

INTEGRATING THE THEORY OF CONSTRAINTS AND A FLOW BALANCING APPROACH INTO INTRALOGISTICS OPERATIONS

Anna LEWANDOWSKA-CISZEK^{1*}, Sylwia KONECKA², Cyryl LESZCZYŃSKI³,
Piotr SZCZYPA⁴

¹ Department of Logistics, Poznań University of Economics and Business;
anna.lewandowska-ciszek@ue.poznan.pl, ORCID: 0000-0001-7246-8866

² Department of Logistics, Poznań University of Economics and Business; sylwia.konecka@ue.poznan.pl,
ORCID: 0000-0001-9283-7059

³ Department of Information Technology, Poznań University of Economics and Business;
cyryl.leszczynski@ue.poznan.pl, ORCID: 0009-0000-2234-796X

⁴ The College of Economics and Social Sciences, Warsaw University of Technology; piotr.szczyapa@pw.edu.pl,
ORCID: 0000-0002-3981-8147

* Correspondence author

Purpose: The aim of this paper is to improve intralogistics efficiency by identifying and eliminating constraints in a medical device sterilization process. The study applies the Theory of Constraints (TOC) and flow balancing to address a real-world bottleneck in healthcare production.

Design/methodology/approach: A single case study was conducted in a sterilization unit handling medical device trays. The TOC Five Focusing Steps were used to identify and resolve the main constraint. Performance indicators were analyzed, and process observation, time measurement, as well as equipment redesign supported the flow-balancing approach in reducing inefficiencies.

Findings: The unloading station emerged as the main constraint. Improvements such as redesigning the tray-handling robot, optimizing buffer usage, and enhancing gripper capacity reduced cycle times and increased throughput. Eliminating delays and improving synchronization across process stages enhanced flow efficiency, shortened waiting times, and improved resource utilization.

Research limitations/implications: As the study is limited to one sterilization unit and organizational context, results may not be directly generalizable. Further research should include multi-case studies and longitudinal analysis to test long-term sustainability and broader applicability.

Practical implications: The study shows how TOC can effectively identify bottlenecks and improve intralogistics performance. Similar methods can help organizations unlock hidden capacity, reduce waste, and synchronize flow without major investments. These improvements strengthen resilience and support demanding production targets in regulated healthcare environments.

Social implications: By improving efficiency and reliability in sterilization processes, the study indirectly contributes to patient safety and healthcare quality. Enhanced flow also promotes responsible resource use and supports broader sustainability goals.

Originality/value: This paper demonstrates the integration of TOC and flow balancing in a real-world healthcare production context. It offers a structured approach to intralogistics challenges and provides actionable insights for production engineers, healthcare logistics managers, and continuous improvement specialists.

Keywords: robotization of logistics processes, waste, Theory of Constraints (TOC), flow balancing, cycle time, organizational improvement.

Category of the paper: Case study.

1. Introduction

In today's business environment, companies must go beyond offering basic products by carefully identifying and addressing unspoken customer needs, providing strong value propositions, supporting and valuing their employees, reducing their environmental footprint, and continually improving production processes and overall efficiency. A consistent focus on improvement is essential for maintaining long-term success, which constitutes the primary objective of any enterprise (Hamrol, 2018). However, achieving this success necessitates the systematic identification and resolution of factors that constrain a system's performance. Within a business context, such a limiting factor is termed a constraint - any element that hinders the system from attaining its optimal operational capacity (Goldratt, Cox, 2016).

This study investigates disruptions affecting the Medical Device Tray Handler during sterilization. Utilizing a focused case study to analyze the real-world process flow and applying the Theory of Constraints (TOC), the research aims to identify opportunities for process improvement to enhance efficiency, reduce waste, and pinpoint the system's bottleneck for targeted improvements based on TOC principles.

The chosen approach enables a detailed analysis of the material flow within a sterilization unit and supports the identification of mechanisms that generate inefficiencies.

Accordingly, the study is guided by the following research questions:

- RQ1: What is the primary constraint that limits the efficiency of the medical device sterilization process?
- RQ2: How can the Theory of Constraints and flow balancing be applied to mitigate this constraint and improve system throughput?
- RQ3: What practical lessons can be derived from this case that may be transferable to other intralogistics contexts?

The novelty of this research lies in integrating the Theory of Constraints with a flow-balancing approach in the context of medical device sterilization, an area where such applications remain underexplored. The results contribute to the ongoing discussion on how intralogistics processes in healthcare can be optimized without major capital investment, thereby offering both theoretical and practical significance.

