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PROCESS CYCLE TIME AS A BASE OF CONSTRAINT IDENTIFICATION IN TOC APPLICATION TO A PRINTING PRODUCTION SYSTEM

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Purpose: The purpose of the article is to locate a bottleneck in a printing production system.
Design/methodology/approach: The study is conducted through a case study utilizing bottleneck detection methods based on processes cycle times.
Findings: The study conducted reveals the problem that finding a bottleneck is not a simple task, and the methods used may point to another bottleneck. The study implies that not every method used identified the same process as the bottleneck of the production system under study.
Research limitations/implications: The study describes a case of a single manufacturing company from the printing industry. The results of the research should be regarded as a pilot study.
Practical implications: The results of the survey are of particular importance to managers in charge of production management, providing valuable insights and pointing out areas that require special attention and monitoring.
Originality/value: In the TOC, the first step is to identify the bottleneck. The study shows that identifying a bottleneck in a production process is not an easy task. Different methods may indicate different bottlenecks.

Keywords: bottleneck identification, Cycle Time, Theory of Constraints, TOC.

Category of the paper: Research paper, Technical paper.

1. Introduction

Identification and management of bottlenecks is a key component of Theory of Constraints (TOC) and is the main objective of implementing the approach in practice. A bottleneck refers to a constraint that is a major obstacle to the operation of a fully efficient system. This means that the work rate of this constraint is lower than the work rate of the other processes in production (Goldratt, Cox, 1992). Bottlenecks are the cause of reduced capacity and throughput of the production system, resulting in, among other things, downtime, built-up inventories, and, above all, reduced productivity of the system as a whole (Urban, Rogowska, 2018).

According to Goldratt, every process has at least one constraint that blocks its full throughput, and improvements should be focused only on that constraint, not on other parts of the process. The creator of TOC has documented his ideas and illustrated their application in many novels such as *The Goal* (Goldratt, Cox, 1984, 1992), *It's Not Luck* (Goldratt, 1994), *Critical Chain* (Goldratt, 1997). On the other hand, a description of the concept itself can be found in books such as *The Haystack Syndrome: Sifting Information from the Data Ocean?* (Goldratt, 1990), *Goldratt's Theory of Constraints: A systems Approach to Continuous Improvement* (Dettmer, 2007) and *Theory of constraints handbook* (Cox and Schleier, 2010). Despite the availability of many literature items related to the application of TOC, there is a need for empirical studies on the issue of practical implementation of this concept in production systems (Urban, 2019). Bottleneck analysis is of high interest in manufacturing operations and in recent years a great deal of research has focused on the area of bottleneck identification (Sims, Wan, 2017; Prasetyaningsih, Deferinanda, 2019; Chen et al., 2021).

The research purpose of this article is to apply selected methods for identifying bottlenecks based on processes cycle times. The study was conducted using the case study method. The object of the study is a printing production system characterized by product diversity, i.e. assortment variability has a major impact on the flow of products through the production system.

2. Theory of Constraints as basis of manufacturing system management

TOC called in practice constraint management is one of the tools designed to support the production manager's continuous decision-making. Israeli physicist Eliyahu Moshe Goldratt is believed to be its creator (Wojakowski, 2015). The origin of the concept dates back to the 1970s, when Goldratt and his team developed a production planning and control system, initially called Optimized Production Timetable (Mabin, Balderstone, 2003). The concept has been gaining many supporters since it was developed. Its holistic approach is based on the idea that an organization should be viewed as an interconnected system, rather than a collection of separate parts. TOC seeks to optimize the performance of the entire system, not just individual parts or processes. According to Goldratt, the real goal of TOC implementation is not to make more money, but to attitude the organization up for continuous improvement and transform it into a constantly evolving entity (Barnard, Immelman, 2010). Application of the concept in industry translates into significant improvements in efficiency and productivity by identifying and eliminating constraints in production. Goldratt bases his theory on three main assumptions:

1. The existence of constraints.
2. The need to identify them.
3. The need to eliminate them through continuous improvement.

