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Designing the Process for Implementing Step Three of the Theory of Constraints in a Make-To-Order Environment: Integrating Sales and Operation Planning

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Abstract:

Purpose: The theory of constraints (TOC) methodology and its drum-buffer-rope (DBR) production planning and control system are well suited to managing production plants in complex environments. The objective of this study was to design an evolution of the systematic process for implementing the third step of the TOC methodology in make-to-order environments.

Design/methodology/approach: Since the research concerned a real context and the phenomenon under investigation is contemporary, a case study was chosen as the research methodology.

Findings: The study investigated, through a case study, the phases and steps necessary for the systematic process to be successfully implemented in a make-to-order environment.

Originality/value: The three main contributions to the systematic implementation process for the third step of the TOC model are identified as the design of the last version of the systematic process, the integration of sales and operations through the TOC methodology and the introduction of the demand-driven adaptive enterprise model's capacity buffer.

Keywords: theory of constraints, make to order, implementation process, sales and operation planning, demand-driven adaptive enterprise model

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1. Introduction

Globalisation has had a direct impact on business management and, in particular, on supply chain management (Lahloua, El Barkany & El Khalfi, 2018). In this globalised environment, many companies have had to migrate from make-to-stock (MTS) environments where few product references are manufactured in large quantities and at low cost to more complex environments, such as mass customisation (De La Calle, Grus & Álvarez, 2017). The make-to-order (MTO) environment is particularly suited to the production of customised products (Chen-Ritzo, Ervolina, Harrison & Gupta, 2010), whereby non-standard products are driven through the production plant. In the absence of finished goods inventory, manufacturing times are longer than in MTS environments. In addition, the variability of job routing increases the difficulties of planning and control. Consequently, production planning and control systems become key elements in managing MTO environments, supporting them to adapt to the customisation (Stevenson, Hendry & Kingsman, 2005).

In the case of the theory of constraints (TOC), its drum-buffer-rope (DBR) scheduling mechanism has proven to be a valid planning and control system for addressing the problems of MTO environments (Chakravorty, 2001; Darlington, Francis, Found & Thomas, 2015; Riezebos, Korte & Land, 2003).

The objective of this article was to further develop the design of the systematic implementation process for the third step of the TOC through a case study in an MTO environment. By doing so, we set out to extend the research initiated by Lizarralde (Lizarralde, 2020; Lizarralde, Apaolaza & Mediavilla, 2019, 2020), who developed a systematic process for modifying the first two steps of the TOC methodology in MTO scenarios, and by Orue, Lizarralde, Amorrotu and Apaolaza (2021), who proposed the necessary phases for the third step of the systematic process.

The article begins with an analysis of the existing literature on the TOC and its third step, in particular, including the implementation process. The research question (RQ) and the objectives of the study are then set out. This is followed by a description of the selected research methodology using a case study. Next, we discuss the extent to which the research objectives were achieved. Lastly, the conclusions and future directions for research are presented.

2. Literature Review

The TOC management methodology is based on systems thinking and the notion that all systems have at least one constraint limiting their output (Boyd & Gupta, 2004). This constraint, also called a bottleneck (BN), can be anything that limits the system from achieving higher performance relative to the target. It sets the basis for the management and improvement of the whole system (Goldratt & Cox, 2004).

The five steps of the TOC methodology are to (1) identify or select the BN of the system, (2) decide how to exploit the BN, (3) subordinate all non-BN resources to the BN, (4) raise the capacity of the BN and (5) return to step 1 if the BN is broken.

The TOC production planning and control system, the DBR, addresses both physical and market constraints (Thürer et al., 2017). It takes a simple approach whereby the system can be controlled by requiring precision in the BN (Gupta & Snyder, 2009).

2.1. TOC Third Step

Step three of the TOC methodology focuses on the management of non-BN resources, working to subordinate them to the BN. By definition, non-BN resources have a greater capacity than the BN, so working with them more than necessary will produce work in progress (Goldratt & Cox, 2004).

Moreover, to ensure the intended throughput is not constrained, the BN must be protected from system variations and uncertainties (Patterson, Fredendall & Craighead, 2002). A lack of protection against system variability can lead to material shortages in the BN caused by non-BN resources. This phenomenon is called constraint starvation and indicates that, although the BN is available, it cannot function due to a lack of material (Blackstone & Cox, 2002).

