative, personal but unbiased synopsis of the information, providing a balanced view that includes conflicting findings and inconsistencies, as well as established and current thinking (WINCHESTER; SALJI, 2016, p. 308).

In addition, a literature review could provide contributions, such as a synthesized overview considering the selected topic and pointing out research gaps (BAKER, 2016; WINCHESTER; SALJI, 2016). Therefore, it could guide further studies (BAKER, 2016; WINCHESTER; SALJI, 2016). There is an aspect about literature reviews. It is mandatory to read the entire published works, in order to gather all the required data, and have enough information to constitute a summary of findings (WINCHESTER; SALJI, 2016). Besides, the present project developed a well-structured scope and research questions aiming to mitigate any sort of bias (WINCHESTER; SALJI, 2016). Thus, there were clear criteria to the selection of keywords and articles.

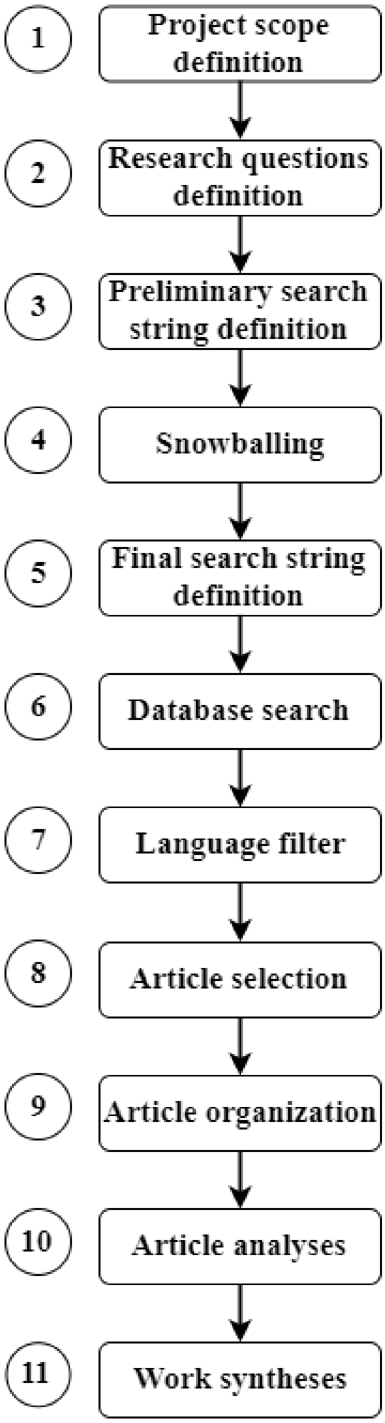
Despite the large number of published articles, it is not possible to comprise all the works, due to indexation issues on the database. Therefore, it constitutes a limitation of any kind of literature review.

In Ikeziri et al. (2018), Scopus database provided approximately 95% of the works exploited by their literature review. Thus, Scopus is a convenient database for the TOC topic.

Moreover, the final project incorporated all the results provided by Scopus and that fitted the work scope, regardless the publication year (the oldest paper was published in 1985).

This work studied deeply 67 articles, which were available on Scopus database up to the end of August 2019. Figure 1 presents a flowchart that was adapted to this work and table 1 summarizes and explains the eleven steps.

Figure 1 - Literature review flowchart



Source: Baker (2016, p. 266) and Winchester and Salji (2016, p. 310) (adapted).

Table 1 - Description of the literature review steps

Number	Step	Explanation
1	Project scope definition	There was a need of addressing the Theory of Constraints applied to the product mix problem. There were other literature reviews, albeit none studied deeply the relation between TOC and the product mix problem.
2	Research questions definition	Afterward the scope definition, there were posed the research questions: 1. What are the main concepts and definitions related to the product mix problem? 2.What are the underlying theories that have contributed to the development of solutions proposed over time? 3. What are the possibilities of research that need attention or could be developed in future research?
3	Preliminary search string definition	The definition of the first keywords considered the author's expertise.
4	Snowballing	When employing the string on the chosen search engine (Scopus), the most cited works could be found. It was possible to understand the most common keywords, synonyms and so forth (WOHLIN, 2014). This was a crucial step since if there were missing important keywords, the search results could be compromised (WOHLIN, 2014).
5	Final search string definition	There were included new keywords and synonyms. It is essential to remark that the search engine ignores hyphens, and likely language variability (US English, British English and World English) was replaced by "*". Thus, this project did not lose relevant works due to orthographic variation.
6	Database search	As aforementioned, the chosen database was Scopus.
7	Language filter	Works published in English, Portuguese and Spanish were selected.

8	Article selection	After searching on Scopus, the list provided by the string was subjected to an analysis. The titles and abstracts were read. The works out of this final project scope were discarded.
9	Article organization	The articles were grouped and categorized according to ascending years of publication. The years ranged from 1985 to 2019.
10	Article analyses	The works were studied based on 11 dimensions. Moreover, there was prospected more information about the definition of TOC, product mix problem, bibliometric indicators, list of authors, countries, keywords etc.
11	Work syntheses	The main outcomes of this senior project were bibliometric analyses, state-of-the-art of the TOC and product mix definitions and further opportunities of research.

Source: Elaborated by the author.

The steps from 1 to 9 were the fastest phases of this project. They were a preparation to the last two steps (10 and 11). Finally, the outcomes of the steps 10 and 11 are presented on the next sections.

2.2 Analysis of the works

A bibliometric analysis provides a big picture of the current published works in a quantitative perspective. These analyses could foster insights about emerging opportunities of research (IKEZIRI et al., 2018). In this context, there are several citation indicators to evaluate the authors' academic contribution. Nevertheless, this work selected only three indicators: g-Index, h-Index and i10-Index. Previously the determination of any indicator, it is mandatory to rank the published works of each author in a non-ascending order of citations (EGGHE, 2006). The g-Index consists of the top G articles whose sum of citations is equal or bigger than G^2 (EGGHE, 2006; SINGH; SINGH, 2019). Moreover, the g-Index is always equal or bigger than the h-Index (EGGHE, 2006). The h-Index coincides with the H articles that have H or more citations (SINGH; SINGH, 2019). Lastly, the i10-Index is equal to the number N of works that have at least 10 citations (SINGH; SINGH, 2019).

The bibliometric analyses performed at this work included:

1. Number of publications per year and density of works;
2. Most cited articles on the literature review;
3. Productivity indexes of the authors that published three works and above about the theory of constraints applied to the product mix problem;
4. List of the involved countries and their respective number of works;
5. Complete list of keywords and the most cited ones on a word cloud; and
6. The list of the journals, publishers or proceedings that contributed to the topics related to the scope of this senior project.

2.3 Analyzed dimensions

The analyses of each one of the 67 works considered 11 dimensions, which are: focus, number of bottlenecks, variables, period, comparison, computational time, aspects about finances and accounting, underlying theory(ies), aspects of scheduling, environmental aspects and main outcomes (tools, frameworks etc). Table 2 summarized each dimension and possible outcomes. The scheduling does not consider the Master Production Schedule (MPS) since the main focuses are approaches like Gantt diagram and so on.

Table 2 - Complete list of analyzed dimensions and their possible outcomes

Dimension	Possible outcomes
Number of Bottlenecks	Zero, Single, Double, Multiple or “not mentioned”.
Focus	Application, conceptual or “not applicable”.
Variables	Deterministic or stochastic.
Period	Single or multiperiod.
Comparison	The corresponding methods were mentioned.
Computational time	Unconsidered, number of iterations, processing time in seconds.

Aspects about finances and accounting	Considered, unconsidered and depth of the analysis.
Underlying theory(ies)	Integer linear programming, theory of constraints, management accounting, biologically inspired algorithms, multi-criteria decision-making approach or metaheuristics. Whether there is more than one theory, all of them are mentioned. There could be also qualifiers such as “genetic algorithm” to one “biologically inspired algorithm”.
Aspects of scheduling	Considered or unconsidered.
Environmental aspects	Considered or unconsidered. This aspect comprised carbon taxes and so forth. For instance, multiple scenarios could be a qualifier for the application.
Main outcomes	Tools, frameworks etc.

Source: Elaborated by the author.

One of the objectives of this classification was grouping works based on similarity, so that further studies could search more easily content that fits their respective scopes. Thus, there were detected research gaps, which are explained in detail on section 5.

3 THEORY OF CONSTRAINTS AND PRODUCT MIX PROBLEM

This section supplies an in-depth definition about the TOC and the product mix problem, concerning all the analyzed works during this literature review. In addition, the following subsection explicates all the differences among literature reviews that comprised the topic of Theory of Constraints.

3.1 Distinction amongst the published literature reviews

The work of Ikeziri et al. (2018) is distinct of the performed in this final project: the published article performed bibliometric analysis of approximately 1,000 articles. However, this analysis only comprised titles, abstracts, keywords and authors. This senior project executed a complete analysis of all the articles associated with the search string.

In addition, Miguel et al. (2010) presented an analysis of tools associated with the TOC philosophy, thinking process, flow management, and focused on some applications of TOC such as drum-buffer-rope. Similarly, Urban and Rogowska's (2019) work focused on the application of TOC. They employed EBSCO, Emerald, ScienceDirect and SpringerLink as databases between the years 2013–2017 (URBAN; ROGOWSKA, 2019).

This senior project studied entirely 67 works from 1985 up to August 2019 concerning the TOC and product mix problem. The analyses were based on the 11 dimensions described on section 2.3. In addition, this work also devoted subsections to the definition of core concepts TOC and product mix. As important contributions, the project provides meaningful insights for further research, and it also provides a scrutiny about each outcome of the studied works referring to their outcomes and their respective advantages and limitations.

3.2 Theory of constraints

3.2.1 Definition and premises

The Theory of Constraints (TOC) often is considered only an analytical rule (MABIN, 2001). However, the TOC is a complete management philosophy (ALSMADI; ALMANI; KHAN, 2014; KAVEH; DALFARD; KARAMI, 2013; LUEBBE; FINCH, 1992; MISHRA et al., 2005), which comprises production planning and control (HSU; CHUNG, 1998; KOMIJAN; SADJADI, 2005).

The origins of TOC are in the operation management (NAZARI-SHIRKOUHI et al., 2010). In addition, the TOC influences a continuous organizational improvement (LUEBBE; FINCH, 1992), containing the organization's operational capabilities and strategic objectives (DRAMAN; LOCKAMY; COX, 2002). Finally, the classical definition of TOC and the traditional TOC heuristic (and the PQ problem) could be found on Luebbe and Finch (1992).

As a TOC premise, an organization has at least one constraint, which hampers the achievement of the projected goals (ALSMADI; ALMANI; KHAN, 2014; ARYANEZHAD; BADRI; KOMIJAN, 2010; SHEU; CHEN; KOVAR, 2003; SOBREIRO; NAGANO, 2013). The slowest process is determining for the performance of a production system (TSAI et al., 2013). In summary, the TOC always considers limited capacity for production planning and control (LEA, 2007).

Meanwhile, TOC addresses questions such as how to identify constraints, what is necessary to change, how build reasonable solutions, and how implement solutions (KÖKSAL, 2004). In addition, the TOC affirms that the system's constraint(s) determine its outputs (LUEBBE; FINCH, 1992; ONWUBOLU; MUTINGI, 2001a). Lastly, the set of outputs may contain the maximization of throughput (HSU; CHUNG, 1998) and profit (MOHANTY; MISHRA; MISHRA, 2009; PLENERT, 1993).

There are evidences that TOC fosters reduction of cycle time and inventory (MIGUEL et al., 2010). Moreover, it is also remarkable that TOC induces product diversity (SHEU; CHEN; KOVAR, 2003). Concurrently, some works also defend that maximum constraint performance leads to maximum performance of a system (MIGUEL et al., 2010; WANG et al., 2009). Nevertheless, it is not always possible to optimize the throughput, albeit the efficient management of the constraints could be more profitable to the enterprises, which causes a throughput gain (RAY; SARKAR; SANYAL, 2010).

There are several kinds of constraints (production, sales constraints and so on) (SINGH et al., 2006; TSAI, 2018a). However, the constraints do not include only tangible resources (MISHRA et al., 2005; SHEU; CHEN; KOVAR, 2003). They could be also policy restrictions (SHEU; CHEN; KOVAR, 2003). Due to an increasing concern about environmental issues, there must be under control the carbon emission limitations and other pollution sources. Thus, they also constitute restrictions (HILMOLA; GUPTA, 2015).

Nonetheless, constraints should not be a problem (MABIN; DAVIES, 2003). They are inherent aspects of a business (MABIN; DAVIES, 2003). Lastly, whenever it is possible to choose the location of a constraint, it is highly recommendable to prefer them inside the organization, which easies the management process (MABIN; DAVIES, 2003).

3.2.2 Accounting

TOC does not consider the labor and overhead costs (MOHANTY; MISHRA; MISHRA, 2009). Similarly, the throughput accounting, whose basis is the TOC, also ignores the bill-of-materials of the products, which may distort the cost estimation (LEA; FREDENDALL, 2002). In addition, it reckons available resources rather than used resources to calculate the period costs (ZHUANG; CHANG, 2017). Meanwhile, the Theory of Constraints is more suitable for short term planning and decision-making, when productive resources may be fixed (ALSMADI; ALMANI; KHAN, 2014; SHEU; CHEN; KOVAR, 2003; TSAI et al., 2016). Lastly, it is also beneficial to come into play that TOC provides little mechanism to manage operating expenses (SHEU; CHEN; KOVAR, 2003).

3.2.3 Organizational performance and indicators

It is uncontroversial that the management focus must be the constrained resources (ALSMADI; ALMANI; KHAN, 2014; GUPTA, 2001; LINHARES, 2009; REZAIE;

NAZARI-SHIRKOUHI; GHODSI, 2010; TSAI et al., 2013). In this context, the ultimate aim of the TOC is improving/maximizing profit (DRAMAN; LOCKAMY; COX, 2002; REZAIE; NAZARI-SHIRKOUHI; MANOUCHEHRABADI, 2009; SINGH et al., 2006) or throughput, by employing adequate constraint management (KOMIJAN; SADJADI, 2005). *Ergo*, the TOC approach integrates an extensive set of management issues like performance indicators, process improvement, accounting and strategical goal (GUPTA; KO; MIN, 2002).

In addition, the organization is regarded as a cluster of interdependent processes (ALSMADI; ALMANI; KHAN, 2014) whose aim is the profit goal achievement (GUPTA; KO; MIN, 2002). Besides, the constraints are the focus of TOC (TANHAEI; NAHAVANDI, 2013; TANHAIE; NAHAVANDI, 2011). In the meantime, this theory reinforces overall performance indicators to the detriment of local indicators (GUPTA; KO; MIN, 2002). The TOC gauges the system's performance mainly based on three key indicators, which are the throughput (rate of money generation through sales), inventory (money spent on required acquisitions to ensure the manufacture the products) and operating expenses (necessary financial resources to transform the inventory into throughput) (ALSMADI; ALMANI; KHAN, 2014; CHAHARSOOGHI; JAFARI, 2007; DRAMAN; LOCKAMY; COX, 2002). Finally, controlling the bottleneck(s) could also be an important approach to hold other key measures (due date, utilization rate and so on) (NAZARI-SHIRKOUHI et al., 2010).

Lea and Fredendall (2002) establish the concern about the bottleneck shiftiness. Furthermore, there are remarked some factors that may cause bottleneck shiftiness, such as changes on product's market demand, resource's capacity requirement and the dynamic workload (WANG et al., 2009). Other work also cites that the constraints could interact or change even in an hour-basis (FINCH; LUEBBE, 2000). This shiftiness could clearly compromise the performance indicators. Thus, it should be a topic of interest when studying the production constraints.

3.2.4 Applications

There is a wide range of applications of TOC (scheduling, logistics, decision-making, market segmentation, project management and so forth) (MIGUEL et al., 2010; NAZARI-SHIRKOUHI et al., 2010; REZAIE; NAZARI-SHIRKOUHI; MANOUCHEHRABADI, 2009). TOC could be associated with other manufacturing and management strategies such as lean manufacturing (ALSMADI; ALMANI; KHAN, 2014).

Moreover, TOC supports decision-making considering the constraints and its tools (thinking processes, five focusing steps, product mix algorithm, evaporating cloud, reality tree, conflict elimination, pre-requirements tree, transition tree etc. (MABIN; DAVIES, 2003; MIGUEL et al., 2010)) could be applied to product mix problem as well (MABIN, 2001; NAZARI-SHIRKOUHI et al., 2010; ONWUBOLU; MUTINGI, 2001b; TANHAEI; NAHAVANDI, 2013; TANHAIE; NAHAVANDI, 2011). In addition, TOC contributes to the product mix problem not only with algorithms, but also with tools, methods and methodologies that embrace management and organizational improvement (MABIN; DAVIES, 2003). The product mix decision-making should also concentrate the choices on throughput per unit working time at the bottleneck (MOHANTY; MISHRA; MISHRA, 2009). It is essential to remark that the TOC provides a short-term product mix (TSAI et al., 2013; ZHUANG; CHANG, 2017).

The procedure (developed by TOC) known as drum-buffer-rope is employed in make-to-stock (MTS) and make-to-order (MTO) production environments (LUEBBE; FINCH, 1992). The TOC approach also pertains and contributes to organizational strategies (DRAMAN; LOCKAMY; COX, 2002). For instance, the contraction strategy boosts the service quality when reducing the market size or portfolio, whereas the market-based strategy employs the throughput per constraint unit as the main driver of product ranking (DRAMAN; LOCKAMY; COX, 2002). *Ergo*, TOC is considered a hybrid of hard and soft systems (MABIN; DAVIES, 2003).

Moreover, the TOC tools contribute to the analysis of the quality improvement (QI) and its relationship with the product mix (KÖKSAL, 2004). Finally, the TOC techniques assist the decision-making with buffer management, capacity buffer management, bottleneck workload control and so forth (DE SOUZA et al., 2013).

3.2.5 Advantages

According to some academical tests, TOC could lead to lower inventory and production time, as the production levels are higher (MIGUEL et al., 2010). Some works remark TOC advantages regarding its well-established framework and the possibility of real improvement of throughput (FINCH; LUEBBE, 2000). Finally, TOC could also improve the production performance without acquiring extra capacity (MABIN; DAVIES, 2003).

3.2.6 Limitations

It is also essential to highlight that multiple bottleneck environments may not result in optimal solutions since they have a higher degree of complexity (PLENERT, 1993; TSAI et al., 2016). For instance, the most traditional TOC algorithm fails when there are multi-bottleneck problems (ARYANEZHAD; KOMIJAN, 2004; BHATTACHARYA; VASANT, 2006; KOMIJAN; SADJADI, 2005; ONWUBOLU; MUTINGI, 2001b; TANHAIE; NAHAVANDI, 2011). This algorithm also could result in non-optimal or unfeasible solutions when it may be possible to add new products to the production line (ARYANEZHAD; KOMIJAN, 2004; KOMIJAN; SADJADI, 2005; ONWUBOLU, 2001; ONWUBOLU; MUTINGI, 2001a). Moreover, the traditional method also requires a cumbersome computational time, because the multiple constraint resources emerge as a combinatorial optimization problem (ONWUBOLU; MUTINGI, 2001a). It occurs since the TOC is a non-deterministic polynomial (NP) problem, which leads to an exponential increase in computational time (WANG et al., 2009). Thus, large-scale problems are also a major issue for many of the existing TOC algorithms (ONWUBOLU; MUTINGI, 2001b).

In a TOC context, Golmohammadi and Mansouri (2015) consider that no previous work scrutinized the occurrence of complex and dynamic operation and their impacts on the throughput. In addition, Golmohammadi and Mansouri (2015) also point out incongruences of TOC models, which do not consider influencing factors (sequence of processes and so on). Finally, this issue is also mentioned by Mohanty, Mishra and Mishra (2009), which cite that mostly TOC approaches do not consider, setup issues, related factors etc.

3.2.7 Branches and classification

Some works divide TOC into three branches, which are the logistics branch, performance measurement system and problem solving or thinking process

(BHATTACHARYA et al., 2008; BHATTACHARYA; VASANT, 2006). Similarly, Chaharsooghi and Jafari (2007) propose a division of TOC algorithms into three groups. The first comprises exact approaches such as linear programming (CHAHARSOOGHI; JAFARI, 2007). The second considers the heuristic methods, such as traditional TOC heuristics (CHAHARSOOGHI; JAFARI, 2007). These two types are suitable for small scale problems (CHAHARSOOGHI; JAFARI, 2007). Finally, the third contains the metaheuristic algorithms, which are appropriate for large-scale problems (CHAHARSOOGHI; JAFARI, 2007). Examples of metaheuristic algorithms are bioinspired algorithms and intelligent search algorithms (CHAHARSOOGHI; JAFARI, 2007).

3.2.8 External conditions and requirements

The TOC focuses on throughput instead of volume (CANNON; CANNON; LOW, 2013). In order to “make more money”, it is mandatory that two conditions must be fully met, which are adequate and dignified work environment to employees, and, simultaneously, supply the market demands in consonance with customer satisfaction (ALSMADI; ALMANI; KHAN, 2014; MOHANTY; MISHRA; MISHRA, 2009). Jointly, it is regarded that an optimized or improved product mix enables the greatest return per unit of constraint since there is a more efficient exploitation of the restrictions (FINCH; LUEBBE, 2000). Thus, quality inspections and preventive maintenance are two examples that permit wiser utilization of the constraints (FINCH; LUEBBE, 2000).

Concerning the organizational background, TOC approach and Lean Manufacturing could be combined. However, there is a contrasting different between Lean Manufacturing and Theory of Constraints (ALSMADI; ALMANI; KHAN, 2014). Lean analyzes the activities that add value for the products, whereas TOC assumes that there are only necessary and adequate production activities (ALSMADI; ALMANI; KHAN, 2014). Therefore, they are not mutually exclusive, they could be combined to deliver improved results.