TOC's basic continuous improvement cycle (in the literature, known as Five Focusing Steps) is based on five steps (Yu et al., 2022):

1. Identify the bottleneck namely place or process that limits the throughput of the entire process.
2. Exploit the identified bottleneck that is decide how to increase its throughput, without major expensive upgrades or changes.
3. Subordinate to the decision made in step 2, that is, to adjust the work rate of the remaining resources to the work rate of the constraint.
4. Elevate the bottleneck namely increase its capacity.
5. Observe if the bottleneck has been eliminated and return to step one.

Despite its simple, straightforward approach, it is not an easy tool to use especially in complex production systems. Many implementation obstacles can be encountered during the practical application of TOC to a production system. Identifying the bottleneck is the first and most important step. If the bottleneck is not identified, it will be difficult to increase the efficiency and profitability of the company. It is important to find the actual bottleneck, not its symptoms, in order to effectively and permanently solve the problem. Without identifying the real bottleneck, the actions taken by the company may be ineffective or temporary. Identifying the bottleneck is a key and important issue in research related to the production system (Urban, Rogowska, 2020). A number of methods for identifying bottlenecks can be found in the literature. This article focuses on three bottleneck detection methods. The first is a cycle time-based method of determining how long it takes to produce a unit of product in a given production process. To do this, measure the duration of each process and compare it to the duration of other processes. Another method is cycle time taking into account production losses, i.e., any delays that prolong the processing of a production batch, such as preparing a machine or production line to produce a specific product, machine stops or breakdowns (Yu, Matta, 2016). The last method is cycle time corrected by process engagement in production of the product range. As the name suggests, cycle time and the individual engagement of each process in production product range should be examined, and the product of these values will indicate the actual time required to produce the product. This approach is aimed at obtaining a more precise assessment of the time required to process a unit of product and its impact on the entire production system (Urban, 2019).

3. Research Method

The article presents the practical application of bottleneck identification methods based on processes cycle times founded on a case study in a printing production system. A case study is a qualitative method of carefully analyzing a single case or series of cases, and can be conducted by a single researcher or a research team. The purpose of this method is to learn the details and circumstances of a case and draw conclusions, as well as implications for further research or practice. The case study uses a variety of data sources to provide a complete and comprehensive picture of a case. In this way, you can study the problem from different perspectives and get a lot of information to make a more precise analysis and get reliable results (Creswell, 2007). An important element of the case study is the research questions, which allow to focus on the key issues related to the case under study. In this paper asks the following question: Will each bottleneck identification method used identify the same process as the bottleneck? Several data sources were used to analyze the case studied, namely: direct observation of the production process, analysis of material flow and historical data, direct interviews with production managers, and participatory observation. The company's historical data represented cognitive material, and the data contained therein enabled detailed analysis. The use of cycle time-based bottleneck identification methods is presented in the following sections of the study.

4. Investigated Manufacturing System

The company under investigation is a manufacturer of specialized printed packaging. The products are designed for the food, medical and healthcare industries. The production system is organized as batch production. This means that packaging is produced in large quantities based on the same design, with uniform quality and dimensions. The company works three shifts, five days a week. Figure 1 presents the stages of the production process.

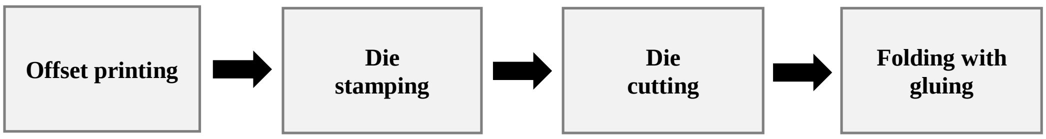

Figure 1. Production process analyzed.

Source: own elaboration.

The production process for printed packaging consists of four stages:

1. offset printing, which involves transferring ink from the print master to the surface of the package,
2. die stamping foil using the hot-stamping method, which involves heating and transferring paint from the foil to the surface of the substrate,
3. die cutting, which is the cutting of shapes from a sheet of paper using a special embossing form called a die-cutter,
4. folding with gluing is an automatic process of folding layers of material in a certain direction and shape, and then gluing the layers of material to each other with an adhesive so that they form a package.

