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OVERVIEW OF THE CONCEPTS OF BOTTLENECK IN THE OPERATION PROCESS

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Purpose: This paper aims to provide insight into currently available corporate operation and control management approaches through the examined articles, focusing on bottlenecks and closely related theories.
Design/methodology/approach: The reviewed publications, which focus on the theory of constraints, different approaches, the concept of bottlenecks, and the presentation of related methods, bring us closer to understanding the changes that have taken place in the past decades.
Findings: The immense impact of digitization and changes in demand affect the requests placed on companies; the way consumer needs are met has changed and accelerated, to which companies must adapt. In the case of services and products, the primary goal of manufacturers and service providers is to generate revenue and profit by satisfying consumer needs. For this, creating and maintaining an efficient operating system that does not contain restrictive elements is necessary. This publication provides a comprehensive overview of how the approach to the unified concept of the bottleneck is an effective tool for companies to improve their processes.
Research limitations/implications: The current study analyzed some of the most relevant publications in the ScienceDirect database based on the keywords. This approach certainly serves as a beginning point for the understanding that to focus on the researched problem space, a systematic literature review is required.
Originality/value: This study provides insight and supports the importance of a unified approach to identifying constraints for effective operational processes.

Keywords: operation management, operation control, bottleneck, Theory of Constraints.

Category of the paper: General review.

1. Introduction

This paper aims to provide an overview of the publications related to corporate operations and control management, with a particular emphasis on the concept of bottlenecks and theories that are closely related to it. Specifically, this article will focus on the idea of bottlenecks and theories. The Theory of Constraints, the concept of bottlenecks, and connected techniques are three of these theories vital for appreciating the alterations that have taken place over the previous few decades and the essential characteristics of the industry.

To get a more accurate view of the bottleneck mentioned above models and the closely related theories, an outline of the new challenges that Industry 4.0 poses to corporations is essential. It will be seen how Industry 4.0 requires organizations to adopt a new approach from different aspects.

The review is based on publications found in the database at sciencedirect.com. These publications reference predefined keywords rather than terms specific to the domain or field being discussed. The selection of the articles was made at random because the purpose of this paper is not to conduct a comprehensive literature review but rather provide an overview of the phenomenon that is being studied. The recent study is fundamental for further research.

Companies can accomplish their management goals by improving their manufacturing processes and their service processes, if they have a thorough understanding of the universal bottleneck and how it works, as well as a definition of the effects of this bottleneck. Undoubtedly, digitalization has had an effect, and not only has it shaped consumer demands, but it has also accelerated and altered how consumer needs are met. As is the case with goods and services, the primary objective of businesses that produce goods or provide services is to generate revenue and profit by catering to customers' requirements. To accomplish this, they will need to design an operating system that is effective and allows them to reach their management objective, which is rare to have fewer customers but rather to have more money.

The casual observation made by Karmarkar and Apte (2007) implies that the focus of research in operations was at the level of the shop floor twenty years ago. This included "process operations, scheduling, batching and buffering, flows, bottlenecks, queues, and routing" (Karmakar, Apte, 2007, p. 450). A significant number of the techniques that were created to address these issues may also be used to improve information processes. For instance, the processing of information at the level of transactions has many similarities with the processing of material. However, there are other components of information processing that are essentially distinct from one another (Karmarkar, Apte, 2007).