3.3 Product mix problem

3.3.1 Definition and premises

The product mix problem is regarded as one of the most remarkable issues concerning the production management (BADRI; GHAZANFARI; MAKUI, 2014; KÖKSAL, 2004; TSAI; LAI; CHANG, 2007; WANG et al., 2009), and, thus, the Theory of Constraints (CHAHARSOOGHI; JAFARI, 2007; REZAIE; NAZARI-SHIRKOUHI; GHODSI, 2010). The product mix problem consists of determining a set of products and their quantities under restrictions (BADRI; GHAZANFARI; SHAHANAGHI, 2014; GHAZINOORY; FATTAHI; SAMOUEI, 2013; HADDOCK; RODRIGUEZ, 1985; REZAIE; NAZARI-SHIRKOUHI; GHODSI, 2010; WANG et al., 2009). In addition, some authors even consider the product mix decision and the master production scheduling (MPS) as synonyms (GOLMOHAMMADI; MANSOURI, 2015). The product mix choices take into consideration not only the financial key indicators, but also productive, strategic and economic issues (SOBREIRO; MARIANO; NAGANO, 2014). Frequently the organizations neglect computational, mathematical and statistical modeling for the product mix problem-solving, because aspects like strategy require high complexity modeling (SOBREIRO; MARIANO; NAGANO, 2014).

The first step is to rank products according to the pre-selected criteria (product margin, throughput etc.) at the constrained resource, respecting the system limitations (KOMIJAN; SADJADI, 2005; MABIN; DAVIES, 2003). Afterward, it is possible to obtain an MPS, which could vary according to the chosen algorithms. Lastly, Hsu and Chung (1998) and Ray, Sarkar and Sanyal (2010) considered the product mix problem as a relevant application of the heuristic (five focusing steps).

The first two steps of the five focusing steps heuristic are considered the product mix problem heuristic (SINGH et al., 2006). Even though the multiple purposes of the product mix decision (BAYOU; REINSTEIN, 2005), it, mostly, aims at entirely utilizing the constrained resources and maximizing the profit (BAYOU; REINSTEIN, 2005; HUANG; CHEN, 2007; LUEBBE; FINCH, 1992; NAZARI-SHIRKOUHI et al., 2010). Some authors also consider the maximum throughput for the product selection (GUPTA, 2001; LEE; PLENERT, 1996; RAY; SARKAR; SANYAL, 2010; SINGH et al., 2006). Finally, the product mix choice targets to reduce inventory and operating expenses at non-constraint work centers (LUEBBE; FINCH, 1992).

In addition, the product mix problem could be modeled as an Integer Linear Programming (ILP) problem (GUPTA, 2001; ONWUBOLU; MUTINGI, 2001b). The classical definition of product mix problem could be found on several works. Moreover, the product mix decision could be also a head start to the Master Production Schedule (MPS) (MISHRA et al., 2005). Around 2008, the product mix problem started to consider multiple constraints more frequently (BHATTACHARYA; VASANT; SUSANTO, 2008). Lastly, the product mix decision also contributes to the improvement process of TOC (ARYANEZHAD; BADRI; KOMIJAN, 2010).

Golmohammadi and Mansouri (2015) state that the product mix problem had been reckoned as a static decision. Meanwhile, most of the product mix algorithms consider that all the products have the same due date, the constraint capacity cannot be altered in the short term, the necessity of integer solutions, demand is limited, and the contribution margins are known in advance (GHAZINOORY; FATTAHI; SAMOUEI, 2013). Nevertheless, in real cases, there are changes throughout the MPS, which may result in underutilization or overutilization of resources whenever scenario alters.

3.3.2 Types

In the field of product mix problems, there is a relevant and frequent case. The joint products use the same machines, resources and processing times till the split-off point (TSAI; LAI; CHANG, 2007). Afterward this point, there are different outcomes that can be further processed or sold. Thus, there is an interdependence amongst the joint products. Finally, the outsourcing product mix problem has been also an emerging example over the last years.

The product mix decision and, therefore, optimization, could determine enterprise's performance, profit, work-in-process and so forth (REZAIE; NAZARI-SHIRKOUHI; MANOUCHEHRABADI, 2009; WANG et al., 2009). Due to constraint issues, many enterprises cannot meet their entire demand (NAZARI-SHIRKOUHI et al., 2010). In these cases, outsourcing may be a suitable and profitable alternative (NAZARI-SHIRKOUHI et al., 2010). Outsourcing happens when enterprises contract external suppliers to manufacture partially or totally products instead of in-house production (NAZARI-SHIRKOUHI et al., 2010). Mohanty, Mishra and Mishra (2009) consider the outsourcing problems for finished goods instead of their parts individually. In addition, Mohanty, Mishra and Mishra (2009, p. 66) state that "it is imperative for companies to embrace virtual collaboration in order to access the global resource base and be first to market with emerging global outsourcing customized solutions". Thus, there is an essential particular case of product mix problem whose denomination is "product mix-outsourcing optimization problem" (NAZARI-SHIRKOUHI et al., 2010, p. 7615).

3.3.3 Relation with TOC

Wang, Chang and Ou (2007) deemed that ABC system was an important information supplier to the product mix decision since system used to be employed in the world's top 500 enterprises. Moreover, the paper also remarked that frequently the product mix was considered based exclusively on profit, ignoring the system constraints (WANG; CHANG; OU, 2007). Finally, Wang, Chang and Ou (2007) regarded the TOC as a significant approach for system's constraint detection.

3.3.4 External factors

Cannon, Cannon and Low (2013) develop the first work that considers the purchase of related products (portfolio interaction). There are portfolio strategies and product interaction approaches, which are summarized on table 3.

Table 3 - Portfolio strategies and product interaction approaches

Strategy or approach	Description
Competitive interaction approach	The "product portfolio" comprises products that are far enough to avoid mutual cannibalism. However, they could not be distant since other players could fill the emerging gaps.

Desired portfolio approach	The “desired portfolio” uses the customers as the unit of measurement of profit. It is frequent whenever the customers prefer purchasing one or more types of products at once.
The volume-oriented resource utilization approach	The “volume-oriented resource utilization” has the strategy of investing on products that have shared parts and manufacturing processes. Thus, the target is the products with shared costs subjected to the strategy of economy of scale.
The constraint-based resource utilization approach	The “constraint-based resource utilization” has a strong relation with the TOC. The focus occurs only on the limiting resource.

Source: Cannon, Cannon and Low (2013) (adapted).

It is essential to remark that this classification does not imply mutual exclusion (CANNON; CANNON; LOW, 2013). In conclusion, these approaches could be combined, in order to provide more significant results.

4 RESULTS AND DISCUSSIONS

This section is divided into four subsections. They comprise brief bibliometric analyses, outcomes and dimensions of each work and remarks, in order to clarify concepts and reinforce key findings.

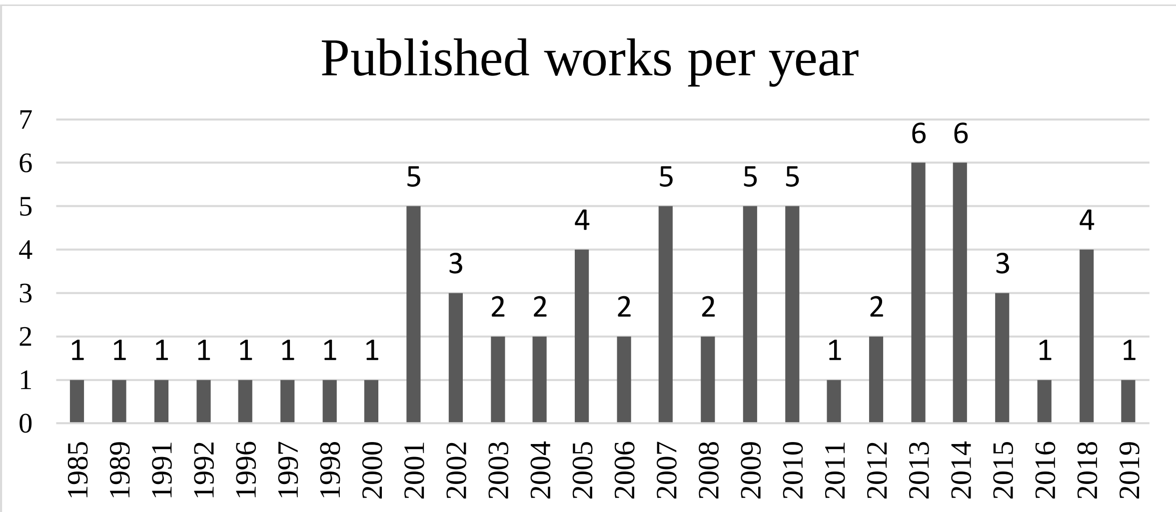
4.1 Bibliometric analysis – Main indicators

The bibliometric analysis supplies an overview in the quantitative perspective of the existing publications that fitted the scope of this work. The main objective is to enable further analysis based on quantitative data.

4.1.1 Timeline - Density of publications

The figure 2 presents the chart that quantifies the number of publications yearly since 1985, which is the year of the oldest paper analyzed.

Figure 2 - Number of published works since 1985 about the product mix problem and TOC



Source: Elaborated by the author.

The number of publications since 1985 has been stabilized. In addition, there are minor gaps in the beginning of the series. This small variation could be an indication that the topic is consolidated. Thus, the academia could advance studies on other correlated fields.

4.1.2 Main contributions

4.1.2.1 Journals

The 67 scrutinized works were published in 35 journals and conference proceedings. The table 4 summarized the publishing sources that were indexed to Scopus and contributed to this literature review.

Table 4 - Complete list of journals, conferences and proceedings that contributed to the studied topics

Number of works	Journals, Conferences and Proceedings
16	International Journal of Production Research
4	The International Journal of Advanced Manufacturing Technology
4	Production Planning and Control
3	European Journal of Operational Research
3	Expert Systems with Applications
3	Sustainability
2	Applied Mathematical Modelling
2	Energies
2	IEEE Transactions on engineering management
2	Integrated Manufacturing Systems
2	International Journal of Production Economics
1	2006 IEEE International Conference on Systems, Man and Cybernetics
1	2007 International Conference on Management Science and Engineering

1	2009 Second International Conference on Developments in eSystems Engineering
1	2011 IEEE International Conference on Industrial Engineering and Engineering Management
1	Decision Science Letters
1	DYNA (Colombia)
1	IFAC Conference - Improving Stability in Developing Nations through Automation
1	IGI Publishing
1	Industrial Management and Data Systems
1	International Conference on Information Technology for Balanced Automation Systems
1	International Journal of Quality and Reliability Management
1	Journal of Advances in Management Research
1	Journal of Applied Sciences Research
1	Journal of Cleaner Production
1	Journal of Intelligent Manufacturing
1	Journal of Optimization in Industrial Engineering
1	Lecture Notes in Computer Science
1	Managerial Finance
1	Naval Research Logistics
1	Omega
1	Produção
1	Production and Inventory Management Journal
1	Scientia Iranica
1	Simulation & Gaming

Source: Elaborated by the author.

It is possible to notice that 20% (7) of the journals, proceedings and conferences published approximately 50% (35) of the works. Moreover, 30% (11) of the journals published about 60% of the reviewed content. In comparison to the top 20 publishing journals (IKEZIRI et al., 2018), the mutual journals are: International Journal of Production Research, the International Journal of Advanced Manufacturing Technology, Production Planning and

Control, European Journal of Operational Research, Expert Systems with Applications, International Journal of Production Economics and Production and Inventory Management Journal. The five journals that most contributed to this work were amongst the top 20 publishing journals of Ikeziri et al. (2018). In summary, the International Journal of Production Research is the one that contributed most to the TOC associated with the product mix problem and to the overall literature about TOC (IKEZIRI et al., 2018).

4.1.2.2 Countries

There are some works with international cooperation. This subsection separated these publications with international cooperation (two or more countries involved in the publication). Thus, it is possible to notice that there are more than 67 occurrences, which is the expected number, because there were 67 works under scrutiny. The table 5 presents the complete list of countries and their corresponding number of papers.

Table 5 - List of countries and their respective number of published works

Number of papers	Country
18	United States
14	Iran
10	Taiwan
8	India
6	China
5	Brazil
4	Malaysia
3	Zimbabwe
2	New Zealand
2	Turkey
1	Canada
1	Colombia
1	Finland
1	Germany

1	Hong Kong
1	Indonesia
1	Japan
1	Jordan
1	Macedonia
1	Spain
1	United Kingdom

Source: Elaborated by the author.

The obtained results for this topic are similar to the outcomes of the analyses performed at Ikeziri et al. (2018). It is also possible to notice that the countries that most contributed to the published works are the United States and Asian countries (Iran, Taiwan, India and China).

4.1.2.3 Number of citations

This subsection summarizes the top 10 works that have the highest number of citations regarding all the works that were subjected to this literature review. Table 6 synthesizes these papers.

Table 6 - The 10 most cited reviewed works

Number of citations	Work
137	Solving the integrated product mix-outsourcing problem using the Imperialist Competitive Algorithm (NAZARI-SHIRKOUHI et al., 2010)
100	Soft-sensing of level of satisfaction in TOC product-mix decision heuristic using robust fuzzy-LP (BHATTACHARYA; VASANT, 2006)
92	Improving the product mix heuristic in the theory of constraint (FREDENDALL; LEA, 1997)
63	Optimizing the multiple constrained resources product mix problem using genetic algorithms (ONWUBOLU; MUTINGI, 2001a)

59	The impact of management accounting, product structure, product mix algorithm, and planning horizon on manufacturing performance (LEA; FREDENDALL, 2002)
57	The TOC-based algorithm for solving product mix problems (HSU; CHUNG, 1998)
47	Hybrid tabu-simulated annealing based approach to solve multi-constraint product mix decision problem (MISHRA et al., 2005)
42	An improved algorithm for optimizing product mix under the theory of constraints (ARYANEZHAD; KOMIJAN, 2004)
42	Tabu search-based algorithm for the TOC product mix decision (ONWUBOLU, 2001)
38	TOC-based performance measures and five focusing steps in a job-shop manufacturing environment (GUPTA; KO; MIN, 2002)

Source: Elaborated by the author.

The number of citations reflects the trend: older works have higher citation rates. The third most cited work is a classical paper, being amongst the ones that contributed most with the discussions about a TOC algorithm regarding multiple constraints. Thus, it explains the rate of citations. In addition, the most cited paper studies the Imperialist Competitive Algorithm, which is employed in several fields, such as artificial intelligence.

4.1.2.4 Authors

There are 133 authors that published works related to the TOC and product mix problem. The complete list of authors, and their respective number of publications, is presented in the appendix B. The first 14 authors, who published three or more works, were scrutinized based on their productivity indexes – H, i10 and G. Table 7 outlines these key indexes.

Table 7 - Key indexes – authors with highest rate of publications

Author	Number of published works	h-Index	i10-Index	g-Index
Wen-Hsien Tsai	7	29	52	45
Arijit Bhattacharya	4	16	20	33
Marcelo Seido Nagano	4	17	25	27
Pandian Vasant	4	27	63	41
Vinicius Amorim Sobreiro	4	9	7	15
Alireza Rashidi Komijan	3	4	2	9
Bih-Ru Lea	3	6	6	13
Bijan Sarkar	3	19	33	29
Gerhard Plenert	3	8	7	17
Godfrey C. Onwubolu	3	18	23	36
Kamran Rezaie	3	11	13	22
Mahesh Gupta	3	22	33	41
Salman Nazari-Shirkouhi	3	15	16	26
Seyed Amin Badri	3	3	1	5

Source: Elaborated by the author.

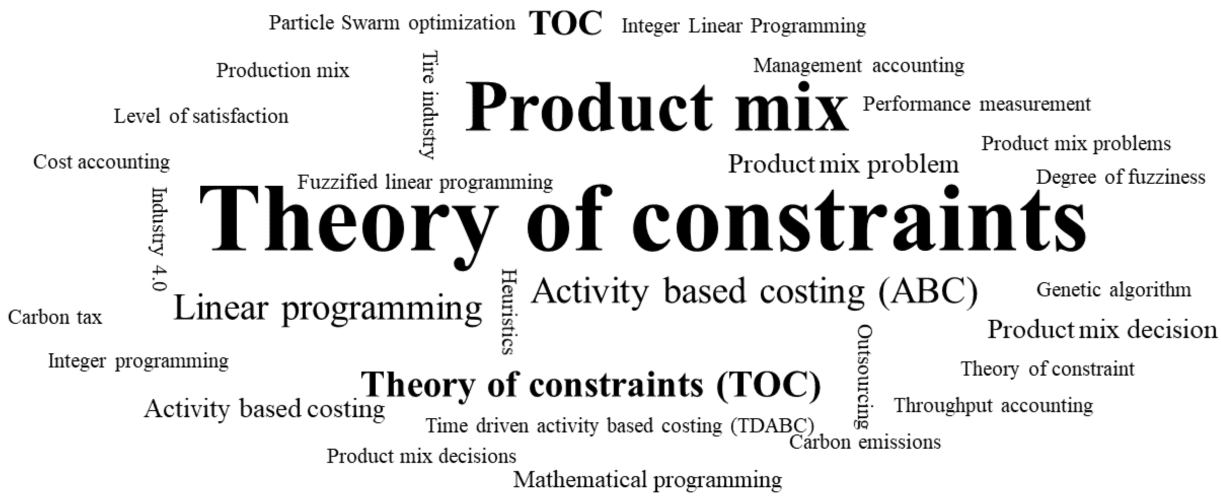
The G index increases according to higher citation rates. Thus, the g-Index combines high impact publications and number of published works. The i10-Index increases according to larger number of publications, in respect to a minimum boundary of 10 citations per work. In addition, the h-Index is more valuable with authors that have more published works, which happens in general to more experienced researchers. Finally, it is possible to conclude that most of the published works about TOC and product mix problem represented less than 10% of all the published works of the main authors.

4.1.2.5 Works

The keywords were represented on a Word Cloud. They are essential since they are responsible for indexing the works to the search engines. Jointly, the abstract and title also contribute to the indexation of these articles. Therefore, if it is possible to list all the keywords, there will be gains for further works, because they could direct more effectively their research efforts.

The hyphens were deleted to ease the analyses, because they are ignored on the search engines. There are 129 distinct keywords at the 67 revised articles. The word cloud contains only the keywords that were cited at least twice. This decision was made due to the large number of words and expressions, which could compromise the comprehension of the diagram. Despite the similarities amongst some expressions, they could cause differences during the searches. Figure 3 introduces the word cloud of the most cited keywords. The complete list could be found on appendix C.

Figure 3 - Word cloud of the keywords



Source: Elaborated by the author

The most cited keywords, as on appendix C and figure 3, were in consonance with the search string of this literature review. Moreover, the word cloud and the table presented words and expressions related to metaheuristics (particle swarm optimization and genetic algorithm), heuristics, fuzziness, accounting management and environmental concern. Thus, it is possible to deliberate that the TOC and product mix problems are associated with multidisciplinary fields of research.

4.2 Principal outcomes of the studied works

In summary, many works focus on maximizing throughput (ARANGO-MARIN; GIRALDO-GARCÍA; CASTRILLÓN-GÓMEZ, 2014; GUPTA, 2001; LEA, 2007; REZAIE; NAZARI-SHIRKOUHI; MANOUCHEHRABADI, 2009) in detriment to minimizing costs. Additionally, some focus on maximizing profit (BADRI; GHAZANFARI; MAKUI, 2014; MOHANTY; MISHRA; MISHRA, 2009; WANG; CHANG; OU, 2007). Furthermore, there are few works that analyze multiple scenarios (HASUIKE; ISHII, 2009; LEA, 2007). Meanwhile, the most considered constraints at the mathematical modeling were demand (market) constraints, machine-hours per period and shifts per period (HADDOCK; RODRIGUEZ, 1985). Finally, it is possible to check the complete list of all the analyzed works, their main outcomes, advantages and limitations of each proposition on appendix D.

4.3 Analyzed dimensions

Each work was analyzed in the perspective of 11 dimensions. In order to provide a more pleasant reading of this work, the complete tables are divided into the appendix E, F, G and H.

Some works do not have bottlenecks (ALSMADI; ALMANI; KHAN, 2014; TSAI et al., 2016). It happens due to unexplored capacities, because the enterprise adopts Lean Manufacturing techniques (ALSMADI; ALMANI; KHAN, 2014). Thus, it is possible to exploit more these idle capacities (ALSMADI; ALMANI; KHAN, 2014).

4.4 Remarks

Plenert (1993) had significant outcomes. Surprisingly, the ILP got worse results than the TOC algorithm (PLENERT, 1993). However, it is important to highlight that the TOC solution was infeasible, because it did not fully meet all the constraints (PLENERT, 1993). Lea and Fredendall (2002) affirm that it is not mandatory that the short-term decision-making is conflicting with the long-term decisions. Moreover, they also mention that the traditional TOC heuristic associated with ABC may lead to minor bottleneck shiftiness regardless the nature of the bill-of-materials of each product (LEA; FREDENDALL, 2002).

Linhares (2009) mentions four facts about the TOC-derived heuristic that exemplify their failures, even when they are analyzing a single bottleneck problem. The facts are summarized on table 9.

Table 8 - Four cases that the TOC-derived heuristic fails

Facts	Description
Fact 1	"There are cases in which the TOC-derived heuristic [which selects based on the ratio (throughput per time constraint)] fails even with a single BN" (LINHARES, 2009, p. 122)
Fact 2	"There are cases in which the TOC-derived heuristic fails to obtain a higher profit than the traditional product margin heuristic" (LINHARES, 2009, p. 122)
Fact 3	"There are cases in which the optimum product mix includes products with the lowest product margin and the lowest ratio of throughput per constraint time, violating both traditional heuristic and the TOC-derived heuristic" (LINHARES, 2009, p. 122)
Fact 4	"There are strong reasons to believe that an efficient and optimum heuristic is simply impossible" (LINHARES, 2009, p. 122)

Source: Linhares (2009) (adapted)

Mabin (2001) highlights the significance of step three at the five steps algorithm proposed by TOC. She considers the impact of the activities at the whole system. These activities may obviate the step four (MABIN, 2001). This work also points out the complementary nature of TOC and LP (MABIN, 2001). LP provides more flexibility and universality, whereas TOC propels innovative exploitation of the LP solutions searching for improvements to the system (MABIN, 2001).

In addition, any of the TOC tools could lead to an entire big picture of a problem (MABIN; DAVIES, 2003). Whether there are employed several tools and techniques, it may enable a progressive improvement of the knowledge about the issue of interest (MABIN;

DAVIES, 2003). Nevertheless, it could not be established a clear guidance to the successive application of each approach or tool (MABIN; DAVIES, 2003).

In a productive system, it is not possible to relate directly the scrap rate and the bottlenecks (KÖKSAL, 2004). Nonetheless, Draman, Lockamy and Cox (2002) consider that a link between the capabilities of a constraint and the organization's performance could be established. In such circumstances, Miguel et al. (2010) mention that the total elimination of the process variability and a total balanced process are not possible, mostly in job shop environments.

