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Analysis of Work Station Capacity Planning Efficiency in A Steel Fabrication Project Using the Theory of Constraints Method (TOC)

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ABSTRACT

PT XYZ is a company engaged in steel fabrication, and there are several issues related to the production system of the PT Metso project that are known to be the source of bottlenecks at certain workstations, causing material flow on the production line to be impeded. This research will discuss the calculation of standard time and identify bottlenecks at several workstations. The application of the theory of constraints that can help identify and control the sources of constraints with several objectives such as maximizing throughput and creating detailed calculations of time buffers and Drum Buffer Rope maps to address issues. Then an analysis was conducted using a fishbone diagram and the Five-M Analysis method to determine the causes that occurred. Based on the calculations that have been made for the company's capacity and capability, a rescheduling of the Spray Bar production process has been carried out with an additional working time of 19 hours divided into 2.5 hours per working day. It is known that the bottleneck workstation is located at the Fit-up/Setting workstation with a percentage of 133%. To reduce this bottleneck, the company provides buffer time or time that serves as a cushion with the aim of protecting the production rate (throughput) Before the bottleneck workstation, it took 19.5 hours, and after the bottleneck workstation, it took 2.2 hours.

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1. INTRODUCTION

Industry refers to a context of activities carried out by humans in the economic field with the aim of transforming a set of inputs, involving raw materials, semi-finished goods, and finished goods. This transformation produces outputs in the form of goods or services that receive an increase in value based on established standards (Ali, 2018). At the micro level, industry is an aggregation of companies involved in the production of goods that have similarities or close relationships with each other, while at the macro dimension, industry plays a significant role in the process of economic income formation (Sudiantini et al., 2023). Overall, industries can be divided into two main categories, namely manufacturing industries and service industries. One significant aspect of the difference is that manufacturing industries are designed to produce limited variations in their processes, allowing for planned repetitive activities. In contrast, service industries exhibit a more dynamic nature, making process standardization have a more limited impact (Fajrah et al., 2023). Each company has its own quality standards, which are the company's efforts to meet the needs and desires of customers. This production process must be controlled to comply with the company's pre-established standards (Rahmawati et al., 2019).

In general, it is very difficult for a factory to achieve synchronized and continuously flowing production conditions over a long period of time. PT XYZ is a company engaged in the field of construction and fabrication services. PT XYZ is experiencing several issues related to the production system, one of which is having a bottleneck at certain workstations. The Fit-up process is a process that takes more time compared to other processes, causing production to be delayed. From the project implementation data, the fit-up workstation has a longer standard working time compared to other workstations, resulting in frequent bottlenecks that cause production output to fall short of targets. Based on the aforementioned issues, PT XYZ needs to analyze the production capacity within the company to optimize the production capacity so that the project can be completed according to the planning.

The Drum Buffer Rope method aligns with the principles of the Theory of Constraints by calculating or testing the data of the workstations that become the bottleneck stations. The Theory of Constraints (TOC) is a management philosophy based on principles of continuous improvement through focusing attention on system constraints. According to Saraswati (2016), TOC has been widely used in the scope of production systems, among other things, to improve material management efficiency, increase assembly line productivity, and observe project completion times. The research begins with analyzing the production process, observing the processing time of each production sector, and calculating the capacity of each sector (Ahadi, 2022).

The method used in this research is the Theory of Constraints method in production control and employs the Drum-Buffer-Rope concept, which can help identify and control the source of constraints with several objectives such as maximizing throughput and minimizing inventory. The principle of the Theory of Constraints can identify and determine the capacity of each workstation, allowing for the implementation of more efficient production scheduling and is expected to optimize the company's performance (Rohman & Muhammad, 2022). In the application of the Theory of Constraints concept, the term Drum-Buffer-Rope is known The Drum is the station with the lowest capacity or the workstation that becomes the constraint (experiences a bottleneck) in the production system. Buffer is a protection for the constraint workstation with the aim of ensuring that the production rate is not disrupted in the production system. Rope is a connecting string between the production rate (throughput) and the starting point of production (Heizer et al., 2017). Therefore, with the implementation of this internship, it is expected to directly identify the ongoing production process of the spray bar pipe and the need to apply the fishbone diagram method to identify the factors causing the bottleneck, as well as using the Five-M analysis method to minimize the bottleneck.