2. The importance of bottleneck

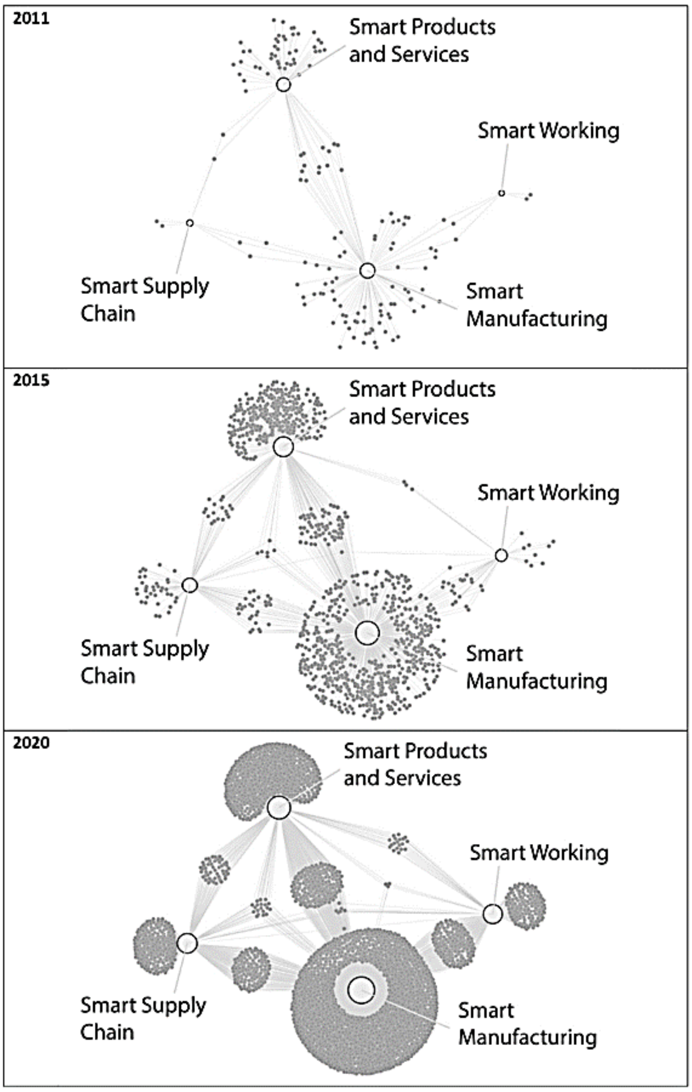
Bottlenecks hamper the performance of companies. The interpretation of bottlenecks focused mainly on the processes used in the production environment, neglecting the mechanism of reducing performance in other contexts. Understanding, defining, and examining the convention of bottlenecks in other environments can give us a more complex picture.

Providing a summary of the requirements of Industry 4.0 is essential before discussing the importance of the bottleneck and the closely related theories. According to Zhou et al. (2015), smart manufacturing is at the forefront of Industry 4.0, the fourth industrial revolution. Industry 4.0 is based on the creation of a cyber-physical system (CPS) that creates a digital and smart factory to make manufacturing more digital, information-driven, customizable and greener. Industry 4.0 aims to create a flexible manufacturing model with real-time interactions between people, goods and technology. A factory that takes customer orders manufactures and ships goods instantly would eliminate the various sales and distribution channels that would affect the current e-commerce sales paradigm. For this to proceed efficiently, decisions on the narrow cross-sections and the optimization of processes are essential. Industry 4.0 will replace old industrial production processes and will impact future manufacturing in Germany and beyond. Digital systems will make future manufacturing systems smarter.

Knowledge-based and thinking factories will increase the efficiency and competitiveness of factories. The German Electricity Association predicts that Industry 4.0 will increase industrial productivity by 30%. In the first three industrial revolutions, mechanical, electrical and information technologies were invented to improve industrial production. The first industrial revolution improved efficiency through hydropower, steam power and machine tools; the second industrial revolution brought electricity and mass production (assembly lines); the third industrial revolution accelerated automation through electronics and information technology; and now the fourth industrial revolution is emerging, spearheaded by CPS technology, which integrates the real world with the digital world (Zhou et al., 2015).