Besides, it should be considered the tripartite decisions - among decision-maker, implementer and analyst (BHATTACHARYA et al., 2008; BHATTACHARYA; VASANT, 2006). It could incorporate the DM satisfaction in the TOC heuristic (BHATTACHARYA; VASANT, 2006). The level of satisfaction is an "emotion" that could impact the decision-making process (BHATTACHARYA; VASANT; SUSANTO, 2008). However, it is not a feasible quantity (BHATTACHARYA; VASANT; SUSANTO, 2008).

Product mix decisions that can impact the core business in the short and long terms require deeper scrutiny (LEA, 2007). In this case, the sales and external factors must be aligned with the product mix strategy, focusing on the most profitable products (LINHARES, 2009). Draman, Lockamy and Cox (2002) bring a distinct viewpoint about business strategies (contraction, market share, product quality, cost leadership and so on). Meanwhile, it should be considered the interdependence amongst products specified in the product portfolio (BAYOU; REINSTEIN, 2005). These multiple available metrics must be combined, and a fuzzy logic approach also contributes to more realistic viewpoints and analyses (BAYOU; REINSTEIN, 2005).

In addition, there could be conflicts among functional areas (GUPTA; KO; MIN, 2002). Most departments focus on local optimality instead of the improvement of overall organization efficiency (GUPTA; KO; MIN, 2002). Finally, it is also important to verify, whenever there is a product mix decision, factors like the enterprise reputation and the complementary nature of some products that could influence directly the business profitability.

There are differences among TOC, ABC and TDABC. According to Tsai et al. (2016, p. 16) "TOC makes assumptions on the basis of resources supplied, while ABC and TDABC make assumptions on the basis of resources used. (...) TOC assumes that resources are uncontrollable; therefore, unused production capacity will be regarded as cost". Additionally, it was reinforced that TOC and ABC are not mutually exclusive (ALSMADI; ALMANI; KHAN, 2014).

Some papers state that applying LP, ILP or MIP to large-scale problems does not always lead to optimal or feasible solutions. In addition, these works affirm it as means to refute the contributions of other papers. Nevertheless, this is not an absolute truth. There is optimization software that can solve large-scale problems concerning mathematical models (LP, ILP and MIP) (GUROBI OPTIMIZATION, 2019). However, an optimum solution is not always possible nor viable. In these cases, a primal-dual modeling could be useful, and enable solutions that are close to convergence (thus, to an optimum value). Alternatively, a solution could be obtained, and may provide a target increase such as a 10% better performance. *Ergo*, the LP, ILP and MIP could not be considered a factor that compromises or impedes the obtainment of organizational or productive improvement.

Lastly, it is undeniable that heuristic, metaheuristic and intelligent search algorithms contribute to the decision making. However, they may not be considered as “absolute truths” since other factors come into play. There is a wide range of variables that must be studied.

5 RESEARCH OPPORTUNITIES

This section summarizes a broad view about the further opportunities of research. In addition, the research opportunities are divided into eight subsections. They furnish deeper comprehension about the opportunities of further studies, environmental concerns, the influence of external factors, production planning, variability, accounting, algorithms and guidelines.

Previously to the big picture of the future opportunities, there are some topics that were deeply studied and may not be utile to keep being studied. The last published works stopped defining the TOC and product-mix problem concepts. Thus, it may be considered that the topic is consolidated, and the academia accepts these definitions and related facts. It is recommendable to shift the focus to other concerns such as modeling.

Moreover, TOC and product mix problem concepts are well-accepted and settled at the literature. It may be recommendable that the further studies focus on providing deeper understanding about modeling and practical implications regarding the current TOC and product-mix problem definitions.

5.1 Focus

It could be fruitful the application of algorithms to real-world environments, in order to consider problems with higher complexity (ALSMADI; ALMANI; KHAN, 2014; DRAMAN; LOCKAMY; COX, 2002; GOLMOHAMMADI; MANSOURI, 2015), that may arise, for example, from several setup operations (GOLMOHAMMADI; MANSOURI, 2015). Many works recommend applying the proposed frameworks and algorithms in real companies, so that it is possible to demonstrate their usefulness and weaknesses (GUPTA, 2001, p. 1180). Lastly, it advocates applying the existing algorithms to large-scale problem (BADRI; GHAZANFARI; MAKUI, 2014; ONWUBOLU; MUTINGI, 2001a).

In a nutshell, the further opportunities concern:

1. There are not many case studies and applications in real environments – it may compromise the performance of some methods at atypical environments (specific kind of industries and so forth);
2. Few articles considered specific environments (automotive manufacturing etc.) for the application of algorithms and methods;
3. Few articles mentioned whether the results were valid for flow shop or job shop environments, nor if the results were only applicable for specific products or industries; and
4. It is not always possible to generalize the results obtained with a proposed approach or algorithm. Thus, it is recommendable the application of the findings to other manufacturing systems, so that the potential of generalization could be tested (LEA; FREDENDALL, 2002).

5.2 Environmental concern

Currently, environmental concerns urge for in-depth studies. Some suggestion of topics for further research are:

1. There are few articles which consider sustainability/environmental issues;
2. Throughout the literature review, the first article that contained environmental concerns related to the product-mix problem was Tsai et al. (2013);
3. Tsai and Lai's (2018) work is the first that mentions the circular economy;
4. Few articles consider carbon trades, carbon taxes, carbon rights etc. (TSAI, 2018b; TSAI et al., 2013, 2016); and
5. It could be utile to extend the proposed models concerning environmental issues to new kinds of carbon taxes and environmental policies (TSAI, 2018b, 2018a). These factors could influence short-term and long-term horizons (TSAI, 2018b).

5.3 External factors analysis

There are some topics that were cited by works more than 20 years ago. Nonetheless, the topics have not been studied so far. The following subjects could be meaningful to in-depth studies:

1. Plenert (1993) suggests that the production schedule would help to validate the feasibility of the proposed models;
2. New tests of the proposed heuristic could be performed under distinguishable situations like when the ratios are too close, or it is difficult or not possible to detect the dominant bottleneck (FREDENDALL; LEA, 1997);
3. Only one article considered so far other aspects (CANNON; CANNON; LOW, 2013) – excluding financial issues and decision maker satisfaction – at the product mix problem – portfolio, volume-based choices and so forth; and
4. Tsai (2018a) is the first work that mentions industry 4.0.

5.4 Production planning and scheduling

Setup and maintenance policies could compromise the availability and the sequence of production and they are not considered on MPS. In this context, the scheduling is not exploited deeply in the product mix problem and TOC applications, which were subjected to studies of this senior project. There are suggestions to in-depth studies:

1. Only de Souza et al. (2013) explicitly mention the importance of a level of protective capacity, in order to guarantee the feasibility of the solutions under uncertain environments;
2. De Souza et al. (2013) cite the existence of interactive restrictions, and that they happen due to statistical fluctuations and dependent events;
3. Only few works, like Tsai et al. (2013), permit the acquisition of more productive capacity, when renting and purchasing additional machinery and overtime work (or new night shifts) of the current employees;
4. There are few studies that consider how to improve the bottleneck utilization. Some methods of improving the bottleneck utilization are training the bottleneck operator,

better setup planning, reduce idle time at the bottleneck, reduce bottleneck workload, reduction of the process variability at the bottleneck and so forth (ARYANEZHAD; BADRI; KOMIJAN, 2010);

5. There is also an emerging need of considering the production processes for longer periods since in general these algorithms represent only short-term decisions (HASUIKE; ISHII, 2009); and
6. Some authors also advert the need of algorithms whose competences include tackling products with different and/or probabilistic due dates (ARYANEZHAD; KOMIJAN, 2004; RAY; SARKAR; SANYAL, 2010; SOBREIRO; NAGANO, 2012). Despite many articles pointed out the necessity of studying the product mix problem with different due dates, works did not exploit this topic so far.

5.5 Variability and uncertainties

The real-world behaves mainly in a stochastic manner. As aforementioned by Miguel et al. (2010), the total elimination of the process variability and a total balanced process are not feasible. Further studies could comprise:

1. Few articles consider multiple scenarios – nonetheless, most of them only perform simplistic analyses;
2. Stochastic variables and fuzzy environments are not so frequently;
3. Hasuike and Ishii (2009) consider that problems involving decision maker's level of satisfaction, randomness and fuzziness had not been scrutinized deeply enough. Moreover, most of the cases consider randomness and fuzziness as separate entities (HASUIKE; ISHII, 2009). Nevertheless, integrating both could lead to more realistic models (HASUIKE; ISHII, 2009);
4. Krauth and Warschat (1989) suggest the inclusion of a time-varying demand function in the models;
5. The risk of capital investments on expanding productive capacity or the product mix choices could be also significant criteria to fuzzified approaches (BHATTACHARYA; VASANT, 2006);

6. Linhares (2009) specifies the necessity of further studies on stochastic situations. Additionally, it is crucial to explore problems with integer production, which tackles more complex combinatorial cases (HASUIKE; ISHII, 2009; LINHARES, 2009);
7. Tanhaie and Nahavandi (2011) recommend further research on probabilistic consumption of resources;
8. Mohanty, Mishra and Mishra (2009) remark the need of considering the raw material costs under fluctuation and the outsourcing decision in fuzzy environments;
9. Bhattacharya et al. (2008) recommend tackling capital venture risks with bio-inspired algorithms in the context of TOC;
10. It could be relevant to comprise more stochastic variables (cycle time, scrap rates and fluctuation of raw material costs (HILMOLA; GUPTA, 2015));
11. Further studies could consider long-term situations, when it is possible to increase production capacity with outsourcing, more equipment and new work strategies (TSAI et al., 2016); and
12. Köksal (2004) reinforces the need of incorporating new quality indicators (rework, inspection error and so forth), so that they improve the accuracy of the proposed model. Finally, few works consider scrap (HILMOLA; GUPTA, 2015).

5.6 Accounting

Accounting is one important part of the TOC management philosophy. Specific approaches could be combined with some TOC algorithms. Nevertheless, there is room for improvement in some fields:

1. Few works provide a more complex costing structure. Cannon, Cannon and Low (2013) present a model with a more realistic depiction of an industry, regarding costs with advertising, operational costs of a specific resource and so forth. Afterward, a model includes more variables regarding costs and expenses (setup, handling, shipping, engineering and design costs, marketing and administration costs) (ZHUANG; CHANG, 2017);
2. Tsai and Lai (2018) mention the need of including costs due to machine failure and periodic maintenance; and

3. Köksal (2004) cites that the TOC literature has not studied deeply the quality costs, scraps and other damaging factors for society.

5.7 New and modified algorithms

New and improved algorithm could represent gains (smaller computational time, simplified problem-solving and modeling etc.). In the field of algorithms, there are also research opportunities such as:

1. Some works cite that new or improved local search methods (for instance, pair interchange) could be employed (FREDENDALL; LEA, 1997; ONWUBOLU, 2001; RAY; SARKAR; SANYAL, 2013); and
2. Onwubolu (2001) and Chaharsooghi and Jafari (2007) mention the need of providing better initial solutions to improve the results and performance of algorithms.

5.8 Business and management

TOC could also contribute more with business and management. There are also topics to be exploited. Some of them are:

1. Draman, Lockamy and Cox (2002) present the need of testing new business strategies;
2. In addition, the algorithms and frameworks could contain new management philosophies (GUPTA, 2001);
3. Bayou and Reinstein (2005) bring the assumption of the multi-criteria-based rankings, which are frequently neglected in literature; and
4. Gupta, Ko and Min (2002) pose some questions, such as the impact of throughput thinking on business strategy and the impacts of TOC-based decision-making on operation capabilities and financial performance.

6 CONCLUSION

This work aims at providing an in-depth description about the main topics concerning the product mix problem and the TOC. There is a detailed scrutiny of all the existing literature, whose publications indexed to the chosen database (Scopus) were from 1985 up to August 2019. Besides, this is the most extensive literature review that came into knowledge of the author, which was performed considering concurrently TOC, product mix problem, their relation and associated algorithms.

The project clarifies concepts, describes 67 works based on 11 dimensions, points out advantages and limitations of each work, uncovers research opportunities, and detects inefficiencies regarding each proposition and fragile arguments that were refuted by other authors. Lastly, it is possible to establish observations based on strong evidences provided by, for instance, bibliometric analyses.

The TOC applied to the product mix problem is a topic that is likely to be consolidated. The number of publications is stagnated. In addition, there are further opportunities of research that were addressed in 2000s, and they were not explored so far (product mix problem with different due dates etc.). Furthermore, there is not a big picture of the product mix problem considering, simultaneously, uncertainty, fuzziness, decision-maker's level of satisfaction, environmental issues and so on. Most of the models include a tight range of variables and parameters. Lastly, the limitation is even more alarming when it was not mentioned on the analyzed content that external factors (business strategy, functional conflicts and so on) could control and imperil the outcomes of the mathematical model.

Finally, the biggest differences amongst this project and previous literature reviews are the employed databases, the scope of the works, the period and depth of the analysis of each article and the number of studied publications. Therefore, this work supplies a distinct viewpoint of this topic and contributes to the consolidation of the core concepts of the TOC and the product mix problem.

7 BIBLIOGRAPHY

ALSMADI, M.; ALMANI, A.; KHAN, Z. Implementing an integrated ABC and TOC approach to enhance decision making in a lean context a case study. **International Journal of Quality and Reliability Management**, v. 31, n. 8, p. 906–920, 2014.

ARANGO-MARIN, J. A.; GIRALDO-GARCÍA, J. A.; CASTRILLÓN-GÓMEZ, O. D. Applying TOC Heuristics to Job Scheduling in a Hybrid Flexible Flow Shop. **Dyna**, v. 81, n. 186, p. 113–119, 2014.

ARYANEZHAD, M. B.; BADRI, S. A.; KOMIJAN, A. R. Threshold-based method for elevating the system's constraint under theory of constraints. **International Journal of Production Research**, v. 48, n. 17, p. 5075–5087, 2010.

ARYANEZHAD, M. B.; KOMIJAN, A. R. An improved algorithm for optimizing product mix under the theory of constraints. **International Journal of Production Research**, v. 42, n. 20, p. 4221–4233, 2004.

BADRI, S. A.; GHAZANFARI, M.; MAKUI, A. An integrated model for product mix problem and scheduling considering overlapped operations. **Decision Science Letters**, v. 3, n. 4, p. 523–534, 2014.

BADRI, S. A.; GHAZANFARI, M.; SHAHANAGHI, K. A multi-criteria decision-making approach to solve the product mix problem with interval parameters based on the theory of constraints. **International Journal of Advanced Manufacturing Technology**, v. 70, n. 5–8, p. 1073–1080, 2014.

BAKER, J. D. The Purpose, Process, and Methods of Writing a Literature Review. **AORN Journal**, v. 103, n. 3, p. 265–269, 2016.

BAYOU, M. E.; REINSTEIN, A. Analyzing the Product-mix Decision by Using a Fuzzy Hierarchical Model. **Managerial Finance**, v. 31, n. 3, p. 35–48, 2005.

BHATTACHARYA, A. et al. **Decision Making in TOC-Product-Mix Selection via Fuzzy Cost Function Optimization**. Improving Stability in Developing Nations through Automation 2006. **Anais**...Prishtina, Kosovo: IFAC Publications, 2006

BHATTACHARYA, A. et al. A fully fuzzified, intelligent theory-of-constraints product-mix decision. **International Journal of Production Research**, v. 46, n. 3, p. 789–815, 2008.

BHATTACHARYA, A.; VASANT, P. Soft-sensing of level of satisfaction in TOC product-mix decision heuristic using robust fuzzy-LP. **European Journal of Operational Research**,

p. 55–70, 2006.

BHATTACHARYA, A.; VASANT, P.; SUSANTO, S. Simulating Theory-of-Constraint Problem with Novel Fuzzy Compromise Linear Programming Model. In: **Simulation and Modeling**. 1. ed. Hershey, New York: IGI Publishing, 2008. p. 307–336.

CANNON, J. N.; CANNON, H. M.; LOW, J. T. Modeling Tactical Product-Mix Decisions: A Theory-of-Constraints Approach. **Simulation and Gaming**, v. 44, n. 5, p. 624–644, 2013.

CHAHARSOOGHI, S. K.; JAFARI, N. A Simulated Annealing Approach for Product Mix Decisions. **Scientia Iranica**, v. 14, n. 3, p. 230–235, 2007.

DE SOUZA, F. B. et al. When less is better: Insights from the product mix dilemma from the Theory of Constraints perspective. **International Journal of Production Research**, v. 51, n. 19, p. 5839–5852, 2013.

DRAMAN, R. H.; LOCKAMY, A.; COX, J. F. Constraint-based accounting and its impact on organizational performance: A simulation of four common business strategies. **Integrated Manufacturing Systems**, v. 13, n. 4, p. 190–200, 2002.

EGGHE, L. Theory and practise of the g-index. **Scientometrics**, v. 69, n. 1, p. 131–152, 2006.

FINCH, B. J.; LUEBBE, R. L. Response to ‘theory of constraints and linear programming: A re-examination’. **International Journal of Production Research**, v. 38, n. 6, p. 1465–1466, 2000.

FREDENDALL, L. D.; LEA, B. R. Improving the product mix heuristic in the theory of constraints. **International Journal of Production Research**, v. 35, n. 6, p. 1535–1544, 1997.

GHAZINOORY, S.; FATTAHI, P.; SAMOUEI, P. A hybrid FRTOC-SA algorithm for product mix problems with fuzzy processing time and capacity. **International Journal of Advanced Manufacturing Technology**, v. 65, n. 9–12, p. 1363–1370, 2013.

GOLDRATT, E. M. **The haystack syndrome**. New York: North River Press, 1990.

GOLDRATT, E. M.; COX, J. **The Goal: Excellence In Manufacturing**. New York: North River Press, 1984.

GOLMOHAMMADI, D.; MANSOURI, S. A. Complexity and Workload Considerations in Product Mix Decisions under the Theory of Constraints. **Naval Research Logistics**, p. 357–369, 2015.

GUPTA, M. Activity-based throughput management in a manufacturing company. **International Journal of Production Research**, v. 39, n. 6, p. 1163–1182, 2001.

GUPTA, M.; KO, H.-J.; MIN, H. TOC-based performance measures and five focusing steps in a job-shop manufacturing environment. **International Journal of Production Research**, v. 40, n. 4, p. 907–930, 2002.

GUROBI OPTIMIZATION. **Mixed-Integer Programming (MIP) – A Primer on the Basics**. Disponível em: <https://www.gurobi.com/resource/mip-basics/>. Acesso em: 24 out. 2019.

HADDOCK, J.; RODRIGUEZ, M. Modelling a product-mix determination problem. **Applied Mathematical Modelling**, v. 9, p. 370–374, 1985.

HASUIKE, T.; ISHII, H. On flexible product-mix decision problems under randomness and fuzziness. **Omega**, v. 37, n. 4, p. 770–787, ago. 2009.

HILMOLA, O.-P.; GUPTA, M. Throughput accounting and performance of a manufacturing company under stochastic demand and scrap rates. **Expert Systems with Applications**, v. 42, n. 22, p. 8423–8431, 2015.

HSU, T.-C.; CHUNG, S.-H. The TOC-based algorithm for solving product mix problems. **Production Planning and Control**, v. 9, n. 1, p. 36–46, 1998.

HUANG, H.-P.; CHEN, T.-Y. **A New Approach to On-Line Rescheduling for a Semiconductor Foundry Fab**. Conference Proceedings - IEEE International Conference on Systems, Man and Cybernetics. **Anais**...Taipei, Taiwan: IEEE, 2007

IKEZIRI, L. M. et al. Theory of constraints: review and bibliometric analysis. **International Journal of Production Research**, v. 7543, p. 1–35, 2018.

KAVEH, M.; DALFARD, V. M.; KARAMI, G. Extension of an algorithm for product mix problems with fuzzy conditions. **Applied Mathematical Modelling**, v. 37, n. 23, p. 9688–9697, 2013.

KÖKSAL, G. Selecting quality improvement projects and product mix together in manufacturing: An improvement of a theory of constraints-based approach by incorporating quality loss. **International Journal of Production Research**, v. 42, n. 23, p. 5009–5029, 2004.

KOMIJAN, A. R.; SADJADI, S. J. **Optimizing Product Mix in a Multi-bottleneck Environment Using Group Decision-Making Approach**. Computational Science and Its Applications - ICCSA - 2005. **Anais**...Singapore: Springer-Verlag Berlin Heidelberg, 2005

KRAUTH, J.; WARSCHAT, J. An optimal production-mix model. **European Journal of Operational Research**, p. 142–151, 1989.

LEA, B.-R. Management accounting in ERP integrated MRP and TOC environments. **Industrial Management and Data Systems**, v. 107, n. 8, p. 1188–1211, 2007.

LEA, B. R.; FREDENDALL, L. D. The impact of management accounting, product structure, product mix algorithm, and planning horizon on manufacturing performance. **International Journal of Production Economics**, v. 79, n. 3, p. 279–299, 2002.

LEE, T.; PLENERT, G. Maximizing product mix profitability - what's the best analysis tool. **Production Planning and Control**, v. 7, n. 6, p. 547–553, 1996.

LINHARES, A. Theory of constraints and the combinatorial complexity of the product-mix decision. **International Journal of Production Economics**, v. 121, n. 1, p. 121–129, 2009.

LUEBBE, R.; FINCH, B. Theory of constraints and linear programming: A comparison. **International Journal of Production Research**, v. 30, n. 6, p. 1471–1478, 1992.

MABIN, V. J. Toward a greater understanding of linear programming, theory of constraints, and the product mix problem. **Production and Inventory Management Journal**, v. 42, n. 3–4, p. 52–54, 2001.

MABIN, V. J.; DAVIES, J. Framework for understanding the complementary nature of TOC frames: Insights from the product mix dilemma. **International Journal of Production Research**, v. 41, n. 4, p. 661–680, 2003.

MEHDIZADEH, E.; JALILI, S. An Algorithm Based on Theory of Constraints and Branch and Bound for Solving Integrated Product-Mix-Outsourcing Problem. **Journal of Optimization in Industrial Engineering**, v. 12, n. 1, p. 167–172, 2019.