All of the manufacturing processes mentioned use advanced technologies. The production system under study is characterized by low batch repeatability, short orders and long changeover times. An additional characteristic is the lack of continuity of the product flow through the production process. This means that the product can, but in most cases does not always include all the previously mentioned manufacturing processes.

5. Bottleneck Identification

A bottleneck is a place in a production process where there is a throughput constraint and is the main reason for slowing down the flow of the entire process. The following are the results of identifying the bottleneck of the production system under study using selected identification methods founded on processes cycle times.

Cycle Time of a process (C/T)

The first method used to identify the bottleneck is the cycle time of each process. Due to the high speed of the machines in the production system under study, actual C/T measurement is not possible. Therefore, in order to determine C/T, the data of each process was analyzed, i.e. production time and the number of products produced (volume) in a typical one month. Table 1 shows the C/Ts of the three manufacturing processes.

Table 1.
Cycle Times of processes

Process	Volume [printing sheet]	Production time [hr.]	Cycle time [sec]
Offset printing	5 832 065	483	0,3
Die stamping	2 648 156	836	1,14
Die cutting	5 810 595	1048	0,65

Source: own elaboration based on company data.

When analyzing the data of the fourth process, which is folding with gluing, an obstacle was encountered regarding the unit in which the process is expressed. The company surveyed expresses the offset printing, die stamping and die cutting process in printing sheets, while the folding process with gluing is expressed in smaller parts so-called final items. The final item is several times smaller than the printing sheet used, so several final items will be printed simultaneously on one sheet. The problem of product multiplication can occur in many manufacturing systems. The C/T method of processes does not take into account the problem described earlier in view of this, an adjustment is needed to remove this obstacle. In order to identify the bottleneck by means of C/T of the processes in the production process under study, it is necessary to assume the same unit in all processes, i.e. the printing sheet. The following is a calculations to determine the common unit. In the first step, C/T expressed on final item was calculated.

C/T on final item

In order to determine C/T on final item, the company's data (process volume and production time) was analyzed considering the same time horizon (one typical month). The results of the analysis are presented in Table 2.

Table 2
Cycle Times of process on one final item

Process	Volume [final item]	Production time [hr.]	Cycle time [sec]
Folding with gluing	37 540 000	1034	0,1

Source: own elaboration based on company data.

Analyzing the data in Table 2, the C/T of the folding with gluing process expressed for one final item is 0.1 seconds. However, before attempting to solve the problem of product multiplication, i.e., expressing each process in a unit of printing sheet, a certain assumption must be made. An analysis of the surveyed company's orders showed that 90% of the output of the die cutting process goes to the next process, which is folding with gluing. The remaining 10% of products in flat form reach the customer. Making this assumption will make it possible to calculate the average number of final items per one printing sheet, which will consequently make it possible to determine the C/T of the folding process with gluing in the same unit as the other processes. The results of the analysis are presented in Table 3.

Table 3
Determination of the cycle time of the folding with gluing process

90% of the monthly output of the die-cutting process [printing sheet]	5 229 535
Monthly output of folding and gluing process [final item]	37 540 000
Average number of final items per printing sheet	8
Cycle time of the folding with gluing process [sec]	0,8

Source: own elaboration based on company data.

Table 3 shows that on average there are 8 final items per printing sheet. Then, the C/T of the folding with gluing process expressed per printing sheet is 0.8 seconds (8 final items x 0.1 sec.). Analyzing the C/T of all production processes (Table 1 and Table 3), it should be noted that these values vary, which means that the performance of each process is different. Figure 2 shows the hourly productivity of each production process calculated from the obtained C/T values of the processes.

As shown in Figure 2, the most efficient process is offset printing, while the lowest efficiency has the die stamping process. This process limits the capacity of the entire production system therefore it can be considered a bottleneck.