2. Literature review

E.M. Goldratt, a visionary management expert, conceptualized the Theory of Constraints (TOC) in his influential book, 'The Goal: Excellence In Manufacturing', published in 1984. This pioneering work established the fundamental principles and practices of TOC, providing a comprehensive framework for enhancing production management (Trojanowska, Dostatni, 2017).

The Theory of Constraints (TOC) emerged from an earlier methodology known as OPT (Optimized Production Technology) (Rogowska, 2023). Originally, OPT aimed to improve performance in production systems by identifying and managing bottlenecks. As the approach developed, TOC expanded its applications beyond manufacturing, evolving into a systems-oriented management philosophy.

Over time, TOC came to be applied in fields such as project management (through the Critical Chain method), logistics, sales, marketing, strategic planning, and organizational change (Ikeziri et al., 2019; Knop, 2024). Key developments included the articulation of the Five Focusing Steps for continuous improvement and the introduction of TOC's logical thinking processes for problem analysis and decision-making (Cyplik et al., 2012; Kosieradzka et al., 2022). Thus, TOC evolved from a production optimization tool into a comprehensive management philosophy focused on systematically identifying and eliminating constraints to maximize value flow across the entire organization (Bilinovics-Sipos, Reicher, 2023; Lewandowska-Ciszek et al., 2024; Mabin, Balderstone, 2003; Tokarski, Łuczak, 2023).

Organizational structures generally comprise networks of interdependent elements, often likened to interconnected chains. Consequently, similar to a chain, the overall strength of a system is determined by its weakest link, commonly referred to as the bottleneck. In response to this dynamic, the Theory of Constraints (TOC) is centered on the identification, management, and elimination of such limitations by aligning the flow of materials, products, information, and human resources with the system's overall capacity (Hamrol et al., 2015; Moore, Scheinkopf, 1998).

Building on this foundation, a core principle of TOC posits that efforts should be directed towards the point of greatest leverage within the system. Notably, this critical point is not necessarily confined to a single, specific area; rather, it may encompass any factor that significantly influences the constraint (Lewandowska-Ciszek, 2018). Therefore, a comprehensive understanding of the system's interdependencies is crucial for effectively enhancing performance and achieving sustained success (Lewandowska-Ciszek, 2022, 2025b).

The Theory of Constraints utilizes the Five Focusing Steps (Figure 1), a systematic methodology that involves: identifying the primary bottleneck; determining the optimal way to leverage this constraint; aligning all other processes with this decision; improving the capacity of the constraint; and iteratively restarting the process if the constraint is no longer the limiting

factor (Ashlag, 2014; Bicheno, Holweg, 2016; Corbett, 1998; Goldratt, 2003; Hadaś et al., 2012; Koliński et al., 2010; Lewandowska-Ciszek, 2025a; Moore, Scheinkopf, 1998; Trojanowska et al., 2011, 2017; Trojanowska, Dostatni, 2017; Trojanowska, Pająk, 2010; Woepfel, 2000).

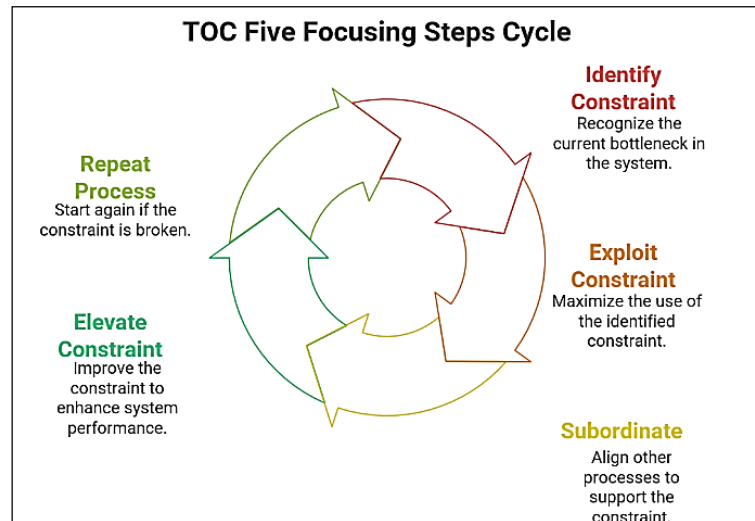


Figure 1. TOC Five Focusing Steps Cycle.

TOC was applied across diverse industries, including aerospace, semiconductors, furniture, and automotive. Most implementations were partial, targeting specific production processes or bottlenecks (Panizzolo, 2016).