MIGUEL, S. E. et al. **Revision to theory of constraints**. IBASYS 2010: Balanced Automation Systems for Future Manufacturing Networks. **Anais**...Valencia, Spain: Springer-Verlag Berlin Heidelberg, 2010

MISHRA, N. et al. Hybrid tabu-simulated annealing based approach to solve multi-constraint product mix decision problem. **Expert Systems with Applications**, v. 29, n. 2, p. 446–454, 2005.

MOHANTY, R. P.; MISHRA, D.; MISHRA, T. Comparative study of production outsourcing models. **Journal of Advances in Management Research**, v. 6, n. 1, p. 41–69, 2009.

NAZARI-SHIRKOUHI, S. et al. Solving the integrated product mix-outsourcing problem using the imperialist competitive algorithm. **Expert Systems with Applications**, v. 37, n. 12, p. 7615–7626, 2010.

ONWUBOLU, G. C. Tabu search-based algorithm for the TOC product mix decision. **International Journal of Production Research**, v. 39, n. 10, p. 2065–2076, 2001.

ONWUBOLU, G. C.; MUTINGI, M. Optimizing the multiple constrained resources product mix problem using genetic algorithms. **International Journal of Production Research**, v. 39, n. 9, p. 1897–1910, 2001a.

ONWUBOLU, G. C.; MUTINGI, M. A genetic algorithm approach to the theory of constraints product mix problems. **Production Planning and Control**, v. 12, n. 1, p. 21–27, 2001b.

PLENERT, G. Optimizing theory of constraints when multiple constrained resources exist. **European Journal of Operational Research**, p. 126–133, 1993.

RAY, A.; SARKAR, B.; SANYAL, S. The TOC-Based Algorithm for Solving Multiple

Constraint Resources. **IEEE TRANSACTIONS ON ENGINEERING MANAGEMENT**, v. 57, n. 2, p. 301–309, 2010.

RAY, A.; SARKAR, B.; SANYAL, S. The TOC-Based Algorithm for Solving Multiple Constraint Resources: A Re-examination. **IEEE TRANSACTIONS ON ENGINEERING MANAGEMENT**, v. 61, p. 138–146, 2013.

REZAIE, K.; NAZARI-SHIRKOUHI, S.; GHODSI, R. Theory of Constraints and Particle Swarm Optimization Approaches for Product Mix Problem Decision. **Australian Journal of Basic and Applied Sciences**, v. 4, n. 12, p. 6483–6491, 2010.

REZAIE, K.; NAZARI-SHIRKOUHI, S.; MANOUCHEHRABADI, B. **Particle swarm optimization algorithm based approach to solve theory of constraint product mix problem**. International Conference on Developments in eSystems Engineering, DeSE 2009. **Anais**...Abu Dhabi, United Arab Emirates: IEEE Computer Society, 2009

SHEU, C.; CHEN, M.-H.; KOVAR, S. Integrating ABC and TOC for better manufacturing decision making. **Integrated Manufacturing Systems**, v. 14, n. 5, p. 433–441, 2003.

SINGH, P. K.; SINGH, C. K. Bibliometric Study of Indian Institutes of Technology in Computer Science. **Proceedings - 2019 Amity International Conference on Artificial Intelligence, AICAI 2019**, p. 384–393, 2019.

SINGH, R. K. et al. Psycho-clonal based approach to solve a TOC product mix decision problem. **International Journal of Advanced Manufacturing Technology**, v. 29, n. 11–12, p. 1194–1202, 2006.

SOBREIRO, V. A.; MARIANO, E. B.; NAGANO, M. S. Product mix: The approach of throughput per day. **Production Planning and Control**, v. 25, n. 12, p. 1015–1027, 2014.

SOBREIRO, V. A.; NAGANO, M. S. A review and evaluation on constructive heuristics to optimise product mix based on the Theory of Constraints. **International Journal of Production Research**, v. 50, n. 20, p. 5936–5948, 2012.

SOBREIRO, V. A.; NAGANO, M. S. Proposta de uma heurística construtiva baseada na TOC para definição de mix de produção. **Produção**, v. 23, n. 3, p. 468–477, 2013.

TANHAEI, F.; NAHAVANDI, N. Algorithm for solving product mix problem in two-constraint resources environment. **International Journal of Advanced Manufacturing Technology**, v. 64, n. 5–8, p. 1161–1167, 2013.

TANHAIE, F.; NAHAVANDI, N. **Considering decision maker ideas in product mix problems by goal programming**. IEEE International Conference on Industrial Engineering and Engineering Management. **Anais**...Singapore: IEEE, 2011

TSAI, W.-H. et al. A product-mix decision model using green manufacturing technologies under activity-based costing. **Journal of Cleaner Production**, p. 178–187, 2013.

TSAI, W.-H. et al. Sustainability concept in decision-making: Carbon tax consideration for joint product mix decision. **Sustainability (Switzerland)**, v. 8, n. 12, p. 1–22, 2016.

TSAI, W.-H. Green Production Planning and Control for the Textile Industry by Using Mathematical Programming and Industry 4.0 Techniques. **Energies**, v. 11, n. 8, p. 2072, 2018a.

TSAI, W.-H. Carbon Taxes and Carbon Right Costs Analysis for the Tire Industry. **Energies**, v. 11, n. 8, p. 2121, 2018b.

TSAI, W.-H.; LAI, C.-W.; CHANG, J. C. An algorithm for optimizing joint products decision based on the theory of constraints. **International Journal of Production Research**, v. 45, n. 15, p. 3421–3437, 2007.

TSAI, W.-H.; LAI, S.-Y. Green production planning and control model with ABC under industry 4.0 for the paper industry. **Sustainability (Switzerland)**, v. 10, n. 8, p. 2932, 2018.

TSAI, W.-H.; LU, Y.-H. A framework of production planning and control with carbon tax under industry 4.0. **Sustainability (Switzerland)**, v. 10, n. 9, p. 3221, 2018.

URBAN, W.; ROGOWSKA, P. **Systematic Literature Review of Theory of Constraints**. Advances in Manufacturing II - Lecture Notes in Mechanical Engineering. **Anais**...Springer, Cham, 2019

WANG, F.; CHANG, H.; OU, P. **Integrating Activity-Based Costing and Theory of Constraints for Making Product-mix Decisions**. 2007 International Conference on Management Science & Engineering. **Anais**...Harbin, China: IEEE, 2007

WANG, J. Q. et al. Theory of constraints product mix optimisation based on immune algorithm. **International Journal of Production Research**, v. 47, n. 16, p. 4521–4543, 2009.

WINCHESTER, C. L.; SALJI, M. Writing a literature review. **Journal of Clinical Urology**, v. 9, p. 308–312, 2016.

WOHLIN, C. Guidelines for snowballing in systematic literature studies and a replication in software engineering. **18th International Conference on Evaluation and Assessment in Software Engineering**, 2014.

ZHUANG, Z.-Y.; CHANG, S.-C. Deciding product mix based on time-driven activity-based costing by mixed integer programming. **Journal of Intelligent Manufacturing**, v. 28, n. 4, p. 959–974, 2017.

Appendix A – List of the works employed on the literature review

Table 9 – List of works employed on the literature review

Author	Title
(HADDOCK; RODRIGUEZ, 1985)	Modelling a product-mix determination problem
(KRAUTH; WARSCHAT, 1989)	An optimal production-mix model
(LUEBBE; FINCH, 1992)	Theory of constraints and linear programming: a comparison
(PLENERT, 1993)	Optimizing theory of constraints when multiple constrained resources exist
(LEE; PLENERT, 1996)	Maximizing product mix profitability - what's the best analysis tool
(FREDENDALL; LEA, 1997)	Improving the product mix heuristic in the theory of constraint
(HSU; CHUNG, 1998)	The TOC-based algorithm for solving product mix problems
(FINCH; LUEBBE, 2000)	Response to 'Theory of constraints and linear programming: a re-examination
(ONWUBOLU; MUTINGI, 2001b)	A genetic algorithm approach to the theory of constraints product mix problems
(GUPTA, 2001)	Activity-Based Throughput Management in a manufacturing company
(ONWUBOLU; MUTINGI, 2001a)	Optimizing the multiple constrained resources product mix problem using genetic algorithms
(ONWUBOLU, 2001)	Tabu search-based algorithm for the TOC product mix decision
(MABIN, 2001)	Toward a greater understanding of linear programming, theory of constraints, and the product mix problem
(GUPTA; KO; MIN, 2002)	TOC-based performance measures and five focusing steps in a job-shop manufacturing environment

(DRAMAN; LOCKAMY; COX, 2002)	Constraint-based accounting and its impact on organizational performance: A simulation of four common business strategies
(LEA; FREDENDALL, 2002)	The impact of management accounting, product structure, product mix algorithm, and planning horizon on manufacturing performance
(MABIN; DAVIES, 2003)	Framework for understanding the complementary nature of TOC frames: Insights from the product mix dilemma
(SHEU; CHEN; KOVAR, 2003)	Integrating ABC and TOC for better manufacturing decision making
(ARYANEZHAD; KOMIJAN, 2004)	An improved algorithm for optimizing product mix under the theory of constraints
(KÖKSAL, 2004)	Selecting quality improvement projects and product mix together in manufacturing: An improvement of a theory of constraints-based approach by incorporating quality loss
(MISHRA et al., 2005)	Hybrid tabu-simulated annealing based approach to solve multi-constraint product mix decision problem
(KOMIJAN; SADJADI, 2005)	Optimizing Product Mix in a Multi-bottleneck Environment Using Group Decision-Making Approach
(BAYOU; REINSTEIN, 2005)	Analyzing the product-mix decision by using a fuzzy hierarchical model
(SINGH et al., 2006)	Psycho-clonal based approach to solve a TOC product mix decision problem
(BHATTACHARYA et al., 2006)	Decision Making in Toc-Product-Mix Selection Via Fuzzy Cost Function Optimization

(BHATTACHARYA; VASANT, 2006)	Soft-sensing of level of satisfaction in TOC product-mix decision heuristic using robust fuzzy-LP
(CHAHARSOOGHI; JAFARI, 2007)	A Simulated Annealing Approach for Product Mix Decisions
(TSAI; LAI; CHANG, 2007)	An algorithm for optimizing joint products decision based on the Theory of Constraints
(HUANG; CHEN, 2007)	A New Approach to On-Line Rescheduling for a Semiconductor Foundry Fab
(LEA, 2007)	Management accounting in ERP integrated MRP and TOC environments
(BHATTACHARYA; VASANT; SUSANTO, 2008)	Simulating Theory-of Constraint Problem with Novel Fuzzy Compromise Linear Programming Model
(BHATTACHARYA et al., 2008)	A fully fuzzified, intelligent theory-of-constraints product-mix decision
(WANG; CHANG; OU, 2007)	Integrating Activity-Based Costing and Theory of Constraints for Making Product-mix Decisions
(WANG et al., 2009)	Theory of constraints product mix optimisation based on immune algorithm
(MOHANTY; MISHRA; MISHRA, 2009)	Comparative study of production outsourcing models
(HASUIKE; ISHII, 2009)	On flexible product-mix decision problems under randomness and fuzziness
(LINHARES, 2009)	Theory of constraints and the combinatorial complexity of the product-mix decision
(REZAIE; NAZARI-SHIRKOUHI; MANOUCHEHRABADI, 2009)	Particle Swarm Optimization Algorithm Based Approach to Solve Theory of Constraint Product Mix Problem
(MIGUEL et al., 2010)	Revision to Theory of Constraints

(NAZARI-SHIRKOUHI et al., 2010)	Solving the integrated product mix-outsourcing problem using the Imperialist Competitive Algorithm
(RAY; SARKAR; SANYAL, 2010)	The TOC-Based Algorithm for Solving Multiple Constraint Resources
(REZAIE; NAZARI-SHIRKOUHI; GHODSI, 2010)	Theory of Constraints and Particle Swarm Optimization Approaches for Product Mix Problem Decision
(ARYANEZHAD; BADRI; KOMIJAN, 2010)	Threshold-based method for elevating the system's constraint under theory of constraints
(TANHAIE; NAHAVANDI, 2011)	Considering decision maker ideas in product mix problems by goal programming
(SOBREIRO; NAGANO, 2012)	A review and evaluation on constructive heuristics to optimise product mix based on the Theory of Constraints
(GHAZINOORY; FATTAHI; SAMOUEI, 2013)	A hybrid FRTOC-SA algorithm for product mix problems with fuzzy processing time and capacity
(SOBREIRO; NAGANO, 2013)	Proposta de uma heurística construtiva baseada na TOC para definição de mix de produção
(TANHAEI; NAHAVANDI, 2013)	Algorithm for solving product mix problem in two-constraint resources environment
(CANNON; CANNON; LOW, 2013)	Modeling Tactical Product-Mix Decisions: A Theory-of-Constraints Approach
(DE SOUZA et al., 2013)	When less is better: Insights from the product mix dilemma from the Theory of Constraints perspective
(TSAI et al., 2013)	A product-mix decision model using green manufacturing technologies under activity-based costing
(KAVEH; DALFARD; KARAMI, 2013)	Extension of an algorithm for product mix problems with fuzzy conditions

(RAY; SARKAR; SANYAL, 2013)	The TOC-Based Algorithm for Solving Multiple Constraint Resources: A Re-examination
(BADRI; GHAZANFARI; MAKUI, 2014)	An integrated model for product mix problem and scheduling considering overlapped operations
(ARANGO-MARIN; GIRALDO-GARCÍA; CASTRILLÓN-GÓMEZ, 2014)	Applying TOC Heuristics to Job Scheduling in a Hybrid Flexible Flow Shop
(ALSMADI; ALMANI; KHAN, 2014)	Implementing an integrated ABC and TOC approach to enhance decision making in a Lean context: A case study
(BADRI; GHAZANFARI; SHAHANAGHI, 2014)	A multi-criteria decision-making approach to solve the product mix problem with interval parameters based on the theory of constraints
(SOBREIRO; MARIANO; NAGANO, 2014)	Product mix: the approach of throughput per day
(GOLMOHAMMADI; MANSOURI, 2015)	Complexity and workload considerations in product mix decisions under the theory of constraints
(HILMOLA; GUPTA, 2015)	Throughput accounting and performance of a manufacturing company under stochastic demand and scrap rates
(TSAI et al., 2016)	Sustainability concept in decision-making: Carbon tax consideration for joint product mix decision
(ZHUANG; CHANG, 2017)	Deciding product mix based on time-driven activity-based costing by mixed integer programming
(TSAI, 2018b)	Carbon Taxes and Carbon Right Costs Analysis for the Tire Industry

(TSAI, 2018a)	Green Production Planning and Control for the Textile Industry by Using Mathematical Programming and Industry 4.0 Techniques
(TSAI; LAI, 2018)	Green Production Planning and Control Model with ABC under Industry 4.0 for the Paper Industry
(TSAI; LU, 2018)	A framework of production planning and control with carbon tax under industry 4.0
(MEHDIZADEH; JALILI, 2019)	An algorithm based on theory of constraints and branch and bound for solving integrated product-mix-outsourcing problem

Source: Elaborated by the author.

This table could represent the entire list of authors and publications. It is possible to notice that the review started in 1985, which is one year later the proposition of the concept of “theory of constraints”. Thus, it enables the statement that this work provides an in-depth analysis, regarding every aspect and every work that was suitable to this scope.

Appendix B – Complete list of the authors – TOC and Product mix problem

Table 10 - Complete list of the authors – TOC and Product mix problem

Author	Number of published works
Wen-Hsien Tsai	7
Arijit Bhattacharya	4
Marcelo Seido Nagano	4
Pandian Vasant	4
Vinicius Amorim Sobreiro	4
Alireza Rashidi Komijan	3
Bih-Ru Lea	3
Bijan Sarkar	3
Gerhard Plenert	3
Godfrey C. Onwubolu	3
Kamran Rezaie	3
Mahesh Gupta	3
Salman Nazari-Shirkouhi	3
Seyed Amin Badri	3
Amitava Ray	2
Byron J. Finch	2
Jui-Chu Chang	2
Jun-Qiang Wang	2
Lawrence D. Fredendall	2
M. K. Tiwari	2
M.B. Aryanezhad	2
Mehdi Ghazanfari	2
Michael Mutingi	2
Nasim Nahavandi	2
Prakash	2
Reza Ghodsi	2
Richard L. Luebbe	2

Shu-Dong Sun	2
Subir Sanyal	2
Terry Lee	2
Thomas W. Lin	2
Victoria J. Mabin	2
Tien-Chun Hsu	1
A. T. Dinibütün	1
A.S. Hoseini	1
Ahmad Almani	1
Ahmad Makui	1
Alan Reinstein	1
Alexandre Linhares	1
Archle Lockamy	1
B. Manouchehrabadi	1
C. Andreeski	1
C.-W. Lai	1
Carlos Manuel Dema Pérez	1
Chang Hua	1
Chu-Lun Hsieh	1
Chung-Wei Wang	1
Chwen Sheu	1
D. Mishra	1
Davood Golmohammadi	1
E. Atashpaz-Gargari	1
Enzo Barberio Mariano	1
Esmaeil Mehdizadeh	1
F. Tanhaie	1
Fahimeh Tanhaei	1
Felix T.S. Chan	1
Fernando Bernardi de Souza	1
G. Köksal	1
G. M. Dimirovski	1
George Q. Huang	1

Golnaz Karami	1
H. Eivazy	1
H.A. Yang	1
Han-Pang Huang	1
Hiroaki Ishii	1
Hokey Min	1
Hugh M. Cannon	1
Hui-Chiao Chen	1
Hyun-Jeung Ko	1
J. Davies	1
J. Haddock	1
J. Krauth	1
J. Warschat	1
Jaime Alberto Giraldo-García	1
Jaime Antero Arango-Marín	1
Jair Wagner de Souza Manfrinato	1
James F. Cox	1
James N. Cannon	1
James T. Low	1
Jian Chen	1
Jiri Hajek	1
José Miguel Albarracín Guillem	1
Jun-Der Leu	1
Kamran Shahanaghi	1
M. C. Patterson	1
M. Rodriguez	1
Majed Alsmadi	1
Ming-Hsian	1
Ming-Hslang Chen	1
Mohamed E. Bayou	1
Mojtaba Kaveh	1
N. Barsoum	1
N. Jafari	1

Nishikant Mishra	1
Olli-Pekka Hilmola	1
Omar Danilo Castrillón-Gómez	1
Ou Pei-yu	1
Parvaneh Samouei	1
Parviz Fattahi	1
R. K. Singh	1
R. Shankar	1
R.P. Mohanty	1
Rexford H. Draman	1
S. Afshin Mansouri	1
S. J. Sadjadi	1
S. K. Chaharsooghi	1
S. Kumar	1
S.B. Si	1
Saeed Jalili	1
Sanat Kumar Mukherjee	1
Sani Susanto	1
Sepehr Ghazinoory	1
Shang-Yu Lai	1
Shu-Chin Chang	1
Shu-Hsing Chung	1
Shuo Wang	1
Sofía Estellés Miguel	1
Stacy Kovar	1
T. Kolemisevska	1
T. Mishra	1
Takashi Hasuike	1
Teresa Barbera Ribera	1
Tien-Ying Chen	1
Ting Qu	1
Tsen-Shu Tsaur	1
Vahid Majazi Dalfard	1

Wang Fang-jun	1
Yao-Chung Chang	1
Yin-Hwa Lu	1
Yin-Zhou Guo	1
Zheng-Yun Zhuang	1
Zhong-Tian Zhang	1
Zulfiqar Khan	1

Source: Elaborated by the author.

This table reinforces insights and conclusions which were introduced previously. The authors do not consider the topic "theory of constraints and the product mix problem" as a priority of research, because they do not have a high percentage of works comprising this scope.

Appendix C – Complete list of keywords

Table 11 - Complete list of keywords

Frequency of citation	Keywords
23	Theory of constraints
21	Product mix
9	Theory of constraints (TOC)
8	TOC
6	Activity based costing (ABC)
6	Linear programming
4	Activity based costing
4	Mathematical programming
4	Product mix decision
4	Product mix problem
3	Carbon tax
3	Industry 4.0
3	Outsourcing
3	Throughput accounting
2	Carbon emissions
2	Cost accounting
2	Degree of fuzziness
2	Fuzzified linear programming
2	Genetic algorithm
2	Heuristics
2	Integer Linear Programming
2	Integer programming
2	Level of satisfaction
2	Management accounting
2	Particle Swarm optimization
2	Performance measurement
2	Product mix decisions

2	Product mix problems
2	Production mix
2	Theory of constraint
2	Time driven activity based costing (TDABC)
2	Tire industry
1	ABC
1	Activity capacity
1	Algorithm
1	Analytical hierarchy process
1	Antibodies
1	Antigens
1	Bottleneck
1	Bottleneck Station
1	Branch and bound algorithm
1	Carbon emission
1	Carbon trading
1	Case study
1	Clonal selection
1	Constraint based product mix
1	Constraint resources
1	Contribution Margin
1	DBR
1	Decision making
1	Demand correlation
1	Drum Buffer Rope
1	Dual simplex method with bounded variables
1	Excess capacity
1	Flexible product mix decision problem
1	Flow Shop
1	Fuzziness patterns
1	Fuzzy analytic hierarchical process
1	Fuzzy capacity
1	Fuzzy conditions

1	Fuzzy linear programming
1	Fuzzy processing time
1	Fuzzy Revised Theory of Constraints (FRTOC)
1	Goal
1	Goldratt
1	Green manufacturing
1	Green manufacturing technologies (GMTs)
1	Heuristic
1	Heuristic algorithm
1	Hybrid RTOC-SA
1	Immune algorithm (IA)
1	Imperialist Competitive Algorithm
1	Integrated mathematical programming
1	Intelligent decision
1	Interval parameters
1	Interval TOPSIS
1	Job scheduling
1	Job shop operations
1	Joint product mix
1	Joint products
1	Lean context
1	Level of satisfaction of decision maker
1	Manufacturing resource planning
1	Manufacturing systems
1	Markovian balance equations
1	Master production schedule
1	Mathematical models
1	Mathematical programming approach
1	Mixed-integer programming
1	Multi constraint product mix decision
1	Multi criteria decision making
1	Needs level
1	NP hardness

1	OPT
1	Optimization
1	Optimized production technology
1	Pontrjagin's maximum principle
1	Product margin heuristic
1	Product mix decision
1	Product mix optimisation
1	Product mix optimization
1	Production inventory systems
1	Production management
1	Production planning
1	Production Priority
1	Profitable product death spiral
1	Ranking
1	Re orientation time
1	Relationship marketing
1	Relative Closeness
1	Revised theory of constraints
1	Scheduling
1	Scrap production
1	Simulated annealing
1	Simulated annealing (SA)
1	Soft sensing
1	Stochastic and fuzzy programming
1	Strategic planning
1	Sustainability
1	Sustainability decision making
1	Switching rules
1	Tabu search
1	Textile industry
1	Thinking Process
1	Throughput per day
1	TOC derived heuristic

1	Two constraint resources environment
1	Uncertain demand

Source: Elaborated by the authors.