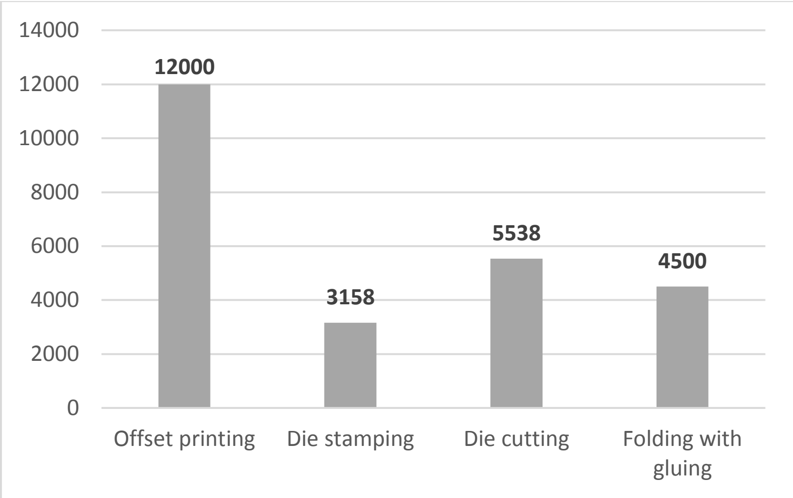

Figure 2. Hourly productivity of production processes [printing sheet/hour].

Source: own elaboration based on company data.

C/T taking into account production losses

Manufacturing companies face casual shutdowns or lengthy changeovers during production. Each casual workstation stoppage causes losses for the company. Therefore, in order to identify the bottleneck in the production system under study, another method was used, which is the determination of C/T taking into account production losses. Production losses should be understood as lost opportunities to produce products, such as machine or process waits, as well as the inability to produce a product due to breakdowns, changeovers or casual downtime. Accounting for production losses to the C/T value of processes is an important element that affects the final result. Table 4 shows the identified production losses of production processes that occurred in the month under review.

Analyzing the company's data, seven production losses were identified, i.e. products not meeting quality standards, changeover time, machine cleaning, machine technical failure, waiting for the graphic department, waiting for approval and input material issues. However, as Table 4 shows, not all production losses occur in every manufacturing process.

Table 4.
Production losses occurring in processes

Production losses	Process			
	Offset printing	Die stamping	Die cutting	Folding with gluing
	[hr.]			
Products not meeting quality standards	5	0,2	1	8
Changeover time	695	190	897	841
Machine cleaning	130,5	6,5	20,5	186
Machine technical failure	48,5	2	21,5	16
Waiting for the graphic department	28	-	-	-
Waiting for approval	18	0,3	0,3	-
Input material issues	40	0,2	0,2	-
Total	965	199,2	940,5	1051

Source: own elaboration based on company data.

Waiting for the graphics department only occurs in the offset printing. Whereas, waiting for approval and problems with the product at the process input do not occur in the folding with gluing process. The Table 4 shows, that in a typical month, the largest share of production loss time occurs in the folding with gluing process (1051 hr.), and the smallest in the die stamping process (199.2 hr.).

With knowledge of production time, production loss time and number of products of each process produced (volume), it is possible to calculate the C/T taking into account production losses. The resulting C/T values are presented in Table 5.

Table 5.
Process cycle time taking into production losses

Process	Production time [hr.]	Production losses [hr.]	Volume [printing sheet]	C/T with over time of production losses [sec]
Offset printing	483	965	5 832 065	0,89
Die stamping	836	199,2	2 648 156	1,40
Die cutting	1048	940,5	5 810 595	1,23
Folding with gluing	1034	1051	5 229 535	1,44

Source: own elaboration based on company data.

Analyzing the data in Table 5, it can be seen that the C/T values of all processes that take into account production loss time differ from each other, and their values are greater than the C/T obtained by the previous method. Figure 3 shows the hourly productivity of each production process taking into account the new C/T values of processes.