Javaid et al. (2022) argue that Industry 4.0 redefines the digital revolution with new market models, higher engineering investments, streamlined processes, shift detection/projective analysis, and expanded industry collaboration. Increasing data capture solutions enable research by incorporating modern instrumentation technologies and analyzing production processes. Physical devices may now observe energy and utility management quantities, comprehend processes and monitor applied control variables. Data, analytics, and networking drive this transformation in production and distribution. Industry 4.0 may utilize and incorporate quality into a company's technological advantages. Javaid et al. (2022) stated that Industry 4.0 technology and software might develop personalized designs digitally. Production, marking, and packing errors provide apparent dangers. Industry 4.0 technology requires tight testing and monitoring. Early manufacturing shifts used economies of scale to manufacture more of the same product. Mechanical producers must provide. Industry 4.0 promises solutions. Intelligent plants with digitally planned integrated workflows offer incredible design and manufacturing flexibility. Data collection, measurement and assessment, inventory management and quality control, and input, in-process, and completed products application techniques. The consequence is increased product uniformity and processes. Digitalizing manufacturing collaboration processes accelerates and sustains growth. Decentralization, interoperability, and virtualization help reduce errors and expenses. IoT-enabled sensors provide active data to engineers and other computers. Apps give maintenance alerts. Big Data may discover patterns, themes, and correlations using computerized analytical tools and techniques. Industry leaders want to use big data to enhance procedures (Javaid et al., 2022)

Between 2011 and March of 2020, Meindl et al. (2021) examined the development of articles that referred to the four smart dimensions, the keywords associated with each smart dimension, and the significance of various journals. Figure 1, a visualization of the network, summarizes the result that most research on Industry 4.0 focuses on smart manufacturing. Since 2011, it was discovered that the proportion of publications related to smart manufacturing has remained approximately constant at roughly 70 percent. There is a relation between smart manufacturing and other smart technologies in around 16% of the articles on smart manufacturing. (Meindl et al., 2021)



Note. The white dots represent the smart dimensions. The size of those circles represents the logarithm of the number of edges (relevant articles until the year). Each of the grey dots represents an article. The lines (edges) indicate a relation between a smart and an article (Meindl et al., 2021, p. 9).

Figure 1. Evolution of the network of articles from 2011 to 2020 (March).

Source: Meindl et al., 2021, p. 9.

Aoun et al. (2021) have also examined the foundations, challenges, barriers and constraints of Industry 4.0 and the areas where they believe that so-called blockchain technology can bring new functionality and added value to the implementation of Industry 4.0. The several approaches show that the implementation of Industry 4.0 poses several challenges for both the business sector and researchers (Aoun et al., 2021).

Based on the main features of Industry 4.0, the general application of bottlenecks to manufacturing and service providing and the importance of managing them have been outlined. According to Chatterjee et al. (2022), several definitions of bottlenecks have been formulated in the literature, which is clearly not universally applicable in manufacturing and service environments. As the authors of the paper point out, Henry Ford introduced the moving assembly line as part of his efforts to produce affordable cars, understanding that the workstation with the highest processing demand, the so-called bottleneck, limits the system's performance. The focus on bottlenecks implicitly captured the importance of capacity utilization metrics as the primary tool for management planning and control in such high-volume, low-variety environments. Identifying bottlenecks becomes complicated when moving from a high-volume, low-variety, repetitive manufacturing scenario to low-volume and project workloads. The complexity of operations has increased enormously since the days of Henry Ford. Rigid assembly lines have given way to various forms of flexible manufacturing systems. Continuous product innovation and the resulting need for product multiplication have led to increased product variety. The fact that Karmarkar and Apte (2007) made a transitory comment on the emphasis of research in operations twenty years ago suggests that the observation was made at the same level as the shop floor. "Process operations," "scheduling," "batching and buffering," "flows," "bottlenecks," and "queues" were all covered in this (Karmakar, Apte, 2007, p. 450). A sizeable portion of the solutions that were developed to solve these problems also have the potential to be used in the process of enhancing information systems. For instance, there are a lot of parallels to be drawn between the processing of material and the processing of information at the level of transactions. Nevertheless, there are more aspects of information processing that may be thought of as being fundamentally separate from one another (Culot et al., 2020; Huang et al., 2020; Karmarkar, Apte, 2007).

There is also no universally applicable bottleneck-focused approach that considers the changing manufacturing and service environment and conditions. The management science literature does not provide a bottleneck that is universally valid for all production/service scenarios, so practising managers who operate a production/service facility have an intuitive way of managing the complexity of focusing on the bottleneck.