2. LITERATURE REVIEW

Theory of Constraints (TOC) was first introduced by Goldratt (1985) in the book The Goal: A Process of Ongoing Improvement. The Goal is a business novel about how to overcome barriers to make money. (making money). This theory explains how to start successfully by emphasizing chronic productivity and quality issues. TOC challenges managers to rethink some basic assumptions about how to achieve their organizational goals, what managers consider as productive actions, and the purpose of cost management (Hidayat et al., 2023). TOC understands and manages constraints, then subordinates all non-constraint resources of the organization to the needs of the primary constraint. TOC provides a unique and focused perspective in identifying products and services that will maximize added value to customers and the organization's capabilities. The TOC concept applies to both large and small organizations, as well as companies in the business sector (Rahmawati et al., 2019).

In the TOC concept, known as "drum-buffer-rope," which is a general technique used to manage resources to maximize system performance (Sugiatna, 2021). Drum is the production rhythm set to overcome system constraints. Buffers are used to protect the bottleneck from fluctuations in the previous workstations. In a production system, there are two types of buffers: Time Buffer is a time buffer aimed at protecting the system's production rate (throughput) from disruptions that always occur in the production system. Second, Stock Buffer is the final product or intermediate product used as a buffer to improve the production system in responding to demand (Rianti et al., 2019).

Drum Buffer Rope is a method used to maximize the performance of the bottleneck workstation. The Drum Buffer Rope logistics system is a limited scheduling mechanism to balance the flow of the system. The initial step of DBR is the establishment of the drum. The establishment of the drum has essentially been carried out during the constraint identification stage. The recap of the constraint identification results shows that the folding workstation is the bottleneck workstation, making the folding workstation the drum for the DBR stage. The buffer determined this time is a time buffer. The calculation process is carried out by adjusting the schedule to meet all requests. Determining the rope is the final step in the DBR stages. The rope is used to communicate and support the drum, ensuring that the flow is effectively controlled (Suwandi et al., 2022).

Standard time is the time required by a normal worker to work reasonably in the best working system at that moment. The establishment of standard time aims to obtain the time needed by a trained worker with good work ability to complete their tasks. The rating factor is the comparison of an operator's performance with its normal concept (Prangawayu et al., 2021). If the evaluator believes that the operator is working above normal, then the rating factor will be greater than 1 (Rf>1), and conversely, if the operator is working below normal, then the rating factor will be less than 1 (Rf<1). If the evaluator believes that the operator is working reasonably, then the rating factor will be equal to 1 (Rf=1) (Simangungsonga & Sitompul, 2023). Leeway is the time needed by each operator; in performing their duties, operators obviously cannot work continuously throughout the day without time for rest. In reality, it will often stop work and require time for personal needs, to relieve fatigue, and for other purposes (Sproull, 2019). Usually, the term "allowance" refers to a certain amount allowed from the standard time percentage, which is then added to that time. This includes allocations for fatigue allowance, which covers the impact of fatigue that may be experienced while performing a job (Novantoro & Singgih, 2023), personal allowance used for personal needs, and delay allowance that occurs due to unavoidable factors in a job beyond planning (Pradana & Pulansari, 2021).

3. RESEARCH METHOD

The data collection techniques applied in this study refer to the strategies or procedures used to obtain the necessary information, such as primary data collection, which is the process of gathering specific and new information or data directly by the researcher from original sources through observation methods, while secondary data in the form of documents to archives. The dependent variable in this study is the amount of production capacity that meets the set target. The independent variables in this study are the quantity of product demand, production target, actual production, working time and machine capacity, cycle time period, and efficiency.