The reduction or elimination of BN starvation depends on two factors. With the first factor, protective capacity, capacity margins are placed on non-BN resources. With the second, protective inventory, work-in-progress inventories are used ahead of the BN (Kim, Cox & Mabin, 2010).

2.2. TOC Implementation Process

Although several studies have validated TOC-DBR as a suitable methodology for MTO environments, other research has highlighted the challenges of applying it in this rapidly evolving context. Darlington et al. (2015), Chakravorty (2001), Riezebos et al. (2003) and Modi, Lowalekar and Bhatta (2019) demonstrated that the

TOC-DBR methodology has a number of benefits when compared to others, such as improved workflow performance, reduced cycle times and reduced lead times, which directly increase revenue. Atwater and Chakravorty (2002), however, revealed major difficulties with implementing TOC-DBR in MTO environments: on the one hand, the difficulty of properly identifying the BN and, on the other hand, the difficulty of quantifying the protective capacity required by non-BN resources.

To solve these problems, Lizarralde (2020; Lizarralde et al., 2019, 2020) provided a strategic vision for the selection and exploitation of the BN. To systematise the first two stages of DBR, the researchers created a process following four phases for identifying and exploiting the BN (Figure 1).

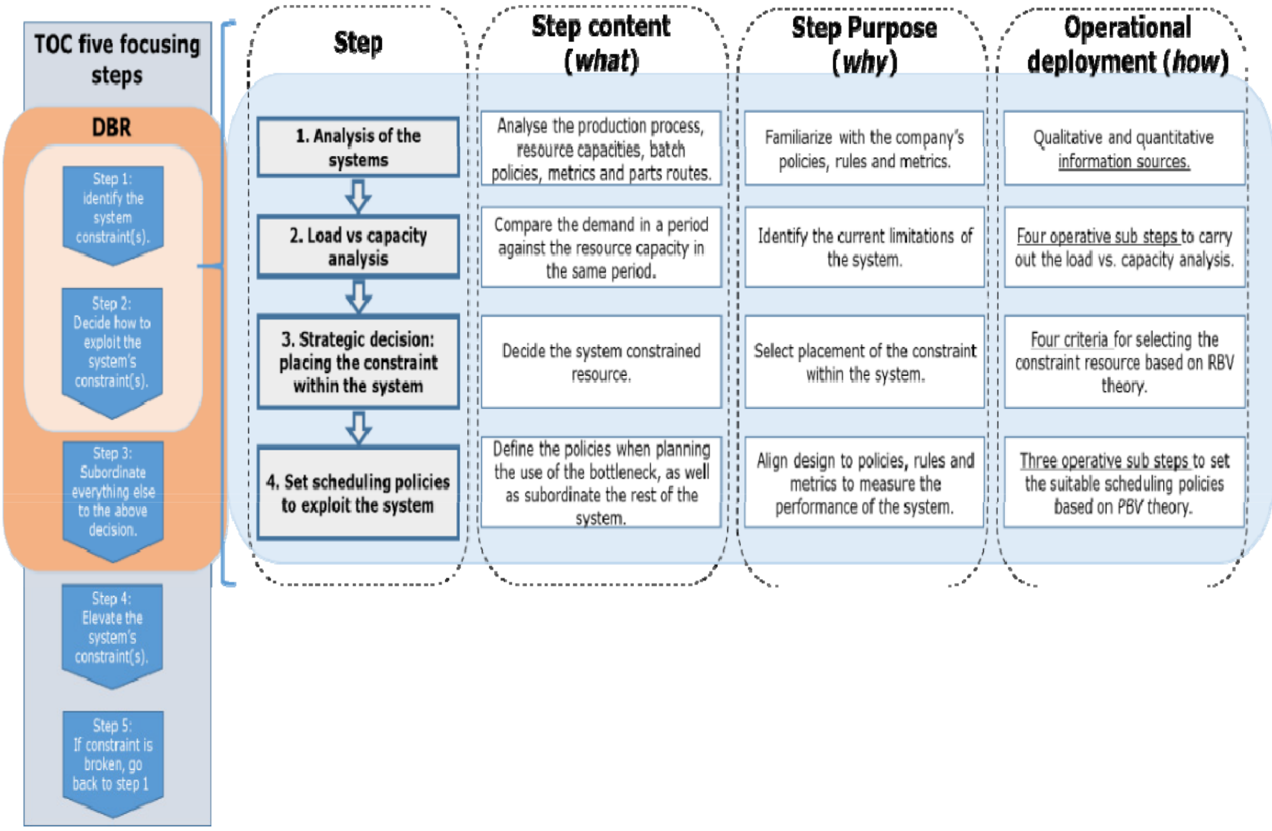

Figure 1. Systematic implementation process for steps one and two of the theory of constraints (Lizarralde et al., 2020)