As expected, the most utilized keywords are in consonance with the ones that were part of the search string. In addition, there is a wide diversity of keywords, which is an evidence of diversity of the works.

Appendix D – Main outcomes, pros and cons of each analyzed work

Table 12 - Main outcomes, advantages and limitations of each work analyzed

Work	Main outcome(s)	Advantage(s)	Limitation(s)
Modelling a product-mix determination problem (HADDOCK; RODRIGUEZ, 1985)	This work presents a combined linear programming	Specific knowledge is not deeply required for the user	It is not suitable for large-scale problems
An optimal production-mix model (KRAUTH; WARSCHAT, 1989)	This work proposes mathematical model (whose basis is the "maximum principle of optimal control theory")	The model is focused on minimizing inventory and production costs.	The model does not perform a multiperiod analysis. Moreover, it does not consider DM level of satisfaction, multi-criteria decision-making and so forth
Theory of constraints and linear programming: a comparison (LUEBBE; FINCH, 1992)	This paper compares linear programming and TOC	The paper clarifies the differences between TOC and LP	There are only simplified examples
Optimizing theory of constraints when multiple constrained resources exist	This paper compares linear programming and TOC	This work addresses in-depth the LP and TOC limitations	"(…) the product mix recommended in the solution has products competing for resources which may cause delays in parts

(PLENERT, 1993)			between production steps." (PLENERT, 1993, p. 132)
Maximizing product mix profitability - what's the best analysis tool (LEE; PLENERT, 1996)	This paper compares linear programming, TOC and accounting methods	The solutions obtained employing TOC and LP-IP were the same and the accounting approach resulted in a non-optimal solution (negative net margin) (LEE; PLENERT, 1996)	This approach may not be suitable for large-scale problems
Improving the product mix heuristic in the theory of constraint (FREDENDALL; LEA, 1997)	This work introduces a Revised TOC heuristic	The algorithm is simple and straightforward	Revised TOC (RTOC) heuristic could not lead to optimal or feasible solutions in cases of multiple bottlenecks (KOMIJAN; SADJADI, 2005; MISHRA et al., 2005). Komijan and Sadjadi (2005) employ neighborhood search. Nevertheless, this search could be excessively time consuming for large-scale problems (KOMIJAN; SADJADI, 2005).

The TOC-based algorithm for solving product mix problems (HSU; CHUNG, 1998)	This work proposes a TOC-based algorithm for multiple bottlenecks	The proposed algorithm had the same results of a dual-simplex method with bounded variables (HSU; CHUNG, 1998)	"Hsu and Chung (1998) (…) fail to incorporate the DM level of satisfaction as well as degree of imprecision (fuzziness) of the solution." (BHATTACHARYA et al., 2008, p. 812)
Response to 'Theory of constraints and linear programming: a re-examination (FINCH; LUEBBE, 2000)	This paper compares linear programming and TOC	The paper elucidates the differences among TOC (philosophy management), TOC (heuristic) and linear programming	There is not numerical explanation
A genetic algorithm approach to the theory of constraints product mix problems (ONWUBOLU; MUTINGI, 2001b)	This paper proposes a Genetic algorithm model	The proposed algorithm has a reasonable computational time for reaching optimality or being close to it	"The genetic algorithm (GA) model presented by Onwubolu and Mutingi (2001) fails to maximize the throughput." (TANHAIE; NAHAVANDI, 2011, p. 1414)
Activity-Based Throughput Management in a	The paper develops a framework - ABTM (activity-based throughput management)	"The most important advantage of the ABTM approach to investment	"The main limitation of this paper is the use of a small and contrived problem with

manufacturing company (GUPTA, 2001)	- it also integrates linear programming	justification is the ability to identify opportunities to increase future throughput as well as the ability to reduce the uncertainty surrounding most investment decisions.” (GUPTA, 2001, p. 1177)	numerous simplifying assumptions.” (GUPTA, 2001, p. 1180)
Optimizing the multiple constrained resources product mix problem using genetic algorithms (ONWUBOLU ; MUTINGI, 2001a)	The paper presents a genetic algorithm - it helps to avoid the optimality loss due to "premature convergence"	“This paper addresses the problem by presenting a genetic algorithm approach which has been developed to solve large, practical problem instances, with very high quality results which are optimum or very close to optimum in most cases.” (ONWUBOLU; MUTINGI, 2001a, p. 1900)	“It is useful to be able to develop an optimal product mix in real-world situation, but if there are interactive constraints, that optimal product mix may not be executable.” (ONWUBOLU; MUTINGI, 2001a, p. 1908)
Tabu search-based algorithm for the TOC product mix decision	The paper proposes a tabu search-based algorithm (it also searches neighborhoods)	The proposed heuristics solves combinatorial optimization problems and large-scale problems with	There is no real case study. There are not considered decision-making criteria

(ONWUBOLU, 2001)		good quality and reasonable computational time (ONWUBOLU, 2001)	
Toward a greater understanding of linear programming, theory of constraints, and the product mix problem (MABIN, 2001)	This paper compares linear programming and TOC	The paper explains deeply the concepts of TOC and linear programming. Moreover, it considers how they could be combined	There are not numerical explanations
TOC-based performance measures and five focusing steps in a job-shop manufacturing environment (GUPTA; KO; MIN, 2002)	The paper presents an integrated framework to the TOC five steps	"(…) provide an in-depth analysis of the characteristic features of TOC (e.g. the goal, performance measures, drum-buffer-rope scheduling and process improvement) using a simulation model." (GUPTA; KO; MIN, 2002, p. 908)	The scope is limited only to job-shop environment (GUPTA; KO; MIN, 2002). It is necessary to apply TOC to real-world problems (GUPTA; KO; MIN, 2002).
Constraint-based accounting	This paper compares the TOC accounting and traditional accounting	The constraint-based [strategy] had superior performance	"With only three products in the model the alternative product

and its impact on organizational performance: A simulation of four common business strategies (DRAMAN; LOCKAMY; COX, 2002)	regarding different strategies	at all the business strategies, regarding the established scenarios. (DRAMAN; LOCKAMY; COX, 2002)	mix decisions were very limited and the impact of the constraint's limited capacity on the alternative was easily established." (DRAMAN; LOCKAMY; COX, 2002, p. 198)
The impact of management accounting, product structure, product mix algorithm, and planning horizon on manufacturing performance (LEA; FREDENDALL, 2002)	This paper compares management accounting, activity-based costing and cost accounting under the perspective of the product mix problem	The paper employs a multiperiod analysis. Moreover, there are considered several aspects that were not considered previously, such as the impact of bill-of-materials on the product mix decision	There is not a real case study
Framework for understanding the complementary nature of TOC frames:	This paper studies TOC approaches and their relation with linear programming, spreadsheet and graphical approaches	"This paper has investigated the product mix dilemma using a variety of TOC approaches that complement and extend traditional	The analysis is deterministic. The results are not necessarily possible to be generalized

Insights from the product mix dilemma (MABIN; DAVIES, 2003)		treatments." (MABIN; DAVIES, 2003, p. 678)	
Integrating ABC and TOC for better manufacturing decision making (SHEU; CHEN; KOVAR, 2003)	This paper compares TOC and activity-based costing (ABC)	It conceals the short run (TOC) and long run (ABC) approaches. (SHEU; CHEN; KOVAR, 2003)	It may not be suitable for large-scale problems. There are not real-scale cases
An improved algorithm for optimizing product mix under the theory of constraints (ARYANEZHAD; KOMIJAN, 2004)	It proposes an improved TOC algorithm. This algorithm is compared to ILP	"The improved algorithm assumes the same importance for all bottlenecks and uses them in the decision-making process." (ARYANEZHAD; KOMIJAN, 2004, p. 4232)	"The proposed algorithm is only suitable for deterministic situations." (ARYANEZHAD; KOMIJAN, 2004, p. 4233)
Selecting quality improvement projects and product mix together in	The paper proposes a TOC-based approach, which combines throughput and quality loss into a quality improvement model.	There is addressed a crucial concern toward incorporating the quality loss in order to provide more realistic deliverables	There is not a real case. In addition, it could be interesting more guidelines to implement the proposed method

manufacturing: An improvement of a theory of constraints-based approach by incorporating quality loss (KÖKSAL, 2004)			
Hybrid tabu-simulated annealing based approach to solve multi-constraint product mix decision problem (MISHRA et al., 2005)	The paper presents a hybrid tabu-simulated annealing	The proposed algorithm performs better than the Traditional TOC algorithm, RTOC, ILP, SA and Tabu search when there are multiple constraints (MISHRA et al., 2005)	"The result of Hybrid tabu-simulated annealing presented by Mishra et al. (2005) is infeasible." (TANHAEI; NAHAVANDI, 2013, p. 1167)
Optimizing Product Mix in a Multi-bottleneck Environment Using Group Decision-Making Approach (KOMIJAN;	The work introduces a new TOC algorithm, which considers all bottlenecks, throughput and late delivery cost. Moreover, it employs TOPSIS for group decision-making	"[the proposed algorithm] This is the result of focus shift from the concept of dominant bottleneck to considering all bottlenecks in decision-making." (KOMIJAN;	It does not present a real case. Moreover, the neighborhood search may be cumbersome for large-scale problems

SADJADI, 2005)		SADJADI, 2005, p. 396)	
Analyzing the product-mix decision by using a fuzzy hierarchical model (BAYOU; REINSTEIN, 2005)	The work proposes an application of fuzzy hierarchical model and AHP	“The ranking can point to the magnitude of importance as perceived by the experts, which can be instrumental to developing the weights of the products in the product mix. The resulting product ranking can further be incorporated as constraints into a fuzzy linear programming model.” (BAYOU; REINSTEIN, 2005, p. 44)	The paper only applies the method to a small-scale problem (ranking four products)
Psycho-clonal based approach to solve a TOC product mix decision problem (SINGH et al., 2006)	The works develops a psycho-clonal algorithm (it combines artificial immunity and Maslow's pyramid)	The proposed algorithm performs better than TOC-based heuristic, Revised-TOC, Tabu search based and ILP (SINGH et al., 2006)	It does not consider the decision maker. Besides, there is no real example

Decision Making in Toc-Product-Mix Selection Via Fuzzy Cost Function Optimization (BHATTACHARYA et al., 2006)	The paper proposes a fuzzified linear programming model	"Thus, fusion of DM's expectations as well as vagueness of decision into a single model makes fuzzified intelligent approach robust and more efficient to apply in TOC product-mix decision." (BHATTACHARYA et al., 2006, p. 60)	It does not present a real case. Furthermore, there is only a small-scale example
Soft-sensing of level of satisfaction in TOC product-mix decision heuristic using robust fuzzy-LP (BHATTACHARYA; VASANT, 2006)	The paper proposes a fuzzified linear programming model	"make the TOC product-mix decision heuristic explicit when multiple constrained resources exist (...) find out fuzziness patterns of TOC product-mix decision heuristic having disparate level of satisfaction" (BHATTACHARYA; VASANT, 2006, p. 58)	"Bhattacharya and Vasant 2006 for product-mix decision fail to incorporate the DM level of satisfaction as well as degree of imprecision (fuzziness) of the solution." (BHATTACHARYA et al., 2008, p. 812)
A Simulated Annealing Approach for Product Mix Decisions (CHAHARSO	The work presents a simulated annealing approach	"The comparison between results obtained with the SA-based heuristic, original TOC, revised TOC and ILP	There is no real example. In addition, the model does not consider uncertainties

OGHI; JAFARI, 2007)		methods shows that SA can find the optimal solution in half of the cases and compares well with the cited methods in five problems" (CHAHARSOOGHI; JAFARI, 2007, p. 233)	
An algorithm for optimizing joint products decision based on the Theory of Constraints (TSAI; LAI; CHANG, 2007)	It is proposed a TOC-based algorithm that is extended to joint product problems	The proposed algorithm and ILP converges to the same results (TSAI; LAI; CHANG, 2007)	There is no real case. It does not consider the decision maker level of satisfaction and uncertainties
A New Approach to On-Line Rescheduling for a Semiconductor Foundry Fab (HUANG; CHEN, 2007)	This paper considers an on-line rescheduling mechanism (which employs adaptive neuro-fuzzy inference system (ANFIS) prediction model) combined with theory of constraints (TOC)	As it employs metaheuristic, the proposed model may be suitable for large-scale problems	There is no real case. Moreover, it does not consider the decision maker
Management accounting in ERP integrated MRP and	This paper examines traditional costing, activity-based costing (ABC) and throughput accounting	"ABC outperforms traditional costing or throughput accounting in terms of short- and long-	"Also, throughput accounting produces the lowest profits among three management

TOC environments (LEA, 2007)		term profitability, customer service level, and WIP inventory." (LEA, 2007, p. 1203)	accounting systems in both MRP and TOC environments." (LEA, 2007, p. 1203)
Simulating Theory-of Constraint Problem with Novel Fuzzy Compromise Linear Programming Model (BHATTACHARYA; VASANT; SUSANTO, 2008)	This book chapter develops a compromise linear programming having fuzzy resources (CLPFR) model	"The proposed CLPFR model finds out a robust optimal solution to the Hsu and Chung's (1998) product mix problem." (BHATTACHARYA; VASANT; SUSANTO, 2008, p. 329)	It does not introduce a real example
A fully fuzzified, intelligent theory-of-constraints product-mix decision (BHATTACHARYA et al., 2008)	This paper proposes a model HMI-FLP (human-machine intelligent - fuzzy linear programming) and an intelligent tool for dimension different impacts of the decision makers	"The HMI will grab the human emotions, i.e. level-of-satisfaction, as well as the solutions sensitivity." (BHATTACHARYA et al., 2008, p. 793)	There is no real example. In addition, it does not consider, for instance, business strategy
Integrating Activity-Based Costing and Theory of	This work develops an ABC-TOC model to make optimal product mix decisions	"(…) proposes an ABC-TOC model to make optimal product-mix	There is no real case. It only considers deterministic variables

Constraints for Making Product-mix Decisions (WANG; CHANG; OU, 2007)		decisions based on the assumptions of static analysis and maximization of profitability." (WANG; CHANG; OU, 2007, p. 620)	and single period analysis
Theory of constraints product mix optimisation based on immune algorithm (WANG et al., 2009)	This work introduces a new intelligent search approach based on immune algorithm (IA-TOC)	This work presents a more complex Immune Algorithm (IA), which considers immune selection, immune self-adaptive regulation, vaccination, crossover, mutation, reproduction rate (WANG et al., 2009). The IA-TOC finds out four optimal solutions, whereas the ILP finds out only one (WANG et al., 2009).	The model does not consider uncertainties and the DM's preferences. There is no real example as well
Comparative study of production outsourcing models (MOHANTY; MISHRA; MISHRA, 2009)	This paper proposes an LP enhancement of TOC method	"The enhancement of TOC with varying contractor's price model is analytically sound and easy to implement. The TOC solution is not always inferior to the LP." (MOHANTY;	"It is observed that the LP enhancement of TOC does not always suggest the optimal outsourcing policy when the contractor's price differs." (MOHANTY;

		MISHRA; MISHRA, 2009, p. 64)	MISHRA; MISHRA, 2009, p. 64)
On flexible product-mix decision problems under randomness and fuzziness (HASUIKE; ISHII, 2009)	The paper proposes a flexible product mix problem employing TOC (regarding fuzziness, randomness, ambiguity and flexibility)	"This paper proposes using stochastic and fuzzy modeling to address probabilistic and ambiguous factors, flexibility to deal with demand volatility and readiness to make various changes from the original product-mix decision, and the theory of constraints (TOC) to identify bottlenecks and portfolio selection approaches to deal with risk management" (HASUIKE; ISHII, 2009, p. 770)	There is no real example
Theory of constraints and the combinatorial complexity of the product-mix decision (LINHARES, 2009)	This paper studies TOC failures	It provides a deeper comprehension about TOC	This paper exposes four facts about the TOC-derived heuristic, which are detailed on subsection 4.4

Particle Swarm Optimization Algorithm Based Approach to Solve Theory of Constraint Product Mix Problem (REZAIE; NAZARI-SHIRKOUHI; MANOUCHEHRABADI, 2009)	This paper proposes a metaheuristic Particle Swarm Optimization (PSO)	“We examined PSO approach against other approaches in the literature (TOC, RTOC, ILP, TS, TS-SA) and obtained better solution in example from Fredendall and Lea (1997).” (REZAIE; NAZARI-SHIRKOUHI; MANOUCHEHRABADI, 2009, p. 442)	The work does not consider a real case. In addition, there is no decision-maker influence nor business strategy
Revision to Theory of Constraints (MIGUEL et al., 2010)	This paper is a literature review whose TOC tools and applications are the focuses	“One of the main benefits of introducing TOC uses to be the generation of clear and realistic productivity indicators, related with the goal of the company.” (MIGUEL et al., 2010, p. 199)	The scope of the literature review consists of only TOC tools and main applications. Thus, there is a more restricted field of research
Solving the integrated product mix-outsourcing problem using the Imperialist Competitive	The paper proposes an Imperialist Competitive Algorithm for product mix outsourcing problem	“All of the cases had similar results and demonstrated the superiority of ICA over TOC and Standard Accounting.”(NAZA	There are not comparisons with other metaheuristic methods. Besides, there is no real example

Algorithm (NAZARI-SHIRKOUHI et al., 2010)		RI-SHIRKOUHI et al., 2010, p. 7625)	
The TOC-Based Algorithm for Solving Multiple Constraint Resources (RAY; SARKAR; SANYAL, 2010)	This work integrates analytic hierarchy process (AHP) and TOC in order to provide an integrated heuristic model	"The numerical result shows that the proposed approach is superior to TOC and to ILP analysis" (RAY; SARKAR; SANYAL, 2010, p. 301)	"Some weakness of our proposed method might be: 1) It would take time to implement the approach. 2) People might be reluctant to use it because they have to justify their own preferences, rather than simply saying yes or no." (RAY; SARKAR; SANYAL, 2010, p. 308)
Theory of Constraints and Particle Swarm Optimization Approaches for Product Mix Problem Decision (REZAIE; NAZARI-SHIRKOUHI; GHODSI, 2010)	The work proposes a modified PSO with a novel intelligent search approach	"We examined PSO approach against other approaches in the literature (TOC, RTOC, ILP, TS, TS-SA) and obtained better solution in example from Fredendall and Lea (1997)." (REZAIE; NAZARI-SHIRKOUHI; GHODSI, 2010, p. 6490)	There is no real example

Threshold-based method for elevating the system's constraint under theory of constraints (ARYANEZHAD; BADRI; KOMIJAN, 2010)	The paper proposes a threshold-based heuristic method (THM)	"The computational results indicate that the THM clearly performs better than M|M|wc|k queuing system." (ARYANEZHAD; BADRI; KOMIJAN, 2010, p. 5087)	The paper does not test the proposed heuristic on a real case
Considering decision maker ideas in product mix problems by goal programming (TANHAIE; NAHAVANDI, 2011)	The paper proposes an alternative employing goal programming via pairwise comparison considering throughput maximization and bottleneck utilization maximization	"It is revealed that the proposed methodology is acceptable in obtaining the optimal product-mix, maximizing throughput under situation that decision maker idea is important." (TANHAIE; NAHAVANDI, 2011, p. 1414)	"the proposed approaches for product mix problem can be used only in situation that time consumption of resources are deterministic, while in real world, this assumption is not correct. So, there is scope for further research in the areas where time consumption of resources is probabilistic." (TANHAIE; NAHAVANDI, 2011, p. 1414–1415)

A review and evaluation on constructive heuristics to optimise product mix based on the Theory of Constraints (SOBREIRO; NAGANO, 2012)	The paper develops a constructive heuristic whose bases are the TOC and the knapsack problem	There is proposed a modification named “B-Greedy-M” that is employed whenever it is not possible, or it is too complex, to distinguish and define the dominant bottleneck (SOBREIRO; NAGANO, 2012).	“The major disadvantages of using a proposed heuristic are only to be used in situations in which the due dates of products are the same, and capacities available for bottleneck resources are deterministic.” (SOBREIRO; NAGANO, 2012, p. 5947)
A hybrid FRTOC-SA algorithm for product mix problems with fuzzy processing time and capacity (GHAZINOORY; FATTAHI; SAMOUEI, 2013)	The work develops a hybrid algorithm whose bases are FRTOC-SA (Fuzzy Revised Theory of Constraints - Simulated Annealing)	“We ran the algorithm 100 times. (…) our results were 98 times better than the FRTOC result.” (GHAZINOORY; FATTAHI; SAMOUEI, 2013, p. 1370)	It does not consider a real case. The paper does not consider the decision maker nor the business strategy
Proposta de uma heurística construtiva baseada na TOC para definição de	The paper develops a constructive heuristic whose bases are the TOC and the knapsack problem	There is proposed a modification named “B-Greedy-M” that is employed whenever it is not possible, or it is too complex, to	It does not consider a real case. The paper does not consider the decision maker nor the business strategy

mix de produção (SOBREIRO; NAGANO, 2013)		distinguish and define the dominant bottleneck (SOBREIRO; NAGANO, 2013).	
Algorithm for solving product mix problem in two-constraint resources environment (TANHAEI; NAHAVANDI, 2013)	This work presents an algorithm suitable in a two-constraint resources environment	“Comparing the result with other solutions (…) reveals that the proposed algorithm is suitable in reaching the optimal product mix, maximizing throughput in a two-constraint resources environment.” (TANHAEI; NAHAVANDI, 2013, p. 1165)	This approach may be not suitable for multiple constraint environment. There is no real case
Modeling Tactical Product-Mix Decisions: A Theory-of-Constraints Approach (CANNON; CANNON; LOW, 2013)	This paper addresses the TOC in a tactical level. It also provides a linear model	"This article extends this line of research [product-mix strategy] to a tactical level, using Goldratt’s theory of constraints to address the impact of supply constraints on product-mix interactions. (…) It shows how these factors can be incorporated into a	This paper does not compare the proposed approach to other algorithms. In addition, it does not study a real example

		standard simulation objective function." (CANNON; CANNON; LOW, 2013, p. 624)	
When less is better: Insights from the product mix dilemma from the Theory of Constraints perspective (DE SOUZA et al., 2013)	This paper proposes a TOC-based heuristic	“The results show that, up to 10% of protective capacity, the performance achieved by applying the proposed heuristic is above 80% of the theoretical maximum allowed by the application of ILP, or over about 84% of the application of ILP with protective capacity.” (DE SOUZA et al., 2013, p. 5847)	“Therefore, the first important conclusion of this paper is that any method that preserves the protective capacity in their solutions is intentionally suboptimal or should allow results that are just good enough and thus any kind of comparison with optimisation methods does not make sense.”(DE SOUZA et al., 2013, p. 5850)
A product-mix decision model using green manufacturing technologies under activity-based costing (TSAI et al., 2013)	The paper presents a mathematical model whose bases are the TOC and ABC. This model is suitable for the adoption of new green manufacturing technologies (GMTs)	“(…) these techniques can be readily utilized to improve product-mix decisions in the context of the current regulatory environment, while producing a better mix of environmentally-friendly products.”	“As a matter of fact, it is impractical to aim to minimize VOC emission quantity or cost.” (TSAI et al., 2013, p. 185)

		(TSAI et al., 2013, p. 186)	
Extension of an algorithm for product mix problems with fuzzy conditions (KAVEH; DALFARD; KARAMI, 2013)	The work proposes a genetic algorithm embedded in Fuzzy Revised Theory of Constraints (FRTOC)	"Results show that GA embedded in FRTOC give us the best solutions in a reasonable time in comparing the past solutions such as TOC, FRTOC and FRTOC-SA." (KAVEH; DALFARD; KARAMI, 2013, p. 9697)	It does not consider a real example. In addition, the paper does not take into account the decision maker satisfaction and so on
The TOC-Based Algorithm for Solving Multiple Constraint Resources: A Re-examination (RAY; SARKAR; SANYAL, 2013)	This paper proposes improvements to the AHP/TOC algorithm	Ray, Sarkar and Sanyal (2013) address advantages of the AHP/TOC method, such as (p.139): 1) All the bottlenecks and decision makers are considered; 2) The product ranking list reckons more dimension factors (such as contribution margin, processing time, available capacity and so forth); 3) The	It is important to highlight that situations when two resources were exhausted simultaneously were not considered on AHP/TOC (RAY; SARKAR; SANYAL, 2013).