After the data is obtained, a data uniformity test and a data adequacy test are conducted. Then, for the uniform and adequate data, the cycle time, normal time, and standard time for each workstation are calculated. After the total time is known, steps can be taken using the Theory of Constraints method, which is a theory that discusses business management conducted to achieve a profit through various identifications of constraints experienced by a company, followed by finding solutions (Riadi & Suryati, 2023). Next, the activity of identifying bottleneck stations is carried out by comparing the total time capacity required for each workstation and the total time capacity available in one work shift. Then, the workstation indicated as a bottleneck will be given buffer time adjusted to the available capacity. The analysis was conducted on several bottleneck workstations, and the workstation with the largest bottleneck will be analyzed using a fishbone diagram and five M analysis. This research focuses on the analysis of production bottlenecks at PT XYZ and identifying solutions to these problems.

Figure 1. Production Flow
Source: Primary data processed

4. RESULT AND DISCUSSION

4.1 Recap of Standard Time

Table 1. Recapitulation of total standard time

No.	Total Standard Time	Standard Time (hours)
1	Marking / Cutting	240
2	Fit up	384
3	Welding	280
4	Finishing	192
5	NDT & Leak Test	96
6	Painting	120
7	Packing	48

Source: Primary data processed

Based on Table 1, it can be confirmed that the Fit up process requires more time compared to other processes, thus hindering the production process. Therefore, to address these constraints, calculations will be carried out using a method capable of overcoming these issues, namely the Drum Buffer Rope method in accordance with the Theory of Constraints principles, to determine the capacity per workstation so that more efficient production scheduling can be implemented, which is expected to maximize the company's performance**.**

4.2 Analysis Theory of Constraints

4.2.1 Identifying Bottleneck Stations

Identifying bottleneck stations in a production floor can be done by comparing the required time capacity with the available time capacity. If the required time capacity is greater than the available time capacity, then that workstation can be categorized as a bottleneck workstation.

Table 2. Utilization of workstations

Work Station	Required Capacity	Available Capacity	Percentage	Remark
M/C	240	288	83%	*Non-Bottleneck*
Fit Up	384	288	133%	*Bottleneck*
Welding	280	288	99%	*Non-Bottleneck*
Finishing	192	192	100%	*Non-Bottleneck*
NDT & LeakTest	96	144	67%	*Non-Bottleneck*
Painting	120	192	75%	*Non-Bottleneck*
Packing	48	48	100%	*Non-Bottleneck*

Source: Primary data processed

From the comparison results above, it can be seen that at the fit-up station, there is a significant difference between the required capacity and the available capacity, which is 384 hours compared to the normal time of 288 hours. Therefore, this station becomes the main bottleneck station.

4.2.2 Addition of a Time Buffer

Table 3. Before the bottleneck and after the bottleneck station

Work Station	Lead Time	Buffer Time 25%	Buffer Time 25%	Remark
M/C	30	8	19,5	Before the Bottleneck station
Fit Up	48	12		
Welding	35	9	2,19	After the bottleneck station
Finishing	24	6		
NDT & Leak Test	12	3		
Painting	15	4		
Packing	6	2		

Source: Primary data processed

It can be noted that the buffer time value before the bottleneck workstation is 19.5 hours or 2.5 hours per day, and after the bottleneck workstation, it is 2.19 hours or 0.273 hours per day.

4.2.3 Drum Buffer Rope Model

After identifying the workstation that is the source of the problem or bottleneck and calculating its buffer time, we proceed with the drum buffer rope concept as follows.

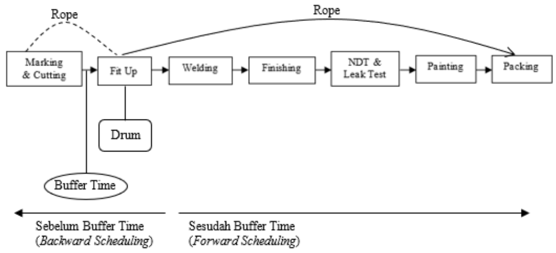

Figure 2. Drum buffer rope model
Source: Primary data processed

On the map above, the drum-buffer-rope is placed at the workstation experiencing a bottleneck, specifically at the fit-up station. The drum is positioned at the fit-up workstation as a marker for the station experiencing a bottleneck or capacity constraint, which is time capacity. The time buffer that has been calculated is placed before the bottleneck station, with the aim of protecting the production rate (throughput) of the system coming from the previous station, thereby minimizing disruptions and product accumulation in the production system. The provision of buffer time aims to maintain the production process and provide additional time to meet production targets.