Orue, Lizarralde, Amorrotu and Apaolaza (2021) then extended the systematic process proposed by Lizarralde et al. (2020) to the third step of the TOC. The researchers proposed that the systematic process for the third step should contain a design and validation phase and an execution phase to enhance operative performance (Figure 2).

The first step in the design and validation phase is the analysis of the load/capacity of the non-BN resources with respect to the BN. If the protective capacity of the non-BN resources is sufficient to eliminate BN starvation, the designed solution will be implemented. If the protective capacity is not sufficient, it will be increased until sufficient. Both BN and non-BN buffers must be defined in parallel to implement the designed solution. Once the above-mentioned solution is implemented, the lack of material in the BN will be re-analysed. If it persists, the protective capacity will be increased again until BN starvation is avoided.

Once the design phase has been validated, the implementation phase will follow. Incoming orders must be closely monitored to guarantee that the protective capacity of non-BN resources is maintained. In addition, buffers must be managed in this phase.

Taking into account the existing research work on the systematic process of implementing the TOC-DBR methodology, the next section defines the objective we set out with when conducting the study.

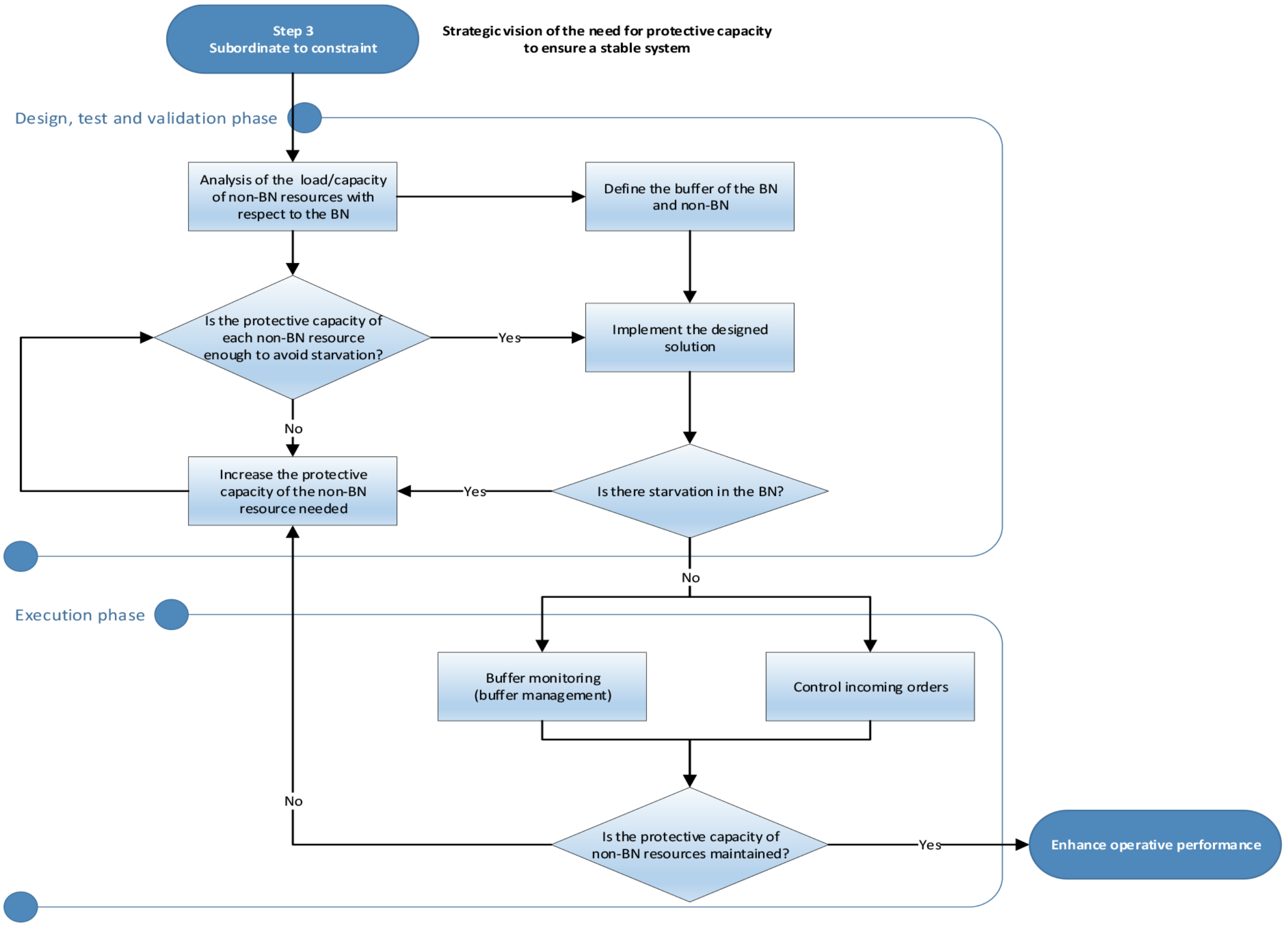

Figure 2. TOC-DBR third-step implementation process (Orue et al., 2021)

3. Objective

The aim of the study was to develop the systematic process for implementing the third step of the TOC-DBR methodology in MTO environments, complementing the work initiated by Lizarralde et al. (2020) and Orue et al. (2021). To that end, a case study methodology was applied to answer the following RQ:

RQ. How can the third step of the TOC-DBR process be systematically implemented in MTO environments to enhance performance?

4. Research Methodology

To investigate a contemporary situation in a real-life context, a case study was selected as the research methodology. We sought to uncover rich information about the particular situation to be explored by utilising a qualitative research design founded on an exploratory and descriptive approach (Robson, 2002; Yin, 2018).

A case study of a single company was selected as the unit of analysis to be investigated. In this case study, the implementation of the third step of TOC-DBR was analysed. Information was extracted through semi-structured interviews with the main actors involved in the implementation.