For example, Sahin (2008), based on Goldratt's (2006) definition, stated that resources could be either bottlenecked or unconstrained resources. Goldratt (2006) interpreted a bottleneck resource as any resource with a capacity equal to or less than the demand for it and a non-constrained resource as a resource with a capacity more significant than the demand. Goldratt (2006) argues that bottlenecks will always remain bottlenecks, and therefore decision-makers must find sufficient capacity to meet the bottleneck so that it grows close to the level of demand. (Sahin, 2008)

2.1. Theory of Constraints

The lack of a universally applicable definition, i.e., a general approach focusing on bottlenecks, was partially remedied by the Theory of Constraints (TOC) proposed by Goldratt and Cox in 1984 (Chatterjee, Mukherjee, 2022; Pacheco et al., 2021).

Following Rand (2000) briefly, the Theory of Constraints is based on five steps. According to Goldratt (1984), the constraint of a system is the part of the system that constrains the purpose of the system. In the case of a money-producing organization, the main aim is for the present and for the future to make more money. In terms of production planning, the constraint on the system is the bottleneck. The first step is to identify the system's constraints; the second step is to decide how the system exploits the constraints; the third step is to subordinate everything else to the first two decisions; the fourth step is to highlight the system's constraint or constraints. Finally, in the fifth step, if a constraint has been removed in the previous steps, return to the first step, and thus prevent inertia from causing the constraint on the system (Rand, 2000).

Goldratt and Cox (1984) argue that the goal of an organization is to make more money now and, in the future, as mentioned above. To earn income, the throughput of an operating system must increase while inventory and operating costs decrease. Therefore, the performance of any system is limited by the degree of throughput at the system boundary; identifying and eliminating the system boundary as the weakest link in the chain is the main idea of TOC. As can be seen, it focuses on the continuous improvement of the system by managing the boundaries, a theory that can be applied to almost any industry and almost any size of the company. TOC has become accepted as a management philosophy and has received wide attention from practitioners and academics (Şimşit et al., 2014).

Balderstone and Mabin (1998), based on a review of published applications, argue that "TOC works very well, even with only partial application of the methodology"; and that "TOC is not a panacea, not a prescription, but a philosophy to help lead to success". (Balderstone, Mabin, 1998). Izmailov (2014) stated that the Theory of Constraints presents a new challenge to the traditional view of organizational profitability. In a wide variety of organizations and environments, its application helps to achieve goals, provided that the theory is applied according to the purpose or the necessary requirements.

Simsit et al. (2014), based on a historical evaluation of TOC over five eras, as it is shown in Figure 2, found that the Theory of Constraints had evolved into a management theory by the time of publication, both in terms of methodology and scope, whereas it was initially a production method. In parallel with the recognition of the importance of the Theory of Constraints, academics and practitioners have also recognized, and studies have begun to shift the emphasis to TOC measures, the thought process that is an essential tool of TOC. These five focusing steps are continuous improvement techniques and critical chain project management. More recent applications of TOC involve the use of the thinking process to a relatively large extent, especially in the service sector, where it is often used in the implementation of TOC. Applying the Theory of Constraints focuses largely on how top management manages human behavior in the project network and in post-project management. Rand (2000) formulated the following key messages regarding the technical aspects: avoiding milestones that are integral to project management; focusing on critical areas by identifying the critical chain, and inserting buoys at the appropriate points in the project network. The suggestion to avoid milestones is surprising, in his view, because they can cause delays in project completion. For many, it is counterintuitive. Acceptance of milestone abandonment depends on understanding the psychology of the workforce. Concern about focusing on critical areas is well established in project management, as exemplified by the critical path, so an extension to the critical chain to include activities using scarce resources is unlikely to be rejected out of hand.