In scheduling at non-bottleneck workstations, the workstations before and after the bottleneck workstation are separated. Scheduling before the bottleneck workstation uses the backward scheduling rule, which means scheduling as late as possible while still arriving on time at the bottleneck workstation. The starting time of an order at the bottleneck workstation is the completion time for the production just before the bottleneck workstation. Scheduling the workstation after the bottleneck workstation uses the forward scheduling rule, which means scheduling as soon as possible in the completion of a production. The completion time of an order at the bottleneck workstation is the starting time of that order at the workstation immediately after the bottleneck workstation.

4.3 Identify Cause and Effect

4.3.1 Fishbone Diagram Analysis and Five-M Analysis

The fishbone diagram is a diagram that can identify the causes of problems and can be understood in detail. The workstation that experiences the biggest bottleneck is the fit-up workstation. To identify and facilitate the understanding of causal factors that have cause-and-effect relationships, an analysis is conducted using a cause-and-effect diagram or fishbone diagram as follows

Based on the improvement identification results using the Five-M Analysis method above, it can be established as an effective solution to reduce or minimize the bottleneck level at the fit-up work station by formulating process activity strategies that enhance product quality. Based on the cause-and-effect analysis and improvement using the Five-M Analysis method, it can be determined that the human factor is the highest root cause of errors, as operators are directly involved during the production process, and the mistakes made by operators will impact product quality. Improvement efforts that can be undertaken by adding manpower from the human factor, namely by increasing manpower at the work station experiencing a bottleneck, can be an effective solution if supported by a proper human factor analysis. Ensuring that the workforce is not fatigued, possesses the appropriate skills, and works in ergonomic conditions can improve the speed and quality of production, as well as prevent bottlenecks. In addition, inefficiencies also occur due to workers' limited understanding of welding procedures and less effective time management, which further contribute to delays at the fit-up workstation.

The cause of errors that also significantly impacts the bottleneck at the fit-up workstation comes from material factors, because if the work method is incorrectly applied in the production process, it will reduce product quality. Material issues such as delayed material availability and specifications that do not meet standards also exacerbate production disruptions, leading to idle time and rework. Improvement efforts that can reduce errors from the method factor include implementing JIT with good coordination with suppliers and a real-time inventory monitoring system, which will help ensure materials are available as needed without causing delays or excess stock. Delays in material arrival can be anticipated with strategies involving good communication with suppliers, optimal inventory management, supplier diversification, and lead time monitoring. Furthermore, long setup times and the use of non-specific work aids should be addressed by standardizing work tools and simplifying setup procedures to accelerate production flow. From the machine aspect, low machine capability and suboptimal performance reduce efficiency and contribute to bottlenecks, while from the environment aspect, non-compliance with 5S principles and material pile-up in the work area further hinder smooth operations.