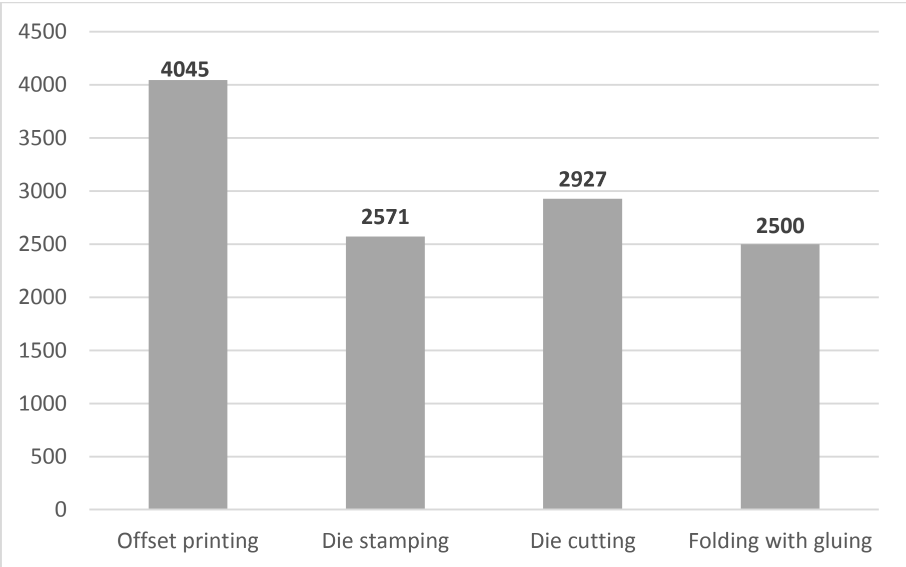

Figure 3. Hourly productivity of production processes including production loss time [printing sheet/hour].

Source: own elaboration based on company data.

According to the data presented in Figure 3, the offset printing process has the highest hourly productivity, while the folding with gluing process has the lowest productivity (and not the die stamping process as shown in the previous bottleneck identification method). This process should be considered the bottleneck of the production system under study.

C/T corrected by process engagement in production

A characteristic feature of the production system under study is the wide variety of products offered. Depending on the customer's requirements and the specifics of the order, the manufactured products cover the company's production processes to varying degrees. The lack of continuity of the product flow through the production process leads to different engagement of individual production processes. For such characteristics of the production system under study, the corrected C/T method developed by Urban (2019) was used to identify the bottleneck. To calculate process engagement, the volume of products produced on each process is compared with the total number of products produced, which is derived from production orders. Table 1 and Table 3 show the C/T values of the processes, which are adjusted using the engagement of each process. The obtained results of the corrected C/T are presented in Table 6.

Table 6.
Process engagement and corrected cycle time

Process	Engagement	Corrected C/T [sec.]
Offset printing	100%	0,3
Die stamping	60%	0,68
Die cutting	100%	0,65
Folding with gluing	90%	0,72

Source: own elaboration based on company data.

Analysis of the data in Table 6 shows that the offset printing and die cutting processes are fully involved in the production of all manufactured products. The other processes are involved with varying degrees of intensity. The individual engagement of each process makes it possible to calculate the corrected C/T. For example, the die stamping process is engagement in 60% of the volume of the total production. Since the actual C/T is 1.14 sec (see Table 1), the corrected C/T value is equal to 0.68 sec. According to Urban (2019), the corrected C/T value symbolically reflects the time it takes to produce a product that serializes through all processes. Figure 4 shows the hourly productivity of each production process calculated from the resulting corrected C/T values of the processes.