The Theory of Constraints (TOC) significantly enhances manufacturing efficiency by systematically identifying and resolving process bottlenecks, leading to substantial reductions in lead times and inventory, as well as increased production throughput. Empirical evidence, such as the research conducted by Mabin and Balderstone, corroborates these benefits (Mabin, Balderstone, 2003). Their analysis of organizations adopting TOC revealed significant performance improvements, including an average decrease of 70% in order-to-delivery lead time and 65% in manufacturing cycle time, accompanied by a 49% mean reduction in inventory. Moreover, Mabin and Balderstone's (2003) findings indicated that TOC implementation resulted in an average increase of 65% in throughput or revenue and a 44% average improvement in meeting due dates.

3. Methodology

This study adopts a single case study methodology, a well-established approach in logistics research known for its depth and versatility. Case studies enable in-depth exploration of complex, real-world phenomena and can uncover underlying mechanisms within logistics activities (Aastrup, Halldórsson, 2008). They accommodate both qualitative and quantitative

approaches, making them suitable for exploring, validating, or extending existing theories (Dinwoodie, Xu, 2008; Hakkinen, Hilmola, 2005). Furthermore, case studies offer high construct validity and can facilitate the discovery of new variables or hypotheses (Bennett, 2004).

The case was selected because the sterilization unit represented a critical stage in medical device production where intralogistics inefficiencies had a direct impact on throughput and compliance with strict healthcare regulations. The research was conducted in 2024 in Germany, providing a real-world context for analyzing time-sensitive and safety-critical processes.

The single case study methodology proves particularly effective for tracking and analyzing material flow processes in industrial manufacturing contexts. Various methodological tools support this approach, including software-based workplace visualization (Dulina et al., 2024), value stream mapping, and lean performance metrics (Domingo et al., 2007). Material flow is assessed at both micro and macro levels (Kósi, Torma, 2005), often within structured improvement frameworks such as Toyota's 8-Step Process. Tools like time studies, SMED (Single-Minute Exchange of Die), and 5-Why analysis are utilized to identify inefficiencies (Halim et al., 2013).

Data collection combined quantitative and qualitative techniques. Quantitative measures included takt time, cycle time, throughput, buffer utilization, and Total Machine Efficiency. These were recorded through direct time measurements and equipment monitoring. Qualitative observations of machine behavior were also collected to capture contextual factors influencing process performance.

These indicators were systematically recorded before the improvement actions, establishing a clear pre-intervention benchmark for quantifying post-intervention performance gains.

The methodology typically unfolds in several phases: assessing the current state of material flow, developing detailed internal transport and logistics programs, and identifying opportunities for rationalization and optimization (Królczyk et al., 2014). Production flow analysis supports optimized cell layouts and more efficient material handling (Modrák, 2009).

In this research, a single in-depth case study approach is employed to analyze real-world challenges in intralogistics operations within a sterilization unit. The study applies the Theory of Constraints (TOC) Five Focusing Steps to systematically identify the primary constraint in the process flow and evaluate targeted improvement strategies. Key performance indicators such as takt time and cycle time are used to assess system behavior and optimize overall throughput.

4. Process description prior to improvement

The scope of this project includes the equipment specifications, design, installation, and testing of the Medical Device Tray Handler, which performs the following steps:

- unloads medical devices from the upstream machine,
- transports them overhead to the Tray Handler,
- places them horizontally onto trays,
- stacks loaded trays to form a full stack,
- conveys full stacks to the Autoclave,
- unloads stacks from the Autoclave,
- unstacks the trays for medical device unloading and places them into an output conveyor,
- returns empty trays back to be loaded,
- has a flip station with camera/vision inspection system and tray ejector with not fully unloaded materials.

The Tray Handler is a machine that is fully integrated into a manufacturing line, which includes inspection stations, medical device handling systems, and automation systems.

This project is designed to help new medical device manufacturing operations and to make it possible to expand the line in the future to meet manufacturing and sales needs.

Essential operating conditions are clearly specified and must be followed exactly as described below. The machine must be able to load, unload, and process 400 products per minute with a yield of at least 99.5%. Yield is measured as the number of products successfully offloaded into the output conveyor divided by the number of products delivered by the input conveyor. Scrapped items impacting yield include product defects caused by machine handling, and dropped or misplaced products. Total machine efficiency must be at least 97%. Yield loss must not exceed 0.5% of the total number of products presented to the input conveyor. Downtime must not exceed 3.0% of available run time.

The Total Machine Efficiency can be calculated as follows:

$$TME = \left(\frac{[ER \times (ERT - DT)] - MP}{ER \times ERT} \right) \times 100 \quad (1)$$

where:

TME – Total Machine Efficiency [%],

ER – Expected Rate [ppm],

ERT – Expected Run Time [min],

DT – Downtime [min],

MP – Mishandled Parts [parts].