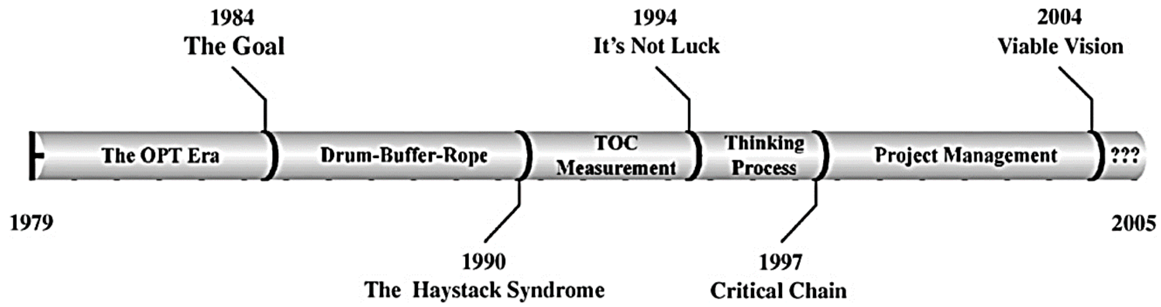


Figure 2. Timelines of major eras in the development on TOC.

Source: Watson et al., 2007; Meindl et al., 2021, p. 9.

The concept of buffers - whether project, feed, or resource - can be easily added to existing approaches, although there may be reluctance to reduce the time of activities that the use of buffers implies.

2.2. Bottleneck

According to Chatterjee et al. (2022), the term bottleneck, widely used in the operational management literature, is defined in few cases, even though practitioners are fully aware of what it means when a resource is classified as a bottleneck. Chatterjee et al. (2022) is quoted by Goldratt (1997), thought that "An hour lost at a bottleneck is an hour lost for the entire system. An hour saved at a non-bottleneck is a mirage" (Chatterjee et al., 2022, p. 3) is the essence of the concept of bottleneck, highlighting its decisive role. In the context of a production/service system, they believe that this means that the improvement of the whole ("whole system") is possible if and only if a significant part of the whole ("bottleneck") improves. All this is based on the setting of the loose conditions applied in the production or service environment.

The system theory interpretation of the bottleneck concept, the new bottleneck management, is Hinckeldeyn et al. (2014) described by system theory as the process of product design and development as the relationship between input and output, as shown in Figure 3. In their opinion, two types of inputs should be considered when dealing with bottlenecks. Input data is received in the product design and engineering process e.g., in the form of customer orders and development projects, which is the first type of input, the second type of input is engineering capacity (Hinckeldeyn et al., 2014). The psychological aspect of the workforce for the examination and understanding of processes also comes to the fore in this model, as was the case with the factors to be taken into account in rand (2000) presented above, since according to Hinckeldeyn et al. (2014), the second type of input, the capacity, comes from engineers and technicians. The combination of the first and second types of input determines the output of the process. In the case of engineering and product design processes, Hinckeldeyn et al. (2014) say the output is entered into the information needed to produce the new product. As an example, drawings, work designs and process descriptions are mentioned. In their view, this approach is intended to improve the performance of the process mentioned above or similar, as it can be used well as a control mechanism. Bottlenecks, in this case, are detected if it exceeds engineering capacity by measuring the line of work facing the engineering resource.