4.1. Case Analysis

The company in question specialises in the manufacture of tubes and is located in the Basque Country (Spain). Its workshop has several zones, such as pressing and extrusion, pipe straightening, stabilisation furnaces, surface cleaning and X-rays. The company mainly manufactures products to order in medium and low quantities, but this has not always been the case. Until a few years ago, the company produced large volumes of tubes in only a few types for customers who were stockists. Due to the large volume of inventory, it could respond to the market with an exceptional level of service. Yet, a radical change in the market in which end customers (e.g. extraction companies and refineries) replaced stockists forced the company to change strategy and migrate from MTS to MTO environments. In the new order, end customers are buying directly from them, and the orders are for many types of pipes, with few units per type.

Data collection and analysis were carried out through semi-structured interviews with four company managers and the staff member who led the implementation process. Their answers revealed that the defined policies were aimed at the local optimisation of specific areas, not at overall optimisation. All areas launched production orders as soon as possible, regardless of their priority or the availability of sufficient materials to support the workload in all zones. The reason was for this that they prioritised maximising production. Additionally, no consideration was given to the balance of orders launched in the three manufacturing routes after the BN. The results were inventory excess that was difficult to control, long lead times and poor service levels.

Lizarralde et al. (2019) designed the TOC-DBR model (Figure 3). Upon analysing the implementation of the third step, two decisions were made to support the system's optimal performance. The first decision was to increase the protective capacity in non-BN resources after the BN, to ensure it would be sufficient to produce orders on time. The second was to define decision rules to control incoming orders in the system, to enable a production order to be programmed and manufactured on time.

Taking into account that in the work carried out by Lizarralde et al. (2019) only the execution of the first two steps of the TOC-DBR methodology has been systematised and after analysing the case study, it is clear the need to design a systematic process for the execution of the third step. The following section describes the designed process.