The Yield Loss can be calculated as follows:

$$YL = \frac{MP}{(ER \times (ERT - DT))} \times 100 \quad (2)$$

where: YL – Yield Loss [%].

The Total Machine Downtime can be calculated as follows:

$$TMD = \frac{DT}{ERT} \times 100 \quad (3)$$

where: TMD – Total Machine Downtime [%].

For example, a 2-hour production run at 400 parts per minute is expected to produce 48,000 parts. However, if the machine is down for 4 minutes during the run, it will only produce 46,400 parts. Additionally, if 200 products are lost within the equipment and not successfully unloaded, the machine's overall efficiency will be reduced.

Total Machine Efficiency:

$$\frac{(400 \times (120 - 4)) - 200}{(400 \times 120)} \times 100 = 96.25\%$$

The following would be the Yield Loss:

$$\frac{200}{(400 \times (120 - 4))} \times 100 = 0.43\%$$

The following would be the Total Machine Downtime:

$$\frac{4}{120} \times 100 = 3.33\%$$

Stages of the designed process (Figure 2, Figure 3).

The first stage of the process is the infeed conveyor. This conveyor transports medical devices from the upstream machine to the Tray Handler at a rate of 400 parts per minute. The Tray Handler then loads the medical devices onto trays, which contain 7 horizontal rows of 40 pieces each, for a total of 280 pieces per tray.

The Tray Loading Robot loads medical devices onto trays. Empty trays are delivered to the loading area on a closed loop conveyor. The robot places products into the trays until they are full, and is able to load trays at a rate of at least 400 parts per minute to support the overall operating speed of the Tray Handler.

Once a tray is full of products, it is inspected to make sure that all of the products are in the correct position. If the tray is acceptable, it is transferred to the stacking cell and added to the stack in progress. If the tray is not acceptable, it is separated from the production line and moved to a location where an operator can be alerted to manually correct the tray. After an operator corrects the loading, it is put back into the production stream at the next available opportunity. As each tray is filled, it is added to the stack. The stack is complete when it has 41 filled trays and one base tray at the bottom. The base tray provides a stable platform for stacking the trays and transporting the stack to and from the Autoclave. The completed stack is then conveyed to a queue of stacks waiting to be sterilized. While the completed stack is being sterilized, new trays are being filled and a new stack is being built.

The Tray Handler communicates with the Autoclave to load trays. When the Autoclave is ready to accept a new load of three stacks, an operator instructs the Autoclave to open its inlet door. Once all three stacks have been transferred into the Autoclave, the operator closes the door and starts the sterilization cycle. Autoclave loading happens independently of tray loading and unloading, and does not affect the speed or timing of these functions.

The Tray Handler communicates with the Autoclave to unload trays. When the Autoclave has completed a cycle and met all required sterilization parameters, it sends a message to the Tray Handler. The operator then instructs the Autoclave to open its outlet door and starts the unloading process.

When the stack arrives at the unstacking station, it is lifted off of the base. The base is then moved to the stacking station, where it is prepared to receive a new stack. Trays are removed from the stack and transferred to the unloading robot, where the products are removed.

When the tray reaches the unloading station, the robot picks up the products and places them on an output conveyor until the tray is empty. The unloading operation can process products at a rate of 400 parts per minute to maintain the overall balance of the line.

The output conveyor transports products to the inspection system. After the tray has been unloaded, any remaining products are removed as scrap and the tray is presented for vision inspection. The inspection verifies that the tray is completely empty and no products are left on it. If the inspection is successful, the empty tray is accumulated in the empty tray buffer and staged for further loading of unprocessed products by the loading side of the Tray Handler. If the inspection fails, the tray is redirected to the inspection drawer for manual operator removal. After the operator confirms that the tray has been cleared, the vision system inspects the tray again. If the inspection is successful, the tray is moved to the empty tray buffer. This process continues until the entire stack is emptied of products.