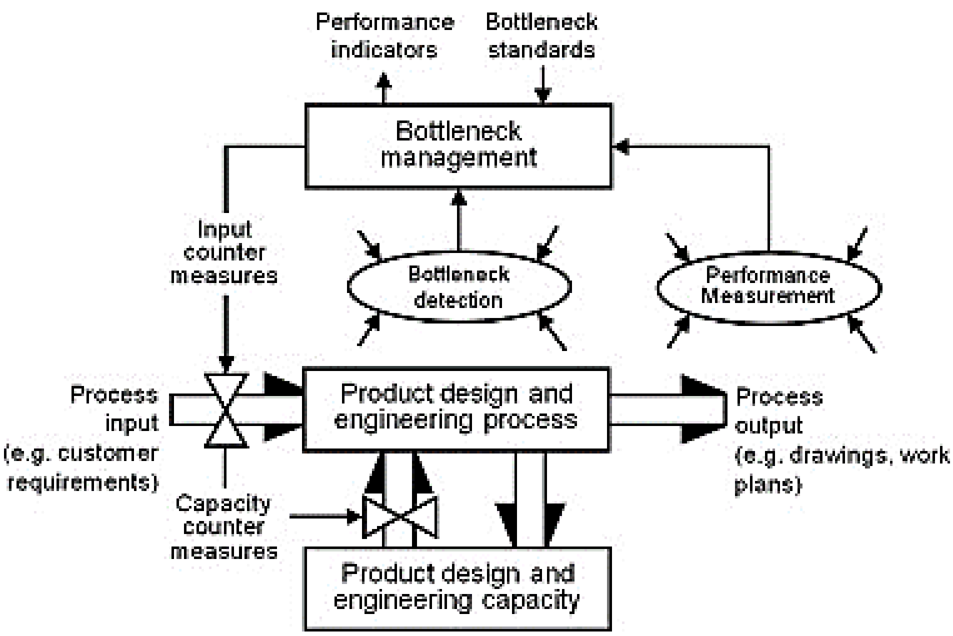


Figure 3. Bottleneck management concept for product design and engineering processes.

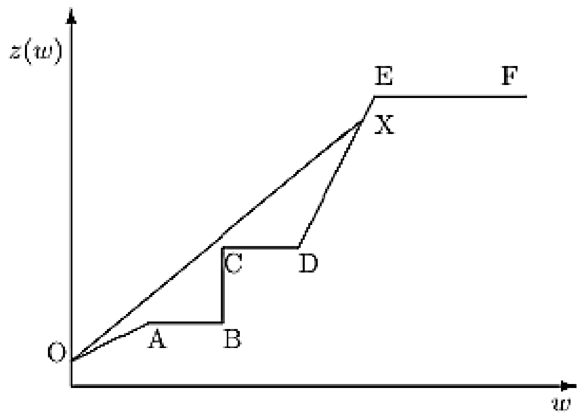
Source: Hinckeldeyn et al., 2014.

In their study, Chatterjee et al. (2022) classified bottleneck definitions into five groups based on their basic characteristics, according to whether they are capacity-based, critical route-based, structure-based, algorithm-based, or system performance-based definitions. Bottleneck definition based on system performance is considered, in a different way than that of others, giving it strict shadow price-based frameworks, applicable to various production environments such as projects, jobs, intermittent production, assembly lines and continuous flow processes.

Among the definitions they mentioned, in this case, the definition that respects the additional conditions of looseness mentioned above is mentioned, and the uniqueness of existence is guaranteed. Quoting Chatterjee et al. (2022), the widely available definition does not assume any predetermined features in the production hall that would limit its applicability, does not declare the method of capacity expansion, nor does it define the goals of decision-makers, "A set of constraints with strictly positive average shadow price is defined as bottleneck" (Chatterjee, Mukherjee, 2022).

According to Chatterjee et al. (2022), this universal bottleneck definition means that the bottleneck may consist of a single constraint or a collection of constraints that together constitute the resource. Following Chatterjee et al. (2022), i.e., in a time-indexed formulation of a scheduling problem, the set of constraints that determine the availability of a resource for each time slice may be a bottleneck.

Mukherjee and Chatterjee (2006) agree that before Kim and Cho (1988), there was no valid public interpretation of the concept of average shadow price, as illustrated in Figure 4, for economic integer programming.



Note. In Figure 1, O−A−B−C−D−E−F is the piecewise linear curve obtained by plotting the objective function value zk(w) as w increases. Let X be any point on this curve. The average shadow price ASPCk is then the maximum gradient of the straight line OX (Mukherjee, Chatterjee, 2006, p. 14).

Figure 4. Graphical representation of Average Shadow Price.

Source: Mukherjee, Chatterjee, 2006; Meindl et al., 2021, p. 9.

The inclusion of the average shadow price in the definition of bottleneck provides an opportunity to apply in addition to the service sector and extend the usage of it widespread as manufacturing processes.