		AHP/TOC merges AHP and TOC advantages at only one method. It combines multi-criteria decision-making process and bottleneck exploitation; 4) Sensitivity analysis provides a more robust method, in order to strengthen the accuracy of the model.	
An integrated model for product mix problem and scheduling considering overlapped operations (BADRI; GHAZANFARI; MAKUI, 2014)	The paper presents an integrated model for product mix problem and scheduling (IPMPS), in order to enable overlapped operations	"In other words, the proposed model has determined the product mix and scheduling, simultaneously. Hence, the obtained product mix is more realistic." (BADRI; GHAZANFARI; MAKUI, 2014, p. 532)	It does not employ the proposed algorithm to real cases. In addition, as it is a deterministic model, it does not consider important variabilities and uncertainties
Applying TOC Heuristics to Job Scheduling in a Hybrid Flexible Flow	This paper proposes an adaptation of TOC heuristic to job scheduling in a hybrid flexible flow shop environment	"It can be seen that the TOC heuristics gets results slightly below than the ones obtained with the Branch and Bound	"TOC heuristics reaches the absolute optimum only when there is a constraint that falls far apart from other productive

Shop (ARANGO-MARIN; GIRALDO-GARCÍA; CASTRILLÓN-GÓMEZ, 2014)		method. However, when compared to the detailed results of the Branch and Bound method, it is observed that the same values are achieved in many variables.” (ARANGO-MARIN; GIRALDO-GARCÍA; CASTRILLÓN-GÓMEZ, 2014, p. 118)	resources in performance.” (ARANGO-MARIN; GIRALDO-GARCÍA; CASTRILLÓN-GÓMEZ, 2014, p. 118)
Implementing an integrated ABC and TOC approach to enhance decision making in a Lean context: A case study (ALSMADI; ALMANI; KHAN, 2014)	This paper integrates ABC and TOC, so that the decision-making in a Lean company is improved	“The results of the case study suggests that the integration of ABC and TOC provides managers with an accurate, timely, and reliable tool that can help in making decisions about pricing, production line development, process improvements and product mix.” (ALSMADI; ALMANI; KHAN, 2014, p. 918)	“Although case study as a research method has various advantages, in that it presents data of real-life situations and provides better insights into the detailed behaviours of the subjects of interest, caution must be exercised in generalising the results presented as the paper is based on a single case study with an action research approach.” (ALSMADI;

			ALMANI; KHAN, 2014, p. 918)
A multi-criteria decision-making approach to solve the product mix problem with interval parameters based on the theory of constraints (BADRI; GHAZANFARI; SHAHANAGHI, 2014)	This paper proposes a multi-criteria decision-making approach to enable the utilization of interval parameters	"The comparison of the proposed algorithm results and the optimal solutions shows that proposed approach can find optimal or near optimal product mix for problems previously cited in the literature." (BADRI; GHAZANFARI; SHAHANAGHI, 2014, p. 1080)	There is no real example. One of the assumptions is that the due dates are the same
Product mix: the approach of throughput per day (SOBREIRO; MARIANO; NAGANO, 2014)	This paper presents a constructive heuristic (named cut SM) whose aim is to provide a throughput per day approach	"The difference between the optimal values calculated by the proposed heuristic remained small, regardless of the difficulty of the problem. It should be emphasised that the good performance of the proposed heuristic was maintained in all	There is not a real case. In addition, it does not compare the proposed approach with other algorithms

		classes of problems." (SOBREIRO; MARIANO; NAGANO, 2014, p. 1025)	
Complexity and workload considerations in product mix decisions under the theory of constraints (GOLMOHAMMADI; MANSOURI, 2015)	The work proposes an algorithm named COLOMAPS that means "COmplexity and LOad driven MAster Production Scheduling"	"(...) Conversely and in problems with setup, COLOMAPS performs significantly better than the benchmark algorithms [Fredendall and Lea (1997), Sobreiro and Nagano (2012) and ILP]." (GOLMOHAMMADI; MANSOURI, 2015, p. 365)	"in the dynamic mode and in problems without setup, COLOMAPS outperforms Sobreiro and Nagano (2012), but the difference between COLOMAPS and the two other benchmarks [Fredendall and Lea (1997) and ILP] are not significant." (GOLMOHAMMADI; MANSOURI, 2015, p. 365)
Throughput accounting and performance of a manufacturing company under stochastic demand and scrap rates	The work develops a system dynamics (SD) simulation model considering stochastic variables and scrap rate	The paper highlights several aspects about the need of reducing the scrap rate into drum operations (HILMOLA; GUPTA, 2015). The work also provides an overview about the necessity of assuring the product flow, in order to respond to	There is no real case

(HILMOLA; GUPTA, 2015)		uncertainties and improve the processes (HILMOLA; GUPTA, 2015)	
Sustainability concept in decision-making: Carbon tax consideration for joint product mix decision (TSAI et al., 2016)	This work proposes three models: TDABC model, TOC model and ABC model (they are elaborated in consonance with mixed-integer programming (MIP)). All the models aim at supporting the green product mix decision-making in a situation of joint products	"The empirical results show that profit based on resources will be the most in the system of TDABC, followed by TOC and ABC." (TSAI et al., 2016, p. 18)	"In addition, limited by the production activity information, as provided by the case company, this study cannot learn the production strategy in the case of insufficient production capacity." (TSAI et al., 2016, p. 18)
Deciding product mix based on time-driven activity-based costing by mixed integer programming (ZHUANG; CHANG, 2017)	The work develops a time-driven activity-based costing (TDABC) model that is established employing MIP	"the comparison of this study has shown that both TOC and TDABC would be preferable to ABC (…) Compared with other programming models proposed, which use either TOC or ABC, the proposed model that uses TDABC supplements knowledge of an area that is seldom the focus of other studies." (ZHUANG;	There is no real case. In addition, there are considered only deterministic variable and single period analysis. TDABC is a relative new approach (ZHUANG; CHANG, 2017), what requires in-depth new studies

		CHANG, 2017, p. 972)	
Carbon Taxes and Carbon Right Costs Analysis for the Tire Industry (TSAI, 2018b)	The paper merges mathematical modeling, ABC and TOC to solve green production decision models in a context of a tire industry	"The contribution of this study is that it incorporates the cost of carbon emissions into the mathematical programming, enabling the tire industry to evaluate emissions projects." (TSAI, 2018b, p. 2)	There is no real case. In addition, there are considered only deterministic variable and single period analysis
Green Production Planning and Control for the Textile Industry by Using Mathematical Programming and Industry 4.0 Techniques (TSAI, 2018a)	The work develops an MIP model associated with ABC, which is combined with TOC, to consider carbon taxes in a context of textile industry	"The main contributions of this research are using mathematical programming approach to formulate the decision model with ABC cost data and TOC constraints for the textile companies and clarifying the relation between mathematical programming models and Industry 4.0 techniques." (TSAI, 2018a, p. 1)	There is no real case. In addition, there are considered only deterministic variable and single period analysis

Green Production Planning and Control Model with ABC under Industry 4.0 for the Paper Industry (TSAI; LAI, 2018)	"The purpose of this study (…) is to pose a mathematical programming decision model which integrates green manufacturing technologies, activity-based costing (ABC), and the theory of constraint (TOC)" (TSAI; LAI, 2018, p. 1)	The paper considers several costs. In addition, there is an environmental concern. Lastly, the work mentions the influence of industry 4.0 on the paper production	It does not consider variability, such as price fluctuations. Moreover, it does not consider, for instance, the decision-maker level of satisfaction. Lastly, "it is difficult to calculate the maintenance costs in detail, which is a limitation of this study." (TSAI; LAI, 2018, p. 23)
A framework of production planning and control with carbon tax under industry 4.0 (TSAI; LU, 2018)	"The mathematical programming model, with Activity-Based Costing (ABC) and Theory of Constraints (TOC) for production planning, is used to achieve the optimal solution under various production and sale constraints in order to find the optimal product-mix maximizing the profit" (TSAI; LU, 2018, p. 1)	"This framework can provide a general approach to help companies execute production management in the way of more efficiency, less cost, lower carbon emission and higher quality across the value chain for the tire industry and other industries." (TSAI; LU, 2018, p. 1)	"The model assumes that the unit prices of products and the unit costs of direct materials are constant within the relevant range of planning." (TSAI; LU, 2018, p. 18)
An algorithm based on theory of constraints	"(…) an integrated product-mix-outsourcing problem (IPMO) is considered to answer	It enables to solve problems that require integer solutions	The work does not have a real case. In addition, the decision makers are not

and branch and bound for solving integrated product-mix-outsourcing problem (MEHDIZADEH; JALILI, 2019)	how many products should be produced inside of the system or purchased from external resources (...) an algorithm based on Theory of Constraints (TOC) and Branch and Bound (B&B) algorithm is proposed." (MEHDIZADEH; JALILI, 2019, p. 167)		considered. Finally, the proposed model does not consider uncertainty and fuzziness

Source: Elaborated by the author.

The most frequent limitations of the model are that they were not employed on real cases, and the models are deterministic. In addition, amongst the advantages are the consideration of fuzziness and uncertainties and models suitable for multi-bottlenecks environment.

Appendix E – List of works and their respective number of bottlenecks, focus and variables

Table 13 - List of works and their respective number of bottlenecks, focus and variables

Work	Number of bottlenecks	Focus	Variables
Modelling a product-mix determination problem (HADDOCK; RODRIGUEZ, 1985)	Not mentioned	Application (numerical application)	Deterministic
An optimal production-mix model (KRAUTH; WARSCHAT, 1989)	Not mentioned	Conceptual (mathematical definition of optimal solutions)	Deterministic
Theory of constraints and linear programming: a comparison (LUEBBE; FINCH, 1992)	Single	Application (simulated example)	Deterministic
Optimizing theory of constraints when multiple constrained resources exist (PLENERT, 1993)	Multiple	Application (numerical example)	Deterministic
Maximizing product mix profitability - what's the best analysis tool (LEE; PLENERT, 1996)	Single	Application (numerical example)	Deterministic
Improving the product mix heuristic in the theory of constraint (FREDENDALL; LEA, 1997)	Double	Application (numerical example)	Deterministic
The TOC-based algorithm for solving product mix problems (HSU; CHUNG, 1998)	Multiple	Application (numerical example)	Deterministic

Response to 'Theory of constraints and linear programming: a re-examination (FINCH; LUEBBE, 2000)	Not mentioned	Conceptual	Not Applicable
A genetic algorithm approach to the theory of constraints product mix problems (ONWUBOLU; MUTINGI, 2001)	Multiple	Application (numerical example)	Stochastic
Activity-Based Throughput Management in a manufacturing company (GUPTA, 2001)	Multiple	Application (fictional case study)	Deterministic
Optimizing the multiple constrained resources product mix problem using genetic algorithms (ONWUBOLU; MUTING, 2001)	Multiple	Application	Stochastic
Tabu search-based algorithm for the TOC product mix decision (ONWUBOLU, 2001)	Multiple	Application (numerical example)	Deterministic
Toward a greater understanding of linear programming, theory of constraints, and the product mix problem (MABIN, 2001)	Multiple	Conceptual	Not Applicable
TOC-based performance measures and five focusing steps in a job-shop manufacturing environment (GUPTA; KO; MIN, 2002)	Multiple	Application (simulated example)	Deterministic
Constraint-based accounting and its impact on organizational performance: A simulation of four common business strategies (DRAMAN; LOCKAMY; COX, 2002)	Single	Application (numerical example)	Deterministic

The impact of management accounting, product structure, product mix algorithm, and planning horizon on manufacturing performance (LEA; FREDENDALL, 2002)	Single	Application (simulated example)	Deterministic
Framework for understanding the complementary nature of TOC frames: Insights from the product mix dilemma (MABIN; DAVIES, 2003)	Single	Application (numerical example (real, but simplified))	Deterministic
Integrating ABC and TOC for better manufacturing decision making (SHEU; CHEN; KOVAR, 2003)	Multiple	Application (numerical example)	Deterministic
An improved algorithm for optimizing product mix under the theory of constraints (ARYANEZHAD; KOMIJAN, 2004)	Multiple	Application (numerical example)	Deterministic
Selecting quality improvement projects and product mix together in manufacturing: An improvement of a theory of constraints-based approach by incorporating quality loss (KÖKSAL, 2004)	Multiple	Application (numerical example)	Deterministic
Hybrid tabu-simulated annealing based approach to solve multi-constraint product mix decision problem (MISHRA et al., 2005)	Multiple	Application (numerical example)	Stochastic
Optimizing Product Mix in a Multi-bottleneck Environment Using	Multiple	Application (numerical example)	Deterministic

Group Decision-Making Approach (KOMIJAN; SADJADI, 2005)			
Analyzing the product-mix decision by using a fuzzy hierarchical model (BAYOU; REINSTEIN, 2005)	Multiple	Application (numerical example)	Deterministic
Psycho-clonal based approach to solve a TOC product mix decision problem (SINGH et al., 2006)	Multiple	Application (numerical example)	Deterministic
Decision Making in Toc-Product-Mix Selection Via Fuzzy Cost Function Optimization (BHATTACHARYA et al., 2006)	Multiple	Application (numerical example)	Deterministic
Soft-sensing of level of satisfaction in TOC product-mix decision heuristic using robust fuzzy-LP (BHATTACHARYA; VASANT, 2006)	Multiple	Application (numerical example)	Deterministic
A Simulated Annealing Approach for Product Mix Decisions (CHAHARSOOGHI; JAFARI, 2007)	Multiple	Application (numerical example)	Deterministic
An algorithm for optimizing joint products decision based on the Theory of Constraints (TSAI; LAI; CHANG, 2007)	Multiple	Application (numerical example)	Deterministic
A New Approach to On-Line Rescheduling for a Semiconductor Foundry Fab (HUANG; CHEN, 2007)	Not mentioned	Application (numerical example)	Stochastic
Management accounting in ERP integrated MRP and TOC environments (LEA, 2007)	Multiple	Application (simulated example)	Stochastic

Simulating Theory-of Constraint Problem with Novel Fuzzy Compromise Linear Programming Model (BHATTACHARYA; VASANT; SUSANTO, 2008)	Multiple	Application (simulated example)	Deterministic
A fully fuzzified, intelligent theory-of-constraints product-mix decision (BHATTACHARYA et al., 2008)	Multiple	Application (numerical example)	Stochastic
Integrating Activity-Based Costing and Theory of Constraints for Making Product-mix Decisions (WANG; CHANG; OU, 2007)	Multiple	Application (numerical example)	Deterministic
Theory of constraints product mix optimisation based on immune algorithm (WANG et al., 2009)	Multiple	Application (simulated example)	Deterministic
Comparative study of production outsourcing models (MOHANTY; MISHRA; MISHRA, 2009)	Multiple	Application (numerical example (real-life situation))	Deterministic
On flexible product-mix decision problems under randomness and fuzziness (HASUIKE; ISHII, 2009)	Multiple	Application (numerical example)	Stochastic
Theory of constraints and the combinatorial complexity of the product-mix decision (LINHARES, 2009)	Multiple	Conceptual	Deterministic
Particle Swarm Optimization Algorithm Based Approach to Solve Theory of Constraint Product Mix Problem (REZAIE; NAZARI-SHIRKOUHI; MANOUCHEHRABADI, 2009)	Multiple	Application (numerical example)	Deterministic

Revision to Theory of Constraints (MIGUEL et al., 2010)	Not mentioned	Conceptual	Not Applicable
Solving the integrated product mix-outsourcing problem using the Imperialist Competitive Algorithm (NAZARI-SHIRKOUHI et al., 2010)	Multiple	Application (numerical example)	Deterministic
The TOC-Based Algorithm for Solving Multiple Constraint Resources (RAY; SARKAR; SANYAL, 2010)	Multiple	Application (numerical example)	Deterministic
Theory of Constraints and Particle Swarm Optimization Approaches for Product Mix Problem Decision (REZAIE; NAZARI-SHIRKOUHI; GHODSI, 2010)	Multiple	Application (simulated example)	Deterministic
Threshold-based method for elevating the system's constraint under theory of constraints (ARYANEZHAD; BADRI; KOMIJAN, 2010)	Single	Application (numerical example)	Deterministic
Considering decision maker ideas in product mix problems by goal programming (TANHAIE; NAHAVANDI, 2011)	Multiple	Application (numerical example)	Deterministic
A review and evaluation on constructive heuristics to optimise product mix based on the Theory of Constraints (SOBREIRO; NAGANO, 2012)	Multiple	Application (simulated example)	Deterministic

A hybrid FRTOC-SA algorithm for product mix problems with fuzzy processing time and capacity (GHAZINOORY; FATTAHI; SAMOUEI, 2013)	Multiple	Application (numerical example)	Stochastic
Proposta de uma heurística construtiva baseada na TOC para definição de mix de produção (SOBREIRO; NAGANO, 2013)	Multiple	Application (simulated example)	Deterministic
Algorithm for solving product mix problem in two-constraint resources environment (TANHAEI; NAHAVANDI, 2013)	Double	Application (numerical example)	Deterministic
Modeling Tactical Product-Mix Decisions: A Theory-of-Constraints Approach (CANNON; CANNON; LOW, 2013)	Multiple	Application (numerical example)	Deterministic
When less is better: Insights from the product mix dilemma from the Theory of Constraints perspective (DE SOUZA et al., 2013)	Multiple	Application (numerical example)	Deterministic
A product-mix decision model using green manufacturing technologies under activity-based costing (TSAI et al., 2013)	Multiple	Application (numerical example (fictional metal components part manufacturer in automotive industry))	Deterministic
Extension of an algorithm for product mix problems with fuzzy conditions (KAVEH; DALFARD; KARAMI, 2013)	Multiple	Application (numerical example)	Stochastic

The TOC-Based Algorithm for Solving Multiple Constraint Resources: A Re-examination (RAY; SARKAR; SANYAL, 2013)	Multiple	Application (numerical example)	Deterministic
An integrated model for product mix problem and scheduling considering overlapped operations (BADRI; GHAZANFARI; MAKUI, 2014)	Multiple	Application (numerical example)	Deterministic
Applying TOC Heuristics to Job Scheduling in a Hybrid Flexible Flow Shop (ARANGO-MARIN; GIRALDO-GARCÍA; CASTRILLÓN-GÓMEZ, 2014)	Not mentioned	Application (numerical example (real case))	Deterministic
Implementing an integrated ABC and TOC approach to enhance decision making in a Lean context: A case study (ALSMADI; ALMANI; KHAN, 2014)	Zero	Application (numerical example (real case))	Deterministic
A multi-criteria decision-making approach to solve the product mix problem with interval parameters based on the theory of constraints (BADRI; GHAZANFARI; SHAHANAGHI, 2014)	Multiple	Application (numerical example)	Stochastic
Product mix: the approach of throughput per day (SOBREIRO; MARIANO; NAGANO, 2014)	Multiple	Application (numerical example)	Deterministic
Complexity and workload considerations in product mix decisions under the theory of constraints (GOLMOHAMMADI; MANSOURI, 2015)	Multiple	Application (simulated example (inspired by auto industry and job-	Stochastic

		shop production))	
Throughput accounting and performance of a manufacturing company under stochastic demand and scrap rates (HILMOLA; GUPTA, 2015)	Multiple	Application (simulated example)	Stochastic
Sustainability concept in decision-making: Carbon tax consideration for joint product mix decision (TSAI et al., 2016)	Zero	Application (simulated example (pharmaceutical industry - fictional))	Deterministic
Deciding product mix based on time-driven activity-based costing by mixed integer programming (ZHUANG; CHANG, 2017)	Not mentioned	Application (numerical example)	Deterministic
Carbon Taxes and Carbon Right Costs Analysis for the Tire Industry (TSAI, 2018b)	Not mentioned	Application (numerical example (tire industry - fictional))	Deterministic
Green Production Planning and Control for the Textile Industry by Using Mathematical Programming and Industry 4.0 Techniques (TSAI, 2018a)	Not mentioned	Application (numerical example (textile industry - fictional))	Deterministic
Green Production Planning and Control Model with ABC under Industry 4.0 for the Paper Industry (TSAI; LAI, 2018)	Not mentioned	Application (numerical example (paper	Deterministic

		industry – fictional))	
A framework of production planning and control with carbon tax under industry 4.0 (TSAI; LU, 2018)	Not mentioned	Application (numerical example (tire industry - fictional))	Deterministic
An algorithm based on theory of constraints and branch and bound for solving integrated product-mix-outsourcing problem (MEHDIZADEH; JALILI, 2019)	Multiple	Application (numerical example)	Deterministic

Source: Elaborated by the author.