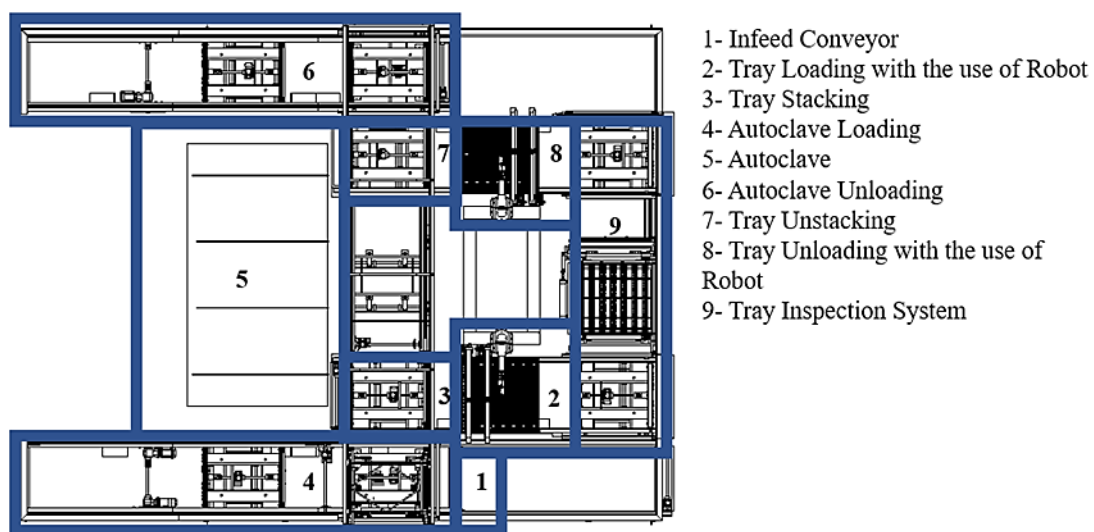


Figure 2. The defined stages of the process.

5. Process improvement

Applying the Theory of Constraints to the case under study, the unloading station was identified as the constraint in the sterilization process. This means that the rate at which customer orders can be fulfilled at this station limits the rate at which materials can flow through the entire system.

The Theory of Constraints shows that the most important factor in managing the flow of materials is to focus all of the enterprise's efforts on the part of the process where the most impact can be made (Bozarth, Handfield, 2008). This could be a constraint, or an area that has a significant impact on the constraint's performance.

Even though the unloading operation is the bottleneck in the material flow in the case study, it is important to make significant changes to the operations that are close to and have a big impact on the unloading operation. These operations are the biggest sources of waste in the company, and improving their efficiency will have the biggest impact on the unloading phase.

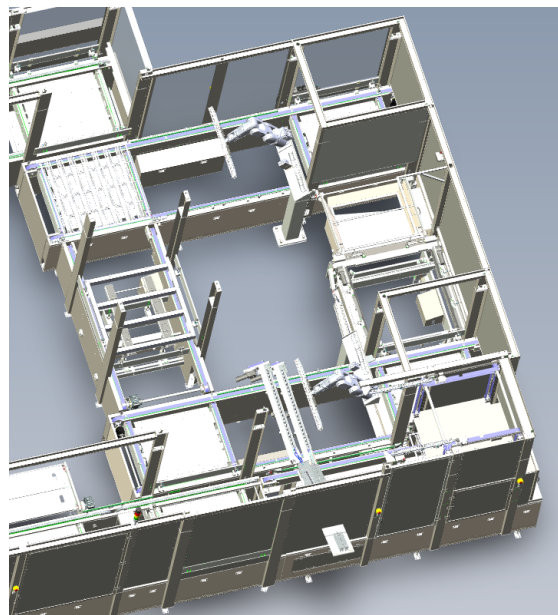


Figure 3. A process model under study.

The Tray Stacking area has three sources of waste:

- 2 seconds of delay until the base frame starts moving from the base tray accumulator to the waiting position on the conveyor with trays,
- 4.25 seconds of base frame waiting time until moving from the waiting position on the conveyor with trays to the stacker,
- 7 seconds of waiting time until the tray with the product moves to the waiting position on the conveyor with trays due to destacking delay from the loading tray buffer.

In summary, eliminating the 13.25 seconds of actual waiting time would reduce the loading waiting time of the entire batch by about 40 seconds.

To compensate the passing of the top tray, Robot in Tray Loading must reach a speed of 267 product in addition to the 400 pieces per minute within each stack. This would result in a cycle time of 41 seconds per tray, which is equivalent to 410 pieces per minute.

After implementing the above improvements, with a particular focus on step 3 of the Theory of Constraints (subordination), the cycle time was reduced. Unfortunately it was still longer than the takt time. Further research showed that there are places in the system that have a direct impact on the upstream and an indirect impact on the downstream.