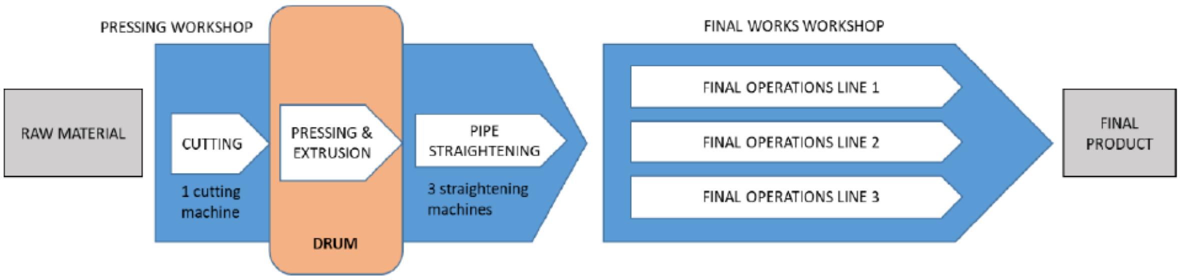

Figure 3. Theory of constraints design model (Lizarralde et al., 2019)

5. Discussion

This section will demonstrate that the research objectives were achieved unambiguously and the RQ: "How can the third step of the TOC-DBR process be systematically implemented in MTO environments to enhance performance?" was accurately answered.

To do so, the results from the presented case study were analysed, and a systematic process for implementing the third step of TOC-DBR in MTO environments was refined (Figure 4). The intention when shaping the systematic process was for the designed system to remain stable over time, ensuring its operational performance. Furthermore, continuous improvement tools were integrated to detect and solve possible problems within the system.

The demand-driven adaptive enterprise (DDAE) model was applied to develop the systematic process. DDAE is a complete management model that was developed in response to today's volatile, uncertain, complex and ambiguous (VUCA) environment (Ptak & Smith, 2018). Authors such as Apaolaza, Orue, Lizarralde and Oyarbide-Zubillaga (2022) have pointed out that for complex environments such as MTO, it is necessary to align the organisation to achieve high performance levels. They have shown that the DDAE model is a suitable guide for that purpose.

The model is composed of the operational, tactical and strategic levels of management. The DDAE approach aims to address these coherently through continuous improvement cycles of configuration, feeding and reconciliation (Ptak & Smith, 2018). Accordingly, the systematic process developed was divided into three phases–model configuration, operating model and tactical sales and operations planning (S&OP)–which are explained below.