Based on this literature processing, there is a clear need for a universally usable framework and its elements to help operating managers make decisions in line with company goals. At the same time, it is crucial to highlight the factor and resource that has been revealed in connection with the research, and that is the human factor in the processes, the approach of which the approach to psychology will not reflect reality only on the assumption of an economic, rational approach. According to Herbert Simon (1987) used the theory of bounded rationality to establish for economists and economic professionals a shift in the view that ignoring human factors distorts models and is, therefore, less useful in practice (Campitelli, Gobet, 2010; Kuo et al., 2021; Simon, 1984).

3. Conclusion

The fourth industrial revolution, also known as Industry 4.0, redefines the digital revolution by introducing new market models, enhanced engineering inputs, faster processes, and shift detection and predictive analysis. The collection of data will become easier thanks to technological advances and the operations of modern industry. Energy, utilities, and process control are all monitored by various physical instruments. Data, analytics, and networking are revolutionizing the production and distribution processes. In the age of Industry 4.0, quality can be a competitive advantage for a company. Software developed with Industry 4.0 can reportedly create digitally customized designs, as Javaid et al. (2022) stated. Errors in manufacturing, labelling, and packaging can put consumers in danger. The scale was the primary factor in early industrial shifts that increased productivity. Smart factories have digitally connected processes, which allows for more remarkable design and manufacturing flexibility. Applications include data collecting, measurement, assessment, inventory management, quality control, and applications for the input, in-process, and finished product. Both the process and the product's consistency are getting better. The process of digitizing manufacturing contributes to economic expansion. Errors and costs can be cut by reducing centralization, increasing interoperability, and adopting virtualization. The leaders of this industry feel that big data has the potential to improve operations, but in order for this to happen, its decision-makers need to be aware of the bottlenecks that exist in the production processes of both goods and services.

In the manufacturing context, bottlenecks were primarily interpreted in terms of the processes that were carried out there, and the mechanism of lowering performance was neglected. A complete picture may be obtained by first comprehending, defining, and then examining the bottleneck convention in various settings. Henry Ford is credited with the invention of the moving assembly line. He did it with the knowledge that the workstation restricts the system's performance with the highest processing demand. This workstation is referred to as the "bottleneck." The idea behind the TOC is to locate and remove the system boundary that constitutes the chain's weakest link. This is the fundamental notion behind TOC.

Implementing the theory in the right circumstances makes it possible to achieve goals in diverse contexts, such as inside businesses and geographical areas, provided that it is applied suitably. The behavior of individuals who are participating in the project network and post-project management can be governed by using the aspect of the Theory of Constraints that is observed the most frequently. The thinking process is commonly utilized in TOC implementation, and more contemporary TOC programs use this process extensively, particularly in the service business. This holds especially true when considering the TOC implementation process. Despite the high likelihood of this outcome, extending the critical chain to include activities that call for limited resources is unlikely to be denied. The term "bottleneck," which only has a defined meaning in a select number of specific settings, is frequently utilized in the written material of operational management.

According to Hinckeldeyn et al. (2014), the outcome of the engineering and product design processes is included in the information required to construct the new product. In this scenario, bottlenecks are found when the volume of work the engineering resource must complete exceeds the capacity of the engineering resource. The research conducted by Chatterjee and colleagues in 2022 classified bottleneck definitions into five distinct groups according to the essential qualities shared by each. The definition of a bottleneck, based on the system's performance, is considered differently from the other purposes of the bottleneck. It makes it possible to create rigorous price-based frameworks that may be applied to projects, tasks, intermittent production, assembly lines, and processes with continuous flow. The utilization of the service in industries other than manufacturing is now a distinct possibility due to the inclusion of the average shadow price in the definition of the bottleneck.

Limitations: Based on the keywords, the present research partially reviewed the most relevant publications in the ScienceDirect database. This method undoubtedly represents a starting point that a systematic literature review is necessary to narrow down the examined problem area.

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