It has been noted that product delivery can be accelerated on infeed. For this purpose, the power of the drive controlling the product feeding screw has been increased. This made it possible for the robot to pick up the product faster, which ultimately further shortened the time needed for the robot to place products on the tray. After accelerating the tray loading time, it turned out that the waiting time for the next empty tray was too long, which resulted in the cycle time not being shortened. The process of delivering empty trays to the infeed needed to be looked at. Knowing that process runs in a closed loop, the rate at which empty trays are received depends on the rate at which the product trays are emptied. Therefore, attention was focused on the stand: Flip station with camera inspection and tray ejector.

The inspection verifies that the tray is completely empty and no products left on the tray. Once accepted by the inspection, the empty tray is now accumulated in the empty tray buffer and staged for further loading of unprocessed products by the loading side of the Tray Handler.

The process of verifying empty trays is time-consuming and critical to the overall process. By emptying product trays faster, a buffer of empty trays can be created, eliminating wait time in the process. To achieve this, the gripper on the robot used to unload product from trays was modified from a 20-piece gripper to a 40-piece gripper. This reduced the unloading time of product trays by approximately 40% and protected the buffer of empty trays. As a result, products could be processed at a rate of 440 pieces per minute.

6. Discussion and summary

The biggest problem was that the average unit production time needed to meet customer demand was lower than the cycle time of the analyzed process. It means that the system was unable to meet customer demand due to the fact that the utilization of the process step (cycle time divided by takt time) amounted to above 100%.

In the above mentioned case study a downstream process step was highly-utilized simultaneously decreasing the utilization of all upstream process steps as the pace of the material flow was limited by the capacity of the bottleneck. By observing the flow of material through a system, it was possible to determine the bottlenecks. A system's throughput was limited by a constraint. Only by increasing flow through the constraint could overall throughput

be increased. Bottlenecks were easy to identify because of the ability to see how stockpiles formed queues in front of overloaded processes stage. This continuous increase in inventory indicated that the next stage of the process was not able to fulfil customer demand.

Our finding that the analyzed process was unable to meet customer demand due to a bottleneck with utilization above 100% is consistent with the observations of Bilinovic-Sipos and Reicher (2023), who emphasized that bottlenecks constrain overall throughput and manifest through growing inventories in front of overloaded stages. Similar to the results reported by Mabin and Balderstone (2003), our study confirms that addressing the identified constraint is the only effective way to increase system-wide performance. Moreover, the evidence from Lewandowska-Ciszek et al. (2024) and Tokarski and Łuczak (2023) aligns with our findings by demonstrating that targeted process improvements and flow simulations can enhance efficiency, reduce waste, and strengthen organizational resilience. While these studies validate our results, the specific application to sterilization processes in healthcare has remained underexplored, which underlines the novelty and practical relevance of our contribution.

Building on these insights, further analysis of the material flow in our case study highlights how interdependencies between process stages shaped system performance. When items moved through the system, the operations undertaken in one part of the system were strictly connected to the other parts. Product processing was only possible when product availability allowed. The aforementioned made it possible to contrast value-adding and non-value-adding activities. Any developments being proposed to eliminate different sources of waste were implemented with greater confidence by exploring the system's dynamics rather than just its static aspects.

This research investigated disruptions affecting the Medical Device Tray Handler during the sterilization process and demonstrated how takt time analysis and process improvements can enhance efficiency and reduce waste. However, as the study focuses on a single case within a unique organizational and operational context, its findings may have limited generalizability. Conducting longitudinal studies would be beneficial to evaluate the long-term sustainability of the improvements achieved.

The comparison of pre- and post-intervention KPIs confirmed measurable performance gains, as reductions in cycle time and increases in throughput were observed directly against the established baseline.

In summary, the study confirmed that eliminating the unloading station bottleneck through targeted improvements enhanced intralogistics flow and overall process efficiency. These results demonstrate the practical value of combining the Theory of Constraints with flow balancing in healthcare operations, while also highlighting the methodological limitation of a single case study. In addition, by improving the efficiency of sterilization processes, the study indirectly contributes to higher patient safety and resource sustainability in healthcare logistics. Future research should therefore validate these findings through multi-case and longitudinal analyses to strengthen their generalizability and long-term applicability.