It is concluded that there are few models that consider stochastic variables. Finally, most of the models take into account multiple bottlenecks and the applications, in general, disregard specific environments.

Appendix F – List of works and their respective period, comparison and computational time

Table 14 - List of works and their respective period, comparison and computational time

Work	Period	Comparison	Computational Time
Modelling a product-mix determination problem (HADDOCK; RODRIGUEZ, 1985)	Single	Other method (LP and Traditional TOC heuristic)	Unconsidered
An optimal production-mix model (KRAUTH; WARSCHAT, 1989)	Single	Unrealized	Unconsidered
Theory of constraints and linear programming: a comparison (LUEBBE; FINCH, 1992)		Unrealized (TOC and LP)	Unconsidered
Optimizing theory of constraints when multiple constrained resources exist (PLENERT, 1993)	Single	Other method (TOC and ILP)	Unconsidered
Maximizing product mix profitability - what's the best analysis tool (LEE; PLENERT, 1996)		Other method (TOC, ILP and accounting methods)	Unconsidered
Improving the product mix heuristic in the theory of constraint (FREDENDALL; LEA, 1997)	Single	Other method (TOC and ILP)	Unconsidered

The TOC-based algorithm for solving product mix problems (HSU; CHUNG, 1998)	Single	Other method (TOC-Based algorithm and Dual-simplex method with bounded variables)	Unconsidered
Response to 'Theory of constraints and linear programming: a re-examination (FINCH; LUEBBE, 2000)		Other method (TOC and LP)	Not Applicable
A genetic algorithm approach to the theory of constraints product mix problems (ONWUBOLU; MUTINGI, 2001)	Multiperiod	Other method (proposed algorithm and TOC-Based algorithms)	Considered (number of iterations was predefined)
Activity-Based Throughput Management in a manufacturing company (GUPTA, 2001)	Single	Other method (proposed algorithm and TOC Five steps algorithm)	Unconsidered
Optimizing the multiple constrained resources product mix problem using genetic algorithms (ONWUBOLU; MUTING, 2001)	Single	Other method (TOC-Based algorithm, Five steps and so on)	Considered (only when comparing to simplex solutions)
Tabu search-based algorithm for the TOC product mix decision (ONWUBOLU, 2001)	Single	Other method (Tabu search-based, TOC, Revised-TOC and ILP)	Considered
Toward a greater understanding of linear programming, theory of constraints, and the product mix problem (MABIN, 2001)		Other method (LP, TOC and both in synergy)	Unconsidered

TOC-based performance measures and five focusing steps in a job-shop manufacturing environment (GUPTA; KO; MIN, 2002)	Multiperiod	Unrealized	Unconsidered
Constraint-based accounting and its impact on organizational performance: A simulation of four common business strategies (DRAMAN; LOCKAMY; COX, 2002)	Single	Other method (Traditional accounting and constraint-based accounting)	Unconsidered
The impact of management accounting, product structure, product mix algorithm, and planning horizon on manufacturing performance (LEA; FREDENDALL, 2002)	Multiperiod	Other method (throughput accounting, ABC and traditional accounting)	Unconsidered
Framework for understanding the complementary nature of TOC frames: Insights from the product mix dilemma (MABIN; DAVIES, 2003)	Multiperiod	Other method (TOC and LP)	Unconsidered
Integrating ABC and TOC for better manufacturing decision making (SHEU; CHEN; KOVAR, 2003)	Single	Other method (TOC and ABC)	Unconsidered
An improved algorithm for optimizing product mix under the theory of constraints (ARYANEZHAD; KOMIJAN, 2004)	Single	Other method (Revised TOC algorithm, ILP and the proposed algorithm)	Considered (only qualitatively (for instance, when more complex problems could represent major

			struggles for computer processing))
Selecting quality improvement projects and product mix together in manufacturing: An improvement of a theory of constraints-based approach by incorporating quality loss (KÖKSAL, 2004)	Single	Other method (proposed algorithm and the one proposed by Atwater and Chakravorty (1995))	Unconsidered
Hybrid tabu-simulated annealing based approach to solve multi-constraint product mix decision problem (MISHRA et al., 2005)	Single	Other method (the proposed heuristics, TOC-based heuristic, Revised-TOC, Tabu Search, ILP and SA (simulated annealing))	Considered (number of iterations)
Optimizing Product Mix in a Multi-bottleneck Environment Using Group Decision-Making Approach (KOMIJAN; SADJADI, 2005)	Single	Other method (the paper only mentions other works, it does not compare methods by itself)	Unconsidered
Analyzing the product-mix decision by using a fuzzy hierarchical model (BAYOU; REINSTEIN, 2005)	Single	Unrealized	Unconsidered
Psycho-clonal based approach to solve a TOC product mix decision problem (SINGH et al., 2006)	Single	Other method (TOC-based heuristic, Revised-TOC, Tabu search based and ILP)	Considered
Decision Making in Toc-Product-Mix Selection Via Fuzzy Cost Function	Single	Other method (Dominance rule (HSU; CHUNG,	Unconsidered

Optimization (BHATTACHARYA et al., 2006)		1998), Traditional TOC, genetic algorithm and the proposed algorithm)	
Soft-sensing of level of satisfaction in TOC product-mix decision heuristic using robust fuzzy-LP (BHATTACHARYA; VASANT, 2006)	Single	Other method (Dominance rule (HSU; CHUNG, 1998), Traditional TOC, genetic algorithm and the proposed algorithm)	Unconsidered
A Simulated Annealing Approach for Product Mix Decisions (CHAHARSOOGHI; JAFARI, 2007)	Single	Other method (Tabu search, genetic algorithm and simulated annealing)	Considered (number of iterations as a stop criterion)
An algorithm for optimizing joint products decision based on the Theory of Constraints (TSAI; LAI; CHANG, 2007)	Single	Other method (ILP and the proposed algorithm)	Unconsidered
A New Approach to On-Line Rescheduling for a Semiconductor Foundry Fab (HUANG; CHEN, 2007)	Multiperiod	Unrealized	Unconsidered
Management accounting in ERP integrated MRP and TOC environments (LEA, 2007)	Multiperiod	Other method (TOC and MRP)	Unconsidered
Simulating Theory-of Constraint Problem with Novel Fuzzy Compromise Linear Programming Model	Single	Other method (TOC, LP, Dominance rule solution (HSU; CHUNG, 1998), GA, Fuzzy-LP	Unconsidered

(BHATTACHARYA; VASANT; SUSANTO, 2008)		(BHATTACHARYA; VASANT, 2007) and the proposed algorithm)	
A fully fuzzified, intelligent theory-of-constraints product-mix decision (BHATTACHARYA et al., 2008)	Multiperiod	Other method (TOC, LP, Dominance rule solution (HSU; CHUNG, 1998), GA, Fuzzy-LP (BHATTACHARYA; VASANT, 2007) and the proposed algorithm)	Unconsidered
Integrating Activity-Based Costing and Theory of Constraints for Making Product-mix Decisions (WANG; CHANG; OU, 2007)	Single	Other method (TOC, ABC and the proposed algorithm)	Unconsidered
Theory of constraints product mix optimisation based on immune algorithm (WANG et al., 2009)	Single	Other method (TOCh, revised TOCh, ILP, TS, GA and the proposed algorithm)	Considered (in minutes and seconds)
Comparative study of production outsourcing models (MOHANTY; MISHRA; MISHRA, 2009)	Single	Other method (standard accounting, theory of constraints (TOC) and linear programming (LP) enhancement of TOC)	Unconsidered
On flexible product-mix decision problems under randomness and fuzziness (HASUIKE; ISHII, 2009)	Single	Other method (superficially, it only pointed out that integrated fuzziness	Unconsidered

		and decision maker satisfaction)	
Theory of constraints and the combinatorial complexity of the product-mix decision (LINHARES, 2009)	Single	Unrealized	Unconsidered
Particle Swarm Optimization Algorithm Based Approach to Solve Theory of Constraint Product Mix Problem (REZAIE; NAZARI-SHIRKOUHI; MANOUCHEHRABADI, 2009)	Single	Other method (TOC, RTOC, ILP, TS, TS-SA and the proposed algorithm (PSO))	Unconsidered
Revision to Theory of Constraints (MIGUEL et al., 2010)		Not Applicable	Unconsidered
Solving the integrated product mix-outsourcing problem using the Imperialist Competitive Algorithm (NAZARI-SHIRKOUHI et al., 2010)	Single	Other method (TOC, Standard accounting and the proposed algorithm)	Considered (number of iterations)
The TOC-Based Algorithm for Solving Multiple Constraint Resources (RAY; SARKAR; SANYAL, 2010)	Single	Other method (Standard TOC, ILP and the proposed algorithm)	Unconsidered
Theory of Constraints and Particle Swarm Optimization Approaches for Product Mix Problem Decision (REZAIE; NAZARI-SHIRKOUHI; GHODSI, 2010)	Single	Other method (TOC, RTOC, ILP, TS, and TS-SA and the proposed PSO algorithm)	Considered (number of iterations)

Threshold-based method for elevating the system's constraint under theory of constraints (ARYANEZHAD; BADRI; KOMIJAN, 2010)	Single	Other method (M|M|wc|k queuing system and the proposed algorithm (THM))	Unconsidered
Considering decision maker ideas in product mix problems by goal programming (TANHAIE; NAHAVANDI, 2011)	Single	Other method (GA of Onwubolu and Mutingi (2001), LP and the proposed methodology)	Unconsidered
A review and evaluation on constructive heuristics to optimise product mix based on the Theory of Constraints (SOBREIRO; NAGANO, 2012)	Single	Other method (TOC-h of Fredendall and Lea (1997) and TOC-AK of Aryanezhad and Komijan (2004), Linear programming and the proposed heuristic)	Considered (time in seconds)
A hybrid FRTOC-SA algorithm for product mix problems with fuzzy processing time and capacity (GHAZINOORY; FATTAHI; SAMOUEI, 2013)	Single	Other method (Fuzzy integer linear programming, FRTOC and the proposed method on the paper (FRTOC-SA))	Considered (number of iterations)
Proposta de uma heurística construtiva baseada na TOC para definição de mix de produção (SOBREIRO; NAGANO, 2013)	Single	Other method (TOC-AK of Aryanezhad and Komijan (2004), Integer linear programming and the proposed heuristic)	Considered (time in seconds)
Algorithm for solving product mix problem in two-constraint	Single	Other method (the standard theory of	Unconsidered

resources environment (TANHAEI; NAHAVANDI, 2013)		constraints, integer linear programming, tabu search, hybrid tabu simulated annealing and proposed algorithm solution)	
Modeling Tactical Product-Mix Decisions: A Theory-of-Constraints Approach (CANNON; CANNON; LOW, 2013)	Single	Unrealized	Unconsidered
When less is better: Insights from the product mix dilemma from the Theory of Constraints perspective (DE SOUZA et al., 2013)	Single	Other method (ILP and the proposed algorithm)	Unconsidered
A product-mix decision model using green manufacturing technologies under activity-based costing (TSAI et al., 2013)	Single	Unrealized	Unconsidered
Extension of an algorithm for product mix problems with fuzzy conditions (KAVEH; DALFARD; KARAMI, 2013)	Single	Other method (TOC, FRTOC and FRTOC-SA and the proposed algorithm)	Considered (time in seconds)
The TOC-Based Algorithm for Solving Multiple Constraint Resources: A Re-examination (RAY; SARKAR; SANYAL, 2013)	Single	Other method (ILP and the proposed algorithm)	Unconsidered
An integrated model for product mix problem and	Single	Other method (Luebbe and Finch	Unconsidered

scheduling considering overlapped operations (BADRI; GHAZANFARI; MAKUI, 2014)		(1992), Lee and Plenert (1993), Fredendall and Lea (1997), Hsu and Chung (1998) and the proposed algorithm)	
Applying TOC Heuristics to Job Scheduling in a Hybrid Flexible Flow Shop (ARANGO-MARIN; GIRALDO-GARCÍA; CASTRILLÓN-GÓMEZ, 2014)	Single	Other method (branch and bound, integer linear programming and the proposed algorithm)	Unconsidered
Implementing an integrated ABC and TOC approach to enhance decision making in a Lean context: A case study (ALSMADI; ALMANI; KHAN, 2014)	Single	Unrealized	Unconsidered
A multi-criteria decision-making approach to solve the product mix problem with interval parameters based on the theory of constraints (BADRI; GHAZANFARI; SHAHANAGHI, 2014)	Single	Other method (Luebbe and Finch (1992), Lee and Plenert (1993), Fredendall and Lea (1997), Hsu and Chung (1998), Patterson (1992) and the proposed algorithm)	Unconsidered
Product mix: the approach of throughput per day (SOBREIRO; MARIANO; NAGANO, 2014)	Single	Unrealized	Considered

Complexity and workload considerations in product mix decisions under the theory of constraints (GOLMOHAMMADI; MANSOURI, 2015)	Multiperiod	Other method (Fredendall and Lea (1997), Sobreiro and Nagano (2012), ILP and the proposed algorithm (COLOMAPS))	Unconsidered
Throughput accounting and performance of a manufacturing company under stochastic demand and scrap rates (HILMOLA; GUPTA, 2015)	Multiperiod	Unrealized	Unconsidered
Sustainability concept in decision-making: Carbon tax consideration for joint product mix decision (TSAI et al., 2016)	Single	Other method (the paper compares TDABC, TOC and ABC, which are presented as MIP models)	Unconsidered
Deciding product mix based on time-driven activity-based costing by mixed integer programming (ZHUANG; CHANG, 2017)	Single	Other method (the paper compares TDABC, TOC and ABC, which are presented as MIP models)	Unconsidered
Carbon Taxes and Carbon Right Costs Analysis for the Tire Industry (TSAI, 2018b)	Single	Unrealized	Unconsidered
Green Production Planning and Control for the Textile Industry by Using Mathematical Programming	Single	Unrealized	Unconsidered

and Industry 4.0 Techniques (TSAI, 2018a)			
Green Production Planning and Control Model with ABC under Industry 4.0 for the Paper Industry (TSAI; LAI, 2018)	Single	Unrealized	Unconsidered
A framework of production planning and control with carbon tax under industry 4.0 (TSAI; LU, 2018)	Single	Unrealized	Unconsidered
An algorithm based on theory of constraints and branch and bound for solving integrated product-mix-outsourcing problem (MEHDIZADEH; JALILI, 2019)	Single	Other method (this paper compares ILP and the proposed algorithm) (MEHDIZADEH; JALILI, 2019)	Unconsidered

Source: Elaborated by the author.

Few works performed multiperiod analysis. Most of the works compare their results to the outcomes obtained with LP or ILP, which are considered, in general, the paramount solutions.

Appendix G – List of works and their respective aspects about finances and accounting, underlying theories and aspects of scheduling

Table 15 - List of works and their respective aspects about finances and accounting, underlying theories and aspects of scheduling

Work	Aspects about Finances and Accounting	Underlying theory (or theories)	Aspects of Scheduling
Modelling a product-mix determination problem (HADDOCK; RODRIGUEZ, 1985)	Unconsidered	Theory of Constraints and Integer Linear Programming	Unconsidered
An optimal production-mix model (KRAUTH; WARSCHAT, 1989)	Considered (the work mentions only basic concepts)	Management Accounting	Unconsidered
Theory of constraints and linear programming: a comparison (LUEBBE; FINCH, 1992)	Unconsidered	Theory of Constraints and Integer Linear Programming	Unconsidered
Optimizing theory of constraints when multiple constrained resources exist (PLENERT, 1993)	Considered (the work mentions only basic concepts)	Theory of Constraints and Integer Linear Programming	Unconsidered
Maximizing product mix profitability - what's the best analysis tool (LEE; PLENERT, 1996)	Considered	Theory of Constraints and Integer Linear Programming	Unconsidered
Improving the product mix heuristic in the theory of constraint (FREDENDALL; LEA, 1997)	Considered (the work mentions only basic concepts)	Theory of Constraints	Unconsidered

The TOC-based algorithm for solving product mix problems (HSU; CHUNG, 1998)	Considered (the work mentions only basic concepts)	Theory of Constraints	Unconsidered
Response to 'Theory of constraints and linear programming: a re-examination (FINCH; LUEBBE, 2000)	Unconsidered	Theory of Constraints and Integer Linear Programming	Unconsidered
A genetic algorithm approach to the theory of constraints product mix problems (ONWUBOLU; MUTINGI, 2001)	Unconsidered	Theory of Constraints and Biologically Inspired Algorithms	Unconsidered
Activity-Based Throughput Management in a manufacturing company (GUPTA, 2001)	Considered (the work mentions only basic concepts)	Theory of Constraints and Management Accounting	Unconsidered
Optimizing the multiple constrained resources product mix problem using genetic algorithms (ONWUBOLU; MUTING, 2001)	Unconsidered	Biologically Inspired Algorithms and Theory of Constraints	Unconsidered
Tabu search-based algorithm for the TOC product mix decision (ONWUBOLU, 2001)	Unconsidered	Theory of Constraints and Metaheuristic	Unconsidered
Toward a greater understanding of linear programming, theory of constraints, and the product	Unconsidered	Theory of Constraints and Integer Linear Programming	Unconsidered

mix problem (MABIN, 2001)			
TOC-based performance measures and five focusing steps in a job-shop manufacturing environment (GUPTA; KO; MIN, 2002)	Considered (the work mentions only basic concepts)	Theory of Constraints and Management Accounting	Considered
Constraint-based accounting and its impact on organizational performance: A simulation of four common business strategies (DRAMAN; LOCKAMY; COX, 2002)	Considered (the work mentions only basic concepts)	Theory of Constraints and Management Accounting	Unconsidered
The impact of management accounting, product structure, product mix algorithm, and planning horizon on manufacturing performance (LEA; FREDENDALL, 2002)	Considered (ABC, traditional accounting and throughput accounting)	Theory of Constraints and Management Accounting	Unconsidered
Framework for understanding the complementary nature of TOC frames: Insights from the product mix dilemma (MABIN; DAVIES, 2003)	Considered (the work mentions only basic concepts)	Theory of Constraints	Unconsidered
Integrating ABC and TOC for better manufacturing decision making (SHEU; CHEN; KOVAR, 2003)	Considered (ABC costing and capacity-adjusted ABC)	Theory of Constraints and Management Accounting	Unconsidered

An improved algorithm for optimizing product mix under the theory of constraints (ARYANEZHAD; KOMIJAN, 2004)	Considered (the work mentions only basic concepts)	Theory of Constraints and Integer Linear Programming	Unconsidered
Selecting quality improvement projects and product mix together in manufacturing: An improvement of a theory of constraints-based approach by incorporating quality loss (KÖKSAL, 2004)	Considered (the work mentions only basic concepts)	Theory of Constraints and Integer Linear Programming	Unconsidered
Hybrid tabu-simulated annealing based approach to solve multi-constraint product mix decision problem (MISHRA et al., 2005)	Considered (the work mentions only basic concepts)	Theory of Constraints and Metaheuristic	Unconsidered
Optimizing Product Mix in a Multi-bottleneck Environment Using Group Decision-Making Approach (KOMIJAN; SADJADI, 2005)	Considered (the work mentions only basic concepts)	Theory of Constraints and Multi-Criteria Decision-Making Approach	Unconsidered
Analyzing the product-mix decision by using a fuzzy hierarchical model (BAYOU; REINSTEIN, 2005)	Considered (the work mentions only basic concepts)	Theory of Constraints and Multi-Criteria Decision-Making Approach	Unconsidered

Psycho-clonal based approach to solve a TOC product mix decision problem (SINGH et al., 2006)	Considered (the work mentions only basic concepts)	Theory of Constraints and Biologically Inspired Algorithms	Unconsidered
Decision Making in Toc-Product-Mix Selection Via Fuzzy Cost Function Optimization (BHATTACHARYA et al., 2006)	Considered (the work mentions only basic concepts)	Theory of Constraints and Integer Linear Programming	Unconsidered
Soft-sensing of level of satisfaction in TOC product-mix decision heuristic using robust fuzzy-LP (BHATTACHARYA; VASANT, 2006)	Considered (the work mentions only basic concepts)	Theory of Constraints and Integer Linear Programming	Unconsidered
A Simulated Annealing Approach for Product Mix Decisions (CHAHARSOOGHI; JAFARI, 2007)	Considered (the work mentions only basic concepts)	Theory of Constraints and Metaheuristic	Unconsidered
An algorithm for optimizing joint products decision based on the Theory of Constraints (TSAI; LAI; CHANG, 2007)	Considered (the work mentions only basic concepts)	Theory of Constraints and Integer Linear Programming	Unconsidered
A New Approach to On-Line Rescheduling for a Semiconductor Foundry	Considered (the work mentions only basic concepts)	Theory of Constraints and Biologically	Considered

Fab (HUANG; CHEN, 2007)		Inspired Algorithms	
Management accounting in ERP integrated MRP and TOC environments (LEA, 2007)	Considered (Traditional cost, ABC and throughput accounting)	Theory of Constraints and Management Accounting	Unconsidered
Simulating Theory-of Constraint Problem with Novel Fuzzy Compromise Linear Programming Model (BHATTACHARYA; VASANT; SUSANTO, 2008)	Considered (the work mentions only basic concepts)	Theory of Constraints and Integer Linear Programming	Unconsidered
A fully fuzzified, intelligent theory-of-constraints product-mix decision (BHATTACHARYA et al., 2008)	Considered (the work mentions only basic concepts)	Theory of Constraints and Integer Linear Programming	Unconsidered
Integrating Activity-Based Costing and Theory of Constraints for Making Product-mix Decisions (WANG; CHANG; OU, 2007)	Considered (the work mentions only basic concepts)	Theory of Constraints and Management Accounting	Unconsidered
Theory of constraints product mix optimisation based on immune algorithm (WANG et al., 2009)	Considered (the work mentions only basic concepts)	Theory of Constraints and Biologically Inspired Algorithms	Unconsidered