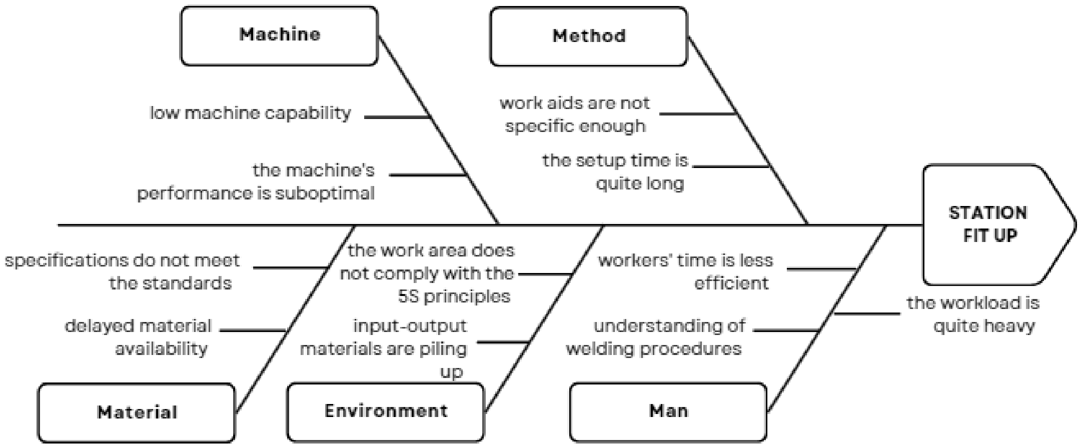

Figure 3. Fishbone diagram analysis
Source: Primary data processed

Table 4. Five-M analysis

No	Factor	Problem	Continuous Improvement Strategies
1	*Method*	a. The work aids are less specific. b. The setup time is quite long	a. More specific tools require regular maintenance to ensure their performance remains optimal. This maintenance is also important to reduce the risk of equipment damage that could disrupt production. b. Placing tools and materials in easily accessible locations to minimize the time spent searching for and preparing equipment.
2	*Man*	a. Lack of understanding of welding procedures b. Heavy workload c. Work time is inefficient	a. Create a detailed SOP regarding welding procedures, including recommendations for ampere settings for various types and thicknesses of steel. The SOP should be written in simple language and accompanied by images or diagrams for clarification. SOP are placed in work areas that are easily accessible to workers so they can quickly refer to the guidelines when needed. b. Add labor to the workstation that has become a bottleneck to help speed up the process. This can include adding operators with the necessary skills or additional workers to aid in the manual process c. By adding manpower, workers can take turns, thereby reducing the risk of fatigue and increasing productivity. Train the workforce at other workstations so they can assist at the bottleneck station when needed. With a workforce that has cross-station skills, you can be more flexible in placing workers according to needs.
3	*Machine*	a. Low machine capability b. Suboptimal machine performance	a. Regular checks on the equipment need to be conducted so that the value of the equipment does not decrease drastically due to its age. Maintenance on production equipment is mandatory to prevent damage to the equipment that can hinder the production process. b. The installation of a voltage stabilizer or automatic voltage regulator (AVR) can help stabilize the electrical current entering the welding machine. This device will keep the voltage within an optimal range, allowing the welding machine to operate more stably and consistently.
4	*Material*	a. Specifications do not meet standards (corrosion) b. Material availability is delayed	a. Ensure that the steel material used has specifications that meet standards, such as corrosion resistance. The use of stainless steel or high-quality steel according to the final product's needs is very important to reduce the risk of corrosion. b. Using more than one supplier for the same material can help reduce dependence and increase flexibility when one of the supplier experiences delays. Implementing JIT with good coordination with suppliers and a real-time inventory monitoring system will help ensure that materials are available as needed without causing delays or excessive stock.
5	*Environment*	a. The work area does not comply with 5S b. Input-output materials are piling up	a. Implement visual management to make it easier for workers to maintain the work area according to the 5R standards. Use signs or colors to identify the storage locations of tools, materials, or other items so that workers can easily return items to their places after use. b. Use the Kanban system to manage the flow of raw materials and products in process. By using Kanban cards, workers can know when to replenish raw materials or move semi-finished products to prevent unnecessary accumulation.

Source: Primary data processed

5. CONCLUSION

Based on the processing and analysis results that have been conducted, it can be concluded that the work station experiencing a bottleneck in the production of spray bars from the PT Metso Outotec Project is found at the fit-up work station, with a required capacity of 384 hours from the available capacity of 288 hours, resulting in a percentage of 133%. The drum buffer rope concept is applied to address the bottleneck issue experienced by the fit-up work station, illustrated by the drum buffer rope map that has been created and provided with time buffers at each bottleneck station, with a buffer time of 19.5 hours before the constraint work station and 2.2 hours after the constraint station, thus serving as a buffer time to protect the production flow (throughput). Identification of the biggest bottleneck station causes was analyzed using two tools, namely the fishbone diagram and five-M analysis at the fit-up workstation

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