References

1. Aastrup, J., Halldórsson, Á. (2008). Epistemological role of case studies in logistics. *International Journal of Physical Distribution & Logistics Management*, 38(10), 746-763. <https://doi.org/10.1108/09600030810926475>
2. Ashlag, Y. (2014). *TOC Thinking: Removing Constraints for Business Growth*. North River Press. <https://books.google.pl/books?id=TMWvoAEACAAJ>
3. Bennett, A. (2004). Case Study Methods: Design, Use, and Comparative Advantages. In: D.F. Sprinz, Y. Wolinsky-Nahmias (Eds.), *Models, Numbers, and Cases: Methods for Studying International Relations* (pp. 19-55). University of Michigan Press.
4. Bicheno, J., Holweg, M. (2016). *The Lean Toolbox, 5th edition. A handbook for lean transformation*. PICSIE Books.
5. Bilinovics-Sipos, J., Reicher, R. (2023). Overview of the concepts of bottleneck in the operation process. *Scientific Papers of Silesian University of Technology. Organization and Management Series*, 55-67. <https://doi.org/10.29119/1641-3466.2023.170.3>
6. Bozarth, C.C., Handfield, R.B. (2008). *Introduction To Operations and Supply Chain Management*. Pearson Education International.
7. Corbett, T. (1998). *Throughput Accounting: TOC's Management Accounting System*. North River Press. <https://books.google.pl/books?id=IQEBAAAACAAJ>
8. Cyplik, P., Adamczak, M., Hadas, Ł. (2012). Critical Chain Project Management and Drum-Buffer-Rope Tools Integration in Construction Industry - Case Study. *Scientific Journal of Logistics*, 8(1).
9. Cyplik, P., Hadaś, Ł., Domański, R. (2009). Implementation of The Theory of Constraints in The Area of Stock Management Within The Supply Chain-A Case Study. *Electronic Scientific Journal of Logistics*, 5(3).
10. Dinwoodie, J., Xu, J. (2008). Case studies in logistics: a review and tentative taxonomy. *International Journal of Logistics Research and Applications*, 11(5), 393-408. <https://doi.org/10.1080/13675560802389130>
11. Domingo, R., Alvarez, R., Melodía Peña, M., Calvo, R. (2007). Materials flow improvement in a lean assembly line: a case study. *Assembly Automation*, 27(2), 141-147. <https://doi.org/10.1108/01445150710733379>
12. Dulina, L., Zuzik, J., Furmannova, B., Kukla, S. (2024). Improving Material Flows in an Industrial Enterprise: A Comprehensive Case Study Analysis. *Machines*, 12(5), 308. <https://doi.org/10.3390/machines12050308>
13. Goldratt, E.M. (2003). *Production the TOC Way with Simulator*. North River Press.
14. Goldratt, E.M., Cox, J. (2016). *The goal: a process of ongoing improvement*. Routledge.
15. Hadaś, Ł., Fertsch, M., Cyplik, P. (2012). *Planowanie i sterowanie produkcją*. Wydawnictwo Politechniki Poznańskiej.

16. Hakkinen, L., Hilmola, O.-P. (2005). Methodological pluralism in case study research: an analysis of contemporary operations management and logistics research. *International Journal of Services and Operations Management*, 1(3), 239. <https://doi.org/10.1504/ijssom.2005.006576>
17. Halim, N.H.A., Jaffar, A., Noriah, Y., Naufal, A.A. (2013). Case Study: The Methodology of Lean Manufacturing Implementation. *Applied Mechanics and Materials*, 393, 3-8. <https://doi.org/10.4028/www.scientific.net/amm.393.3>
18. Hamrol, A. (2018). A new look at some aspects of maintenance and improvement of production processes. *Management and Production Engineering Review*, 9(1). <https://doi.org/10.24425/119398>
19. Hamrol, A., Gawlik, J., Skołod, B. (2015). *Strategies and practices of efficient operation. Lean, Six Sigma, and other (methods)*. PWN.
20. Ikeziri, L.M., Souza, F.B. de, Gupta, M.C., de Camargo Fiorini, P. (2019). Theory of constraints: review and bibliometric analysis. *International Journal of Production Research*, Vol. 57, Iss. 15-16. <https://doi.org/10.1080/00207543.2018.1518602>
21. Knop, K. (2024). Using the theory of constraints thinking process tools to solve critical problems in the organization. *Scientific Papers of Silesian University of Technology. Organization and Management Series*, 197, 305-331. <https://doi.org/10.29119/1641-3466.2024.197.18>
22. Koliński, A., Trojanowska, J., Pająk, E. (2010). Theory of constraints as supporting element of logistics controlling. In: E. Badzińska (Ed.), *Sources of Competitive Advantage for Enterprises* (pp. 71-84). Publishing House of Poznan University of Technology.
23. Kósi, K., Torma, A. (2005). Tracing material flows on industrial sites. *Periodica Polytechnica Social and Management Sciences*, 13(2), 133-149.
24. Kosieradzka, A., Węgrzyk, J., Smętek, W., Strzelec, P. (2022). Maximising performance of a hospital's HBOT laboratory using the theory of constraints. *Scientific Papers of Silesian University of Technology Organization and Management Series*, 155, 187-208. <https://doi.org/10.29119/1641-3466.2022.155.13>
25. Królczyk, G., Legutko, S., Królczyk, J., Tama, E. (2014). Materials Flow Analysis in the Production Process - Case Study. *Applied Mechanics and Materials*, 474, 97-102. <https://doi.org/10.4028/www.scientific.net/amm.474.97>
26. Lewandowska-Ciszek, A. (2018). Theory of constraints as a stimulus towards warehouse transformation process on the example of the distribution center. *Management and Production Engineering Review*, 9(4). <https://doi.org/10.24425/119550>
27. Lewandowska-Ciszek, A. (2022). The Lean Industry 4.0 approach on the example of an automated line for dosing loose raw materials. *Scientific Papers of Silesian University of Technology. Organization and Management Series*, 163, 343-356. <https://doi.org/10.29119/1641-3466.2022.163.20>