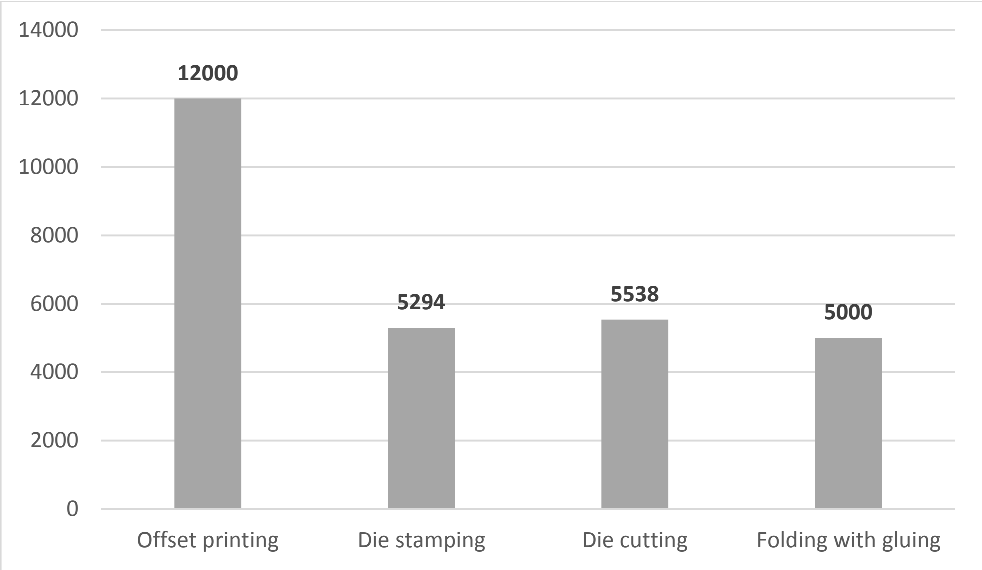

Figure 4. Hourly productivity of production processes with corrected C/T [printing sheet/hour].
Source: own elaboration based on company data.

According to the data presented in Figure 4, the highest hourly productivity is from the offset printing process. On the other hand, the most important information from Figure 4 is the hourly productivity of the folding with gluing process, which is the lowest compared to the other production processes, so this process should be considered the bottleneck of the production system under study.

6. Discussion

In TOC, identifying the bottleneck is the first step seeking to improve the production system. This is a crucial step because it is at this stage that the actual bottleneck should be found. Focusing on other constraints will not achieve the desired result of increasing the throughput of the entire production system. Consequently, failure to identify the true bottleneck can lead to inefficient operations and investments, as well as the persistence of constraints in the production system. There are many bottleneck identifying methods in the literature. The article focuses on three selected methods, namely: Cycle Time of a process (C/T), C/T taking into account production losses and C/T corrected by process engagement in production of the entire range. The first C/T based method used indicated that the bottleneck was the die stamping process. Further calculations showed that the real bottleneck of the system under study is another process, specifically the folding with gluing process. The production system under study is characterized by a wide variety of products, as well as uneven process engagement in the production stream. Comparing the hourly productivity of production processes calculated on the basis of C/T is not a correct approach for such characteristics of the production system, in which the product stream does not flow through all processes. The C/T method's indication of other bottleneck (than the other two methods) may be due to the fact that it only considers the direct execution time of the process, and does not take into account other important factors affecting production efficiency, for example, changeover time, waiting time, failures that occur, or the engagement of processes in the production of the entire range. In order to identify the bottleneck, it is necessary to consider additional factors affecting the process and analyze the characteristics of the production system under study. The case study conducted shows that the first step of TOC, i.e. identifying constraints, is not a simple task. This step should be considered important, requiring further research and the determination of practical guidelines.

7. Conclusions

TOC is used in many manufacturing companies. According to Goldratt, every enterprise has at least one bottleneck that effectively limits the use of its full potential. The study was conducted using the case study method. This allowed for a deeper understanding and analysis of the problem of identifying the bottleneck. Referring to the practical use of TOC, specifically its first step, a bottleneck was identified that determines the capabilities of the entire production system. In the case studied, the bottleneck is the folding with gluing process. Three selected methods based on C/T of the processes were used to detect the bottleneck. The study shows that identifying the bottleneck is not a simple and obvious task. There are a number of methods available in the literature that can be used at this stage. However, not every method can pinpoint the same bottleneck. Therefore, it is important to individual approach to determine the specifics and circumstances of the production system. In summary, the first course of action should be to study how the production system under study actually works and what factors affect it. Then, in order to identify the bottleneck, a suitable method should be selected that takes into account the characteristics of the production system in question. In the case under review, the C/T method of processes was not the correct solution, as this method does not take into account a number of factors affecting the production system under study.

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