Comparative study of production outsourcing models (MOHANTY; MISHRA; MISHRA, 2009)	Considered (the work mentions only basic concepts)	Theory of Constraints and Integer Linear Programming	Unconsidered
On flexible product-mix decision problems under randomness and fuzziness (HASUIKE; ISHII, 2009)	Considered (the work mentions only basic concepts)	Theory of Constraints	Unconsidered
Theory of constraints and the combinatorial complexity of the product-mix decision (LINHARES, 2009)	Considered (the work mentions only basic concepts)	Theory of Constraints	Unconsidered
Particle Swarm Optimization Algorithm Based Approach to Solve Theory of Constraint Product Mix Problem (REZAIE; NAZARI-SHIRKOUHI; MANOUCHEHRABADI, 2009)	Considered (the work mentions only basic concepts)	Theory of Constraints and Biologically Inspired Algorithms	Unconsidered
Revision to Theory of Constraints (MIGUEL et al., 2010)	Considered (the work mentions only basic concepts)	Theory of Constraints	Unconsidered
Solving the integrated product mix-outsourcing problem using the Imperialist Competitive Algorithm (NAZARI-SHIRKOUHI et al., 2010)	Considered (the work mentions only basic concepts)	Theory of Constraints and Metaheuristic	Unconsidered

The TOC-Based Algorithm for Solving Multiple Constraint Resources (RAY; SARKAR; SANYAL, 2010)	Considered (the work mentions only basic concepts)	Theory of Constraints and Multi-Criteria Decision-Making Approach	Unconsidered
Theory of Constraints and Particle Swarm Optimization Approaches for Product Mix Problem Decision (REZAIE; NAZARI-SHIRKOUHI; GHODSI, 2010)	Considered (the work mentions only basic concepts)	Theory of Constraints and Biologically Inspired Algorithms	Unconsidered
Threshold-based method for elevating the system's constraint under theory of constraints (ARYANEZHAD; BADRI; KOMIJAN, 2010)	Considered (the work mentions only basic concepts)	Theory of Constraints	Unconsidered
Considering decision maker ideas in product mix problems by goal programming (TANHAIE; NAHAVANDI, 2011)	Considered (the work mentions only basic concepts)	Theory of Constraints and Multi-Criteria Decision-Making Approach	Unconsidered
A review and evaluation on constructive heuristics to optimise product mix based on the Theory of Constraints (SOBREIRO; NAGANO, 2012)	Considered (the work mentions only basic concepts)	Theory of Constraints and Integer Linear Programming	Unconsidered
A hybrid FRTOC-SA algorithm for product mix problems with fuzzy processing time and	Considered (the work mentions only basic concepts)	Theory of Constraints	Unconsidered

capacity (GHAZINOORY; FATTAHI; SAMOUEI, 2013)			
Proposta de uma heurística construtiva baseada na TOC para definição de mix de produção (SOBREIRO; NAGANO, 2013)	Considered (the work mentions only basic concepts)	Theory of Constraints	Unconsidered
Algorithm for solving product mix problem in two-constraint resources environment (TANHAEI; NAHAVANDI, 2013)	Considered (the work mentions only basic concepts)	Theory of Constraints	Unconsidered
Modeling Tactical Product-Mix Decisions: A Theory-of-Constraints Approach (CANNON; CANNON; LOW, 2013)	Considered (the work mentions only basic concepts)	Theory of Constraints and Integer Linear Programming	Unconsidered
When less is better: Insights from the product mix dilemma from the Theory of Constraints perspective (DE SOUZA et al., 2013)	Considered (the work mentions only basic concepts)	Theory of Constraints and Integer Linear Programming	Unconsidered
A product-mix decision model using green manufacturing technologies under activity-based costing (TSAI et al., 2013)	Considered (the proposed model employs ABC)	Theory of Constraints and Management Accounting	Unconsidered
Extension of an algorithm for product mix problems with fuzzy conditions	Considered (the work mentions only basic concepts)	Theory of Constraints and Biologically	Unconsidered

(KAVEH; DALFARD; KARAMI, 2013)		Inspired Algorithms	
The TOC-Based Algorithm for Solving Multiple Constraint Resources: A Re-examination (RAY; SARKAR; SANYAL, 2013)	Considered (the work mentions only basic concepts)	Theory of Constraints and Multi-Criteria Decision-Making Approach	Unconsidered
An integrated model for product mix problem and scheduling considering overlapped operations (BADRI; GHAZANFARI; MAKUI, 2014)	Considered (the work mentions only basic concepts)	Theory of Constraints and Integer Linear Programming	Considered
Applying TOC Heuristics to Job Scheduling in a Hybrid Flexible Flow Shop (ARANGO-MARIN; GIRALDO-GARCÍA; CASTRILLÓN-GÓMEZ, 2014)	Considered (the work mentions only basic concepts)	Theory of Constraints	Considered
Implementing an integrated ABC and TOC approach to enhance decision making in a Lean context: A case study (ALSMADI; ALMANI; KHAN, 2014)	Considered (the work mentions "lean accounting")	Theory of Constraints and Management Accounting	Unconsidered
A multi-criteria decision-making approach to solve the product mix problem with interval parameters based on the theory of constraints (BADRI;	Considered (the work mentions only basic concepts)	Theory of Constraints and Multi-Criteria Decision-Making Approach	Unconsidered

GHAZANFARI; SHAHANAGHI, 2014)			
Product mix: the approach of throughput per day (SOBREIRO; MARIANO; NAGANO, 2014)	Considered (the work mentions only basic concepts)	Theory of Constraints	Unconsidered
Complexity and workload considerations in product mix decisions under the theory of constraints (GOLMOHAMMADI; MANSOURI, 2015)	Considered (the work mentions only basic concepts)	Theory of Constraints	Unconsidered
Throughput accounting and performance of a manufacturing company under stochastic demand and scrap rates (HILMOLA; GUPTA, 2015)	Considered (the work mentions only basic concepts)	Theory of Constraints and Management Accounting	Unconsidered
Sustainability concept in decision-making: Carbon tax consideration for joint product mix decision (TSAI et al., 2016)	Considered (ABC and TDABC are employed for exploring results)	Theory of Constraints and Management Accounting	Unconsidered
Deciding product mix based on time-driven activity-based costing by mixed integer programming (ZHUANG; CHANG, 2017)	Considered (it considers, TDABC, ABC and TOC accounting)	Theory of Constraints and Integer Linear Programming	Unconsidered

Carbon Taxes and Carbon Right Costs Analysis for the Tire Industry (TSAI, 2018b)	Considered (the work mentions only basic concepts)	Theory of Constraints and Management Accounting	Unconsidered
Green Production Planning and Control for the Textile Industry by Using Mathematical Programming and Industry 4.0 Techniques (TSAI, 2018a)	Considered (ABC is part of the MIP model)	Theory of Constraints and Management Accounting	Unconsidered
Green Production Planning and Control Model with ABC under Industry 4.0 for the Paper Industry (TSAI; LAI, 2018)	Considered (it employs ABC)	Theory of Constraints and Management Accounting	Unconsidered
A framework of production planning and control with carbon tax under industry 4.0 (TSAI; LU, 2018)	Considered (it employs ABC)	Theory of Constraints and Management Accounting	Unconsidered
An algorithm based on theory of constraints and branch and bound for solving integrated product-mix-outsourcing problem (MEHDIZADEH; JALILI, 2019)	Considered (the work mentions only basic concepts)	Theory of Constraints and Integer Linear Programming	Unconsidered

Source: Elaborated by the author.

Aspects regarding scheduling were not the focus of most works. In general, they take into consideration only basic concepts concerning accounting. Finally, the ILP and metaheuristic were frequently associated with the Theory of Constraints.

Appendix H – List of works and their respective environmental aspects and main outcomes

Table 16 - List of works and their respective environmental aspects and main outcomes

Work	Environmental Aspects	Main outcome(s)
Modelling a product-mix determination problem (HADDOCK; RODRIGUEZ, 1985)	Unconsidered	This work presents a combined linear programming
An optimal production-mix model (KRAUTH; WARSCHAT, 1989)	Unconsidered	This work proposes mathematical model (whose basis is the "maximum principle of optimal control theory")
Theory of constraints and linear programming: a comparison (LUEBBE; FINCH, 1992)	Unconsidered	This paper compares linear programming and TOC
Optimizing theory of constraints when multiple constrained resources exist (PLENERT, 1993)	Unconsidered	This paper compares linear programming and TOC
Maximizing product mix profitability - what's the best analysis tool (LEE; PLENERT, 1996)	Unconsidered	This paper compares linear programming, TOC and accounting methods
Improving the product mix heuristic in the theory of constraint (FREDENDALL; LEA, 1997)	Unconsidered	This work introduces a Revised TOC heuristic

The TOC-based algorithm for solving product mix problems (HSU; CHUNG, 1998)	Unconsidered	This work proposes a TOC-based algorithm for multiple bottlenecks
Response to 'Theory of constraints and linear programming: a re-examination (FINCH; LUEBBE, 2000)	Unconsidered	This paper compares linear programming and TOC
A genetic algorithm approach to the theory of constraints product mix problems (ONWUBOLU; MUTINGI, 2001)	Unconsidered	This paper proposes a Genetic algorithm model
Activity-Based Throughput Management in a manufacturing company (GUPTA, 2001)	Unconsidered	The paper develops a framework - ABTM (activity-based throughput management) - it also integrates linear programming
Optimizing the multiple constrained resources product mix problem using genetic algorithms (ONWUBOLU; MUTING, 2001)	Unconsidered	The paper presents a genetic algorithm - it helps to avoid the optimality loss due to "premature convergence"
Tabu search-based algorithm for the TOC product mix decision (ONWUBOLU, 2001)	Unconsidered	The paper proposes a tabu search-based algorithm (it also searches neighborhoods)
Toward a greater understanding of linear programming, theory of constraints, and the product mix problem (MABIN, 2001)	Unconsidered	This paper compares linear programming and TOC
TOC-based performance measures and five focusing steps in a job-shop manufacturing	Unconsidered	The paper presents an integrated framework to the TOC five steps

environment (GUPTA; KO; MIN, 2002)		
Constraint-based accounting and its impact on organizational performance: A simulation of four common business strategies (DRAMAN; LOCKAMY; COX, 2002)	Unconsidered	This paper compares the TOC accounting and traditional accounting regarding different strategies
The impact of management accounting, product structure, product mix algorithm, and planning horizon on manufacturing performance (LEA; FREDENDALL, 2002)	Unconsidered	This paper compares management accounting, activity-based costing and cost accounting under the perspective of the product mix problem
Framework for understanding the complementary nature of TOC frames: Insights from the product mix dilemma (MABIN; DAVIES, 2003)	Unconsidered	This paper studies TOC approaches and their relation with linear programming, spreadsheet and graphical approaches
Integrating ABC and TOC for better manufacturing decision making (SHEU; CHEN; KOVAR, 2003)	Unconsidered	This paper compares TOC and activity-based costing (ABC)
An improved algorithm for optimizing product mix under the theory of constraints (ARYANEZHAD; KOMIJAN, 2004)	Unconsidered	It proposes an improved TOC algorithm. This algorithm is compared to ILP
Selecting quality improvement projects and product mix together in manufacturing: An improvement of a theory of constraints-based approach by	Unconsidered	The paper proposes a TOC-based approach, which combines throughput and quality loss into a quality improvement model.

incorporating quality loss (KÖKSAL, 2004)		
Hybrid tabu-simulated annealing based approach to solve multi-constraint product mix decision problem (MISHRA et al., 2005)	Unconsidered	The paper presents a hybrid tabu-simulated annealing
Optimizing Product Mix in a Multi-bottleneck Environment Using Group Decision-Making Approach (KOMIJAN; SADJADI, 2005)	Unconsidered	The work introduces a new TOC algorithm, which considers all bottlenecks, throughput and late delivery cost. Moreover, it employs TOPSIS for group decision-making
Analyzing the product-mix decision by using a fuzzy hierarchical model (BAYOU; REINSTEIN, 2005)	Unconsidered	The work proposes an application of fuzzy hierarchical model and AHP
Psycho-clonal based approach to solve a TOC product mix decision problem (SINGH et al., 2006)	Unconsidered	The works develops a psycho-clonal algorithm (it combines artificial immunity and Maslow's pyramid)
Decision Making in Toc-Product-Mix Selection Via Fuzzy Cost Function Optimization (BHATTACHARYA et al., 2006)	Unconsidered	The paper proposes a fuzzified linear programming model
Soft-sensing of level of satisfaction in TOC product-mix decision heuristic using robust fuzzy-LP (BHATTACHARYA; VASANT, 2006)	Unconsidered	The paper proposes a fuzzified linear programming model

A Simulated Annealing Approach for Product Mix Decisions (CHAHARSOOGHI; JAFARI, 2007)	Unconsidered	The work presents a simulated annealing approach
An algorithm for optimizing joint products decision based on the Theory of Constraints (TSAI; LAI; CHANG, 2007)	Unconsidered	It is proposed a TOC-based algorithm that is extended to joint product problems
A New Approach to On-Line Rescheduling for a Semiconductor Foundry Fab (HUANG; CHEN, 2007)	Unconsidered	This paper considers an on-line rescheduling mechanism (which employs adaptive neuro-fuzzy inference system (ANFIS) prediction model) combined with theory of constraints (TOC)
Management accounting in ERP integrated MRP and TOC environments (LEA, 2007)	Unconsidered	This paper examines traditional costing, activity-based costing (ABC) and throughput accounting
Simulating Theory-of Constraint Problem with Novel Fuzzy Compromise Linear Programming Model (BHATTACHARYA; VASANT; SUSANTO, 2008)	Unconsidered	This book chapter develops a compromise linear programming having fuzzy resources (CLPFR) model
A fully fuzzified, intelligent theory-of-constraints product-mix decision (BHATTACHARYA et al., 2008)	Unconsidered	This paper proposes a model HMI-FLP (human-machine intelligent - fuzzy linear programming) and an intelligent tool for dimension different impacts of the decision makers
Integrating Activity-Based Costing and Theory of Constraints for Making	Unconsidered	This work develops an ABC-TOC model to make optimal product mix decisions

Product-mix Decisions (WANG; CHANG; OU, 2007)		
Theory of constraints product mix optimisation based on immune algorithm (WANG et al., 2009)	Unconsidered	This work introduces a new intelligent search approach based on immune algorithm (IA-TOC)
Comparative study of production outsourcing models (MOHANTY; MISHRA; MISHRA, 2009)	Unconsidered	This paper proposes an LP enhancement of TOC method
On flexible product-mix decision problems under randomness and fuzziness (HASUIKE; ISHII, 2009)	Unconsidered	The paper proposes a flexible product mix problem employing TOC (regarding fuzziness, randomness, ambiguity and flexibility)
Theory of constraints and the combinatorial complexity of the product-mix decision (LINHARES, 2009)	Unconsidered	This paper studies TOC failures
Particle Swarm Optimization Algorithm Based Approach to Solve Theory of Constraint Product Mix Problem (REZAIE; NAZARI-SHIRKOUHI; MANOUCHEHRABADI, 2009)	Unconsidered	This paper proposes a metaheuristic Particle Swarm Optimization (PSO)
Revision to Theory of Constraints (MIGUEL et al., 2010)	Unconsidered	This paper is a literature review whose TOC tools and applications are the focuses
Solving the integrated product mix-outsourcing problem using the Imperialist Competitive	Unconsidered	The paper proposes an Imperialist Competitive Algorithm for product mix outsourcing problem

Algorithm (NAZARI-SHIRKOUHI et al., 2010)		
The TOC-Based Algorithm for Solving Multiple Constraint Resources (RAY; SARKAR; SANYAL, 2010)	Unconsidered	This work integrates analytic hierarchy process (AHP) and TOC in order to provide an integrated heuristic model
Theory of Constraints and Particle Swarm Optimization Approaches for Product Mix Problem Decision (REZAIE; NAZARI-SHIRKOUHI; GHODSI, 2010)	Unconsidered	The work proposes a modified PSO with a novel intelligent search approach
Threshold-based method for elevating the system's constraint under theory of constraints (ARYANEZHAD; BADRI; KOMIJAN, 2010)	Unconsidered	The paper proposes a threshold-based heuristic method (THM)
Considering decision maker ideas in product mix problems by goal programming (TANHAIE; NAHAVANDI, 2011)	Unconsidered	The paper proposes an alternative employing goal programming via pairwise comparison considering throughput maximization and bottleneck utilization maximization
A review and evaluation on constructive heuristics to optimise product mix based on the Theory of Constraints (SOBREIRO; NAGANO, 2012)	Unconsidered	The paper develops a constructive heuristic whose bases are the TOC and the knapsack problem
A hybrid FRTOC-SA algorithm for product mix problems with fuzzy processing time and capacity (GHAZINOORY; FATTAHI; SAMOUEI, 2013)	Unconsidered	The work develops a hybrid algorithm whose bases are FRTOC-SA (Fuzzy Revised Theory of Constraints - Simulated Annealing)

Proposta de uma heurística construtiva baseada na TOC para definição de mix de produção (SOBREIRO; NAGANO, 2013)	Unconsidered	The paper develops a constructive heuristic whose bases are the TOC and the knapsack problem
Algorithm for solving product mix problem in two-constraint resources environment (TANHAEI; NAHAVANDI, 2013)	Unconsidered	This work presents an algorithm suitable in a two-constraint resources environment
Modeling Tactical Product-Mix Decisions: A Theory-of-Constraints Approach (CANNON; CANNON; LOW, 2013)	Unconsidered	This paper addresses the TOC in a tactical level. It also provides a linear model
When less is better: Insights from the product mix dilemma from the Theory of Constraints perspective (DE SOUZA et al., 2013)	Unconsidered	This paper proposes a TOC-based heuristic
A product-mix decision model using green manufacturing technologies under activity-based costing (TSAI et al., 2013)	Considered	The paper presents a mathematical model whose bases are the TOC and ABC. This model is suitable for the adoption of new green manufacturing technologies (GMTs)
Extension of an algorithm for product mix problems with fuzzy conditions (KAVEH; DALFARD; KARAMI, 2013)	Unconsidered	The work proposes a genetic algorithm embedded in Fuzzy Revised Theory of Constraints (FRTOC)
The TOC-Based Algorithm for Solving Multiple Constraint Resources: A Re-examination	Unconsidered	This paper proposes improvements to the AHP/TOC algorithm

(RAY; SARKAR; SANYAL, 2013)		
An integrated model for product mix problem and scheduling considering overlapped operations (BADRI; GHAZANFARI; MAKUI, 2014)	Unconsidered	The paper presents an integrated model for product mix problem and scheduling (IPMPS), in order to enable overlapped operations
Applying TOC Heuristics to Job Scheduling in a Hybrid Flexible Flow Shop (ARANGO-MARIN; GIRALDO-GARCÍA; CASTRILLÓN-GÓMEZ, 2014)	Unconsidered	This paper proposes an adaptation of TOC heuristic to job scheduling in a hybrid flexible flow shop environment
Implementing an integrated ABC and TOC approach to enhance decision making in a Lean context: A case study (ALSMADI; ALMANI; KHAN, 2014)	Unconsidered	This paper integrates ABC and TOC, so that the decision-making in a Lean company is improved
A multi-criteria decision-making approach to solve the product mix problem with interval parameters based on the theory of constraints (BADRI; GHAZANFARI; SHAHANAGHI, 2014)	Unconsidered	This paper proposes a multi-criteria decision-making approach to enable the utilization of interval parameters
Product mix: the approach of throughput per day (SOBREIRO; MARIANO; NAGANO, 2014)	Unconsidered	This paper presents a constructive heuristic (named cut SM) whose aim is to provide a throughput per day approach
Complexity and workload considerations in product mix decisions under the theory of constraints	Unconsidered	The work proposes an algorithm named COLOMAPS that means "COmplexity and LOad driven MAster Production Scheduling"

(GOLMOHAMMADI; MANSOURI, 2015)		
Throughput accounting and performance of a manufacturing company under stochastic demand and scrap rates (HILMOLA; GUPTA, 2015)	Considered	The work develops a system dynamics (SD) simulation model considering stochastic variables and scrap rate
Sustainability concept in decision-making: Carbon tax consideration for joint product mix decision (TSAI et al., 2016)	Considered	This work proposes three models: TDABC model, TOC model and ABC model (they are elaborated in consonance with mixed-integer programming (MIP)). All the models aim at supporting the green product mix decision-making in a situation of joint products
Deciding product mix based on time-driven activity-based costing by mixed integer programming (ZHUANG; CHANG, 2017)	Unconsidered	The work develops a time-driven activity-based costing (TDABC) model that is established employing MIP
Carbon Taxes and Carbon Right Costs Analysis for the Tire Industry (TSAI, 2018b)	Considered	The paper merges mathematical modeling, ABC and TOC to solve green production decision models in a context of a tire industry
Green Production Planning and Control for the Textile Industry by Using Mathematical Programming and Industry 4.0 Techniques (TSAI, 2018a)	Considered	The work develops an MIP model associated with ABC, which is combined with TOC, to consider carbon taxes in a context of textile industry
Green Production Planning and Control Model with ABC under	Considered	“The purpose of this study (…) is to pose a mathematical

Industry 4.0 for the Paper Industry (TSAI; LAI, 2018)		programming decision model which integrates green manufacturing technologies, activity-based costing (ABC), and the theory of constraint (TOC)” (TSAI; LAI, 2018, p. 1)
A framework of production planning and control with carbon tax under industry 4.0 (TSAI; LU, 2018)	Considered	“The mathematical programming model, with Activity-Based Costing (ABC) and Theory of Constraints (TOC) for production planning, is used to achieve the optimal solution under various production and sale constraints in order to find the optimal product-mix maximizing the profit.” (TSAI; LU, 2018, p. 1)
An algorithm based on theory of constraints and branch and bound for solving integrated product-mix-outsourcing problem (MEHDIZADEH; JALILI, 2019)	Unconsidered	“(…) an integrated product-mix-outsourcing problem (IPMO) is considered to answer how many products should be produced inside of the system or purchased from external resources (...) an algorithm based on Theory of Constraints (TOC) and Branch and Bound (B&B) algorithm is proposed.” (MEHDIZADEH; JALILI, 2019, p. 167)

Source: Elaborated by the author.

The section 5 summarized research opportunities. This table reinforces the need of consider environmental aspects at further models. The first work that considered environmental issues was Tsai et al. (2013). Besides, the main outcomes contain algorithm such as metaheuristic, ILP and accounting approaches such as ABC.