28. Lewandowska-Ciszek, A. (2025a). Achieving End-of-Line Efficiency Through Automated and Robotic Logistics: A Simulation-Driven Approach. In: A. Burduk, M.A. Xavier, J.M. Machado, S. Butdee, K. Krot, P. Srikhumsuk, D. Lapczynska (Eds.), *Intelligent Systems in Production Engineering and Maintenance, IV. Vol. 1: Mechanical Engineering*. (pp. 214-228). Springer. https://doi.org/10.1007/978-3-031-99159-2_16
29. Lewandowska-Ciszek, A. (2025b). Znaczenie symulacji procesów biznesowych dla projektowania odpornych łańcuchów dostaw. In: *Logistyka i zarządzanie łańcuchem dostaw w czasach turbulencji, zakłóceń i niestabilnej gospodarki* (pp. 141-159). Wydawnictwo Uniwersytetu Ekonomicznego w Poznaniu. <https://doi.org/10.18559/978-83-8211-251-1/8>
30. Lewandowska-Ciszek, A., Szczypa, P., Szymkowiak, M., Grabański, S. (2024). Navigating hyper-individualization: building resilience systems through process simulation. *Scientific Papers of Silesian University of Technology. Organization and Management Series*, 209, 229-247. <https://doi.org/10.29119/1641-3466.2024.209.13>
31. Mabin, V.J., Balderstone, S.J. (2003). The performance of the theory of constraints methodology: Analysis and discussion of successful TOC applications. *International Journal of Operations and Production Management*, 23(5-6). <https://doi.org/10.1108/01443570310476636>
32. Modrák, V. (2009). *Case on Manufacturing Cell Formation Using Production Flow Analysis*.
33. Moore, R., Scheinkopf, L. (1998). Theory of constraints and lean manufacturing: friends or foes. *Chesapeake Consulting Inc*.
34. Panizzolo, R. (2016). Theory of constraints (TOC) production and manufacturing performance. *International Journal of Industrial Engineering and Management*, 7(1). <https://doi.org/10.24867/ijiem-2016-1-103>
35. Rogowska, P. (2023). Process cycle time as a base of constraint identification in TOC application to a printing production system. *Scientific Papers of Silesian University of Technology. Organization and Management Series*, 177, 529-541. <https://doi.org/10.29119/1641-3466.2023.177.30>
36. Tokarski, D., Łuczak, Ł. (2023). Optimization of logistics processes in the sustainable development of manufacturing enterprises. *Scientific Papers of Silesian University of Technology. Organization and Management Series*, 178, 683-692. <https://doi.org/10.29119/1641-3466.2023.178.37>
37. Trojanowska, J., Dostatni, E. (2017). Application of the theory of constraints for project management. *Management and Production Engineering Review*, 8(3). <https://doi.org/10.1515/mper-2017-0031>
38. Trojanowska, J., Koliński, A., Kolińska, K. (2011). Using of throughout accounting in manufacturing companies – case studies. *Management and Production Engineering Review, Vol. 1*, 58-65.

39. Trojanowska, J., Kolinski, A., Varela, M.L.R., Machado, J. (2017). The use of theory of constraints to improve production efficiency – Industrial practice and research results. *24th International Conference on Production Research, ICPR 2017*. <https://doi.org/10.12783/dtetr/icpr2017/17667>
40. Trojanowska, J., Pająk, E. (2010). Using the theory of constraints to production processes improvement. *Proceedings of the International Conference of DAAAM Baltic*.
41. Woepfel, M. (2000). Manufacturer's Guide to Implementing the Theory of Constraints. In: *Manufacturer's Guide to Implementing the Theory of Constraints*. <https://doi.org/10.1201/9781420025712>