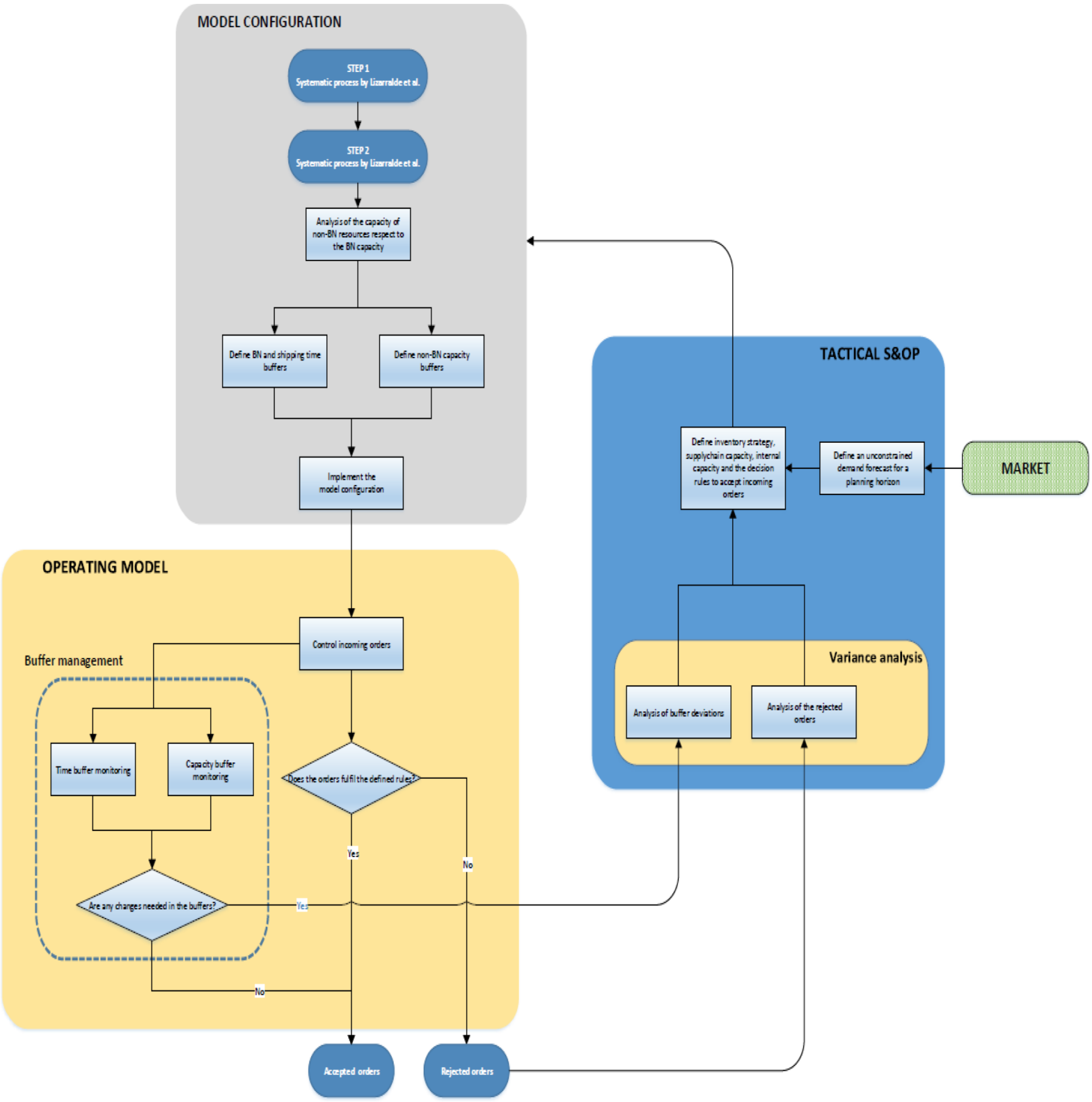

Figure 4. Systematic process for step three of the theory of constraints methodology

5.1. Model Configuration Phase

The model configuration phase concerns the steps to be followed when designing a solution for the implementation of the third step of the TOC-DBR methodology. Once the first two steps of the systematic process developed by Lizarralde et al. (2020) have been implemented, the next step is to analyse the capacity of non-BN resources and compare that with the BN capacity. To do so, the capacity of each must first be calculated.

Next, two actions with a similar description must be carried out in parallel. The BN and shipping time buffers must be defined, along with the capacity buffer of the non-BN resources. For the time buffers, necessary levels must be defined to avoid starvation in the BN. To do so, it is advisable to generate families of orders, taking into account the routes that each order follows before and after the BN. As for the capacity buffer, a similar action must be performed, defining the level of protective capacity needed in the non-BN resources to avoid starvation in the BN. It should be noted that the capacity buffer and its control are novel concepts in the TOC-DBR literature. In the DDAE model, the capacity buffer protects the control points and decoupling points from system variability. The capacity buffer can be defined as the protective capacity that provides agility and flexibility for upstream resources to match system variability (Ptak & Smith, 2018: page 72).

The third and final step of this first phase is the implementation of the designed TOC-DBR solution. Figure 5 shows the design resulting from the model configuration phase.

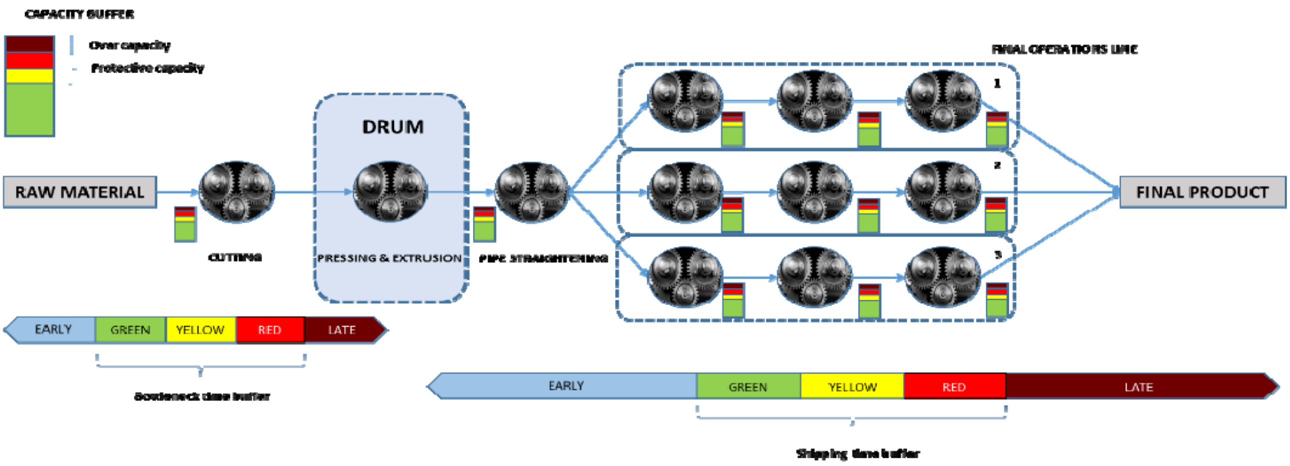

Figure 5. Case study's third-step solution design

5.2. Operating Model Phase

Once the design of the solution has been implemented, the operational model phase will follow. This phase lasts for between one week and one month, depending on the type of company and environment. In other words, the planning period for the operational part should be defined.

The first step in this phase is to control incoming orders, which involves defining rules or conditions for them to be accepted. The rules refer to the type of work that must enter the system for it to remain stable. They may include, for example, the percentage of orders that must necessarily pass through the BN and the specific weight of non-BN work with respect to the BN. Once the rules have been defined and the incoming orders have been controlled, the path is divided into two.

In the first path, the question is whether the incoming orders comply with the defined acceptance rules. If the answer is no, the order is rejected. If the answer is yes, the next steps will be to accept the order and schedule and manufacture it.

The second path requires monitoring both the BN and shipping time buffers, as well as the capacity buffer. For this monitoring, the intuitive traffic light method is used. This method is based on dividing the buffer into green, yellow and red zones. This method acts as a tool for continuous improvement of the system as it allows the buffer sizes to be improved by observing and analysing how much is consumed in each zone. For example, when considering the extremes, if more than 100% of the red zone is consumed, there will be starvation in the BN. This is a clear sign of the need to increase the buffer. On the other hand, if there is a large percentage of time in the green zone, it means the buffer is too large and can be reduced.

5.3. Tactical Sales and Operations Planning Phase

In this last phase, after analysing the implementation in the case study, we identified a need to integrate the S&OP process concepts, to link the organisation's strategic plans with the execution phase.

S&OP is a key business process of preparing an operations plan to meet the expected demand (Olhager, Rudberg & Wikner, 2001). The S&OP process typically produces plans for the next 1-18 months incorporating all procedures that connect the company's strategic objectives with the production plan, to effectively match supply (or capacity) to the market demand (Feng, D'Amours & Beauregard, 2008). In that way, S&OP aims to efficiently use the production capacity to respond effectively to the market demand in terms of cost, time and quality (Lahloua et al., 2018).

In the systematic process of implementing the third TOC-DBR step, it is necessary to consider the strategic aspects of the sales plan as well as those of the operational phase. For this purpose, and based on the continuous improvement process of the DDAE model, the deviation of the buffers and the rejected orders must be analysed. Taking into account the projection of the future demand, a strategy should be defined that follows with the inventory, supply chain, internal capacity and the decision rules for accepting production orders.

In the case of any change, return to the model configuration phase and once again analyse the bottleneck and define the buffer levels.

6. Conclusion and Future Research

Management of production plants operating in MTO environments is challenging due to the variability of the market, meaning demand cannot be accurately predicted. For this reason, choosing an appropriate production planning and control system is a key factor in ensuring optimal performance. As presented in this article, several authors have shown that the application of the TOC-DBR methodology in MTO environments can raise performance and offer a user-friendly approach. Lizarralde (2020; Lizarralde et al., 2019, 2020), developed a systematic process for implementing the first two steps of the TOC-DBR methodology for MTO environments, centring on a change in the decision-making process. Furthermore, following the work initiated by Orue et al. (2021) then proposed the necessary phases for the third step of the systematic process.

In this article, the aforementioned third step has been studied in depth through a case study, and an evolution of the systematic process for implementing the third step of the TOC-DBR methodology has been designed.

This study's three key contributions focus on the MTO environment. The first contribution is to have enriched the design of the implementation process for the third step of the TOC-DBR. The second contribution is to have introduced the demand-driven adaptive enterprise model's capacity buffer concept to the TOC-DBR methodology. Finally, the last contribution has been to propose how an organisation can integrate the S&OP process through the TOC-DBR methodology.

Future research may further explore this field and develop the process, as well as test it in other real companies, executing each of the steps defined in the process. In this way, the results obtained can be evaluated, and any possible errors may be corrected.

Declaration of Conflicting Interests

In respect to the research, authorship and/or publication of this work, the authors hereby declare that they have no potential conflicts of interest.

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