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Article

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Bottleneck Identification through Simulation Modelling: A Case of Solid Tire Manufacturing Sector

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Abstract: Businesses are constantly making productivity improvements to survive in the highly competitive marketplace. Bottlenecks have been identified as one of the main factors limiting the system performance of manufacturing firms. Thus, identifying bottlenecks in the production process is extremely important to increase productivity. Considering its importance, this case study was designed to identify causes for not meeting the tire target and determine the implications of bottlenecks in the tire manufacturing process. For this purpose, simulation analysis was carried out for the solid resilience tire-building process. Through the investigation, the cushion layer-building process was identified as the bottleneck. To validate the identified limitation, Line balancing and Pareto analysis were conducted. Analysis results confirmed the presence of a bottleneck in the cushion layer-building process. Further, to identify the root causes for not reaching the maximum tire target, Cause-and-Effect analysis and 5WHY analysis were adopted. The study revealed that inadequately maintained outdated machines and frequent power failures are the leading causes of not meeting the maximum production. By answering these issues, the target production can be increased, and the results showed the opportunity to increase the efficiency of the manufacturing process by more than 95%.

Keywords: simulation modelling; bottlenecks; productivity; line balancing; solid tire manufacturing.

Introduction

The tyre manufacturing industry is the world's largest consumer of natural and synthetic rubbers (Xiao et al., 2022). Tires comprise a sizable component of Sri Lanka's diverse rubber product output; the country is among the world's top producers of natural rubber. To maintain a productive solid tire manufacturing process, firms must continuously streamline the production process. Supplying nearly one-quarter of the global demand for solid and industrial tyres, Sri Lanka is the global hub for solid tyre manufacturing (Export Development Board, 2022). As identified, tire performances heavily depend on rubber properties (Li et al., 2018). Due to the quality attributes provided by natural rubber products, solid tires made of natural rubber are utilized in vehicles under severe conditions such as heavy loads, high speeds, and high temperatures (Chetpattananondh et al., 2008; Gent, 1992; Premarathna et al., 2022). Higher levels of safety endurance, stability, puncture resistance, and economic features of solid tires compared to other synthetic products (National Highway Traffic Safety Administration, 2006; Phromjan & Suvanjumrat, 2018) are the main reason for this usage. Due to these characteristics, solid tire brands on the market vary in design, structures, rubber compositions, and reinforcement (Dechwayukul et al., 2010). Also, by changing the types of compounds and their composition, product designers are interested in developing different attributes of a solid tire (Gunasekara, 2017). As a result, solid tyre products have become the most expensive product in the tyre production spectrum, allowing companies to increase their profit margins. Thus, the firm's management devoted more attention to its manufacturing

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process than any other. Moreover, though solid industrial tire production is a bit stable and complex, firms focus on productivity improvements by reducing non-value-added activities, bottlenecks, and processing time.

Cycle time in a manufacturing system determines the production rate of the overall integrated structure. If the cycle time exceeds the target time, the performance of the system decreases, and the targets cannot be met (Karthikeyan, 2010). Bottleneck machines and improper process plan selection are some of the main factors limiting system performance (Li et al., 2008). Also, timely identification of bottlenecks enables firms to take solid decisions to effectively manage firm resources considering throughput improvement (Lai et al., 2021). As a result, greater attention is required to reach the maximum tire target the planning department sets. According to Lai, Shui, Ding, and Ni (2021), the identification of throughput bottlenecks in manufacturing firms is not a trivial task. As a result, it is vital to analyse the whole production process to recognize the presence of bottlenecks to minimize their implications in the tire manufacturing process when targeting productivity improvements. Since production efficiency directly influences the overall performance of the manufacturing plant, it is vital for the management to develop a systematic approach to identify bottlenecks to support them to take appropriate and timely actions to avoid such losses. There are many challenges in effectively identifying bottlenecks in complex systems (Su et al., 2022). Thus, this study was mainly designed to identify bottlenecks in the production floor of the tire production sector. Also, another set of procedures was tested to validate these identifications. For this study, the resilience tire-building process was selected since it is the most productive resilience tire manufacturing process.

In addition to the performance research gap abovementioned, this study highlighted an empirical research gap. There are scant research papers that find bottlenecks in the tire manufacturing process and almost no research papers that find bottlenecks in the solid tire manufacturing process. Most research papers are limited to the pneumatic tire manufacturing process. Focusing on these gaps, the bottleneck of the resilience solid tire manufacturing process is identified and validated in this study. As an initial step, an extensive review of past findings was referred to, and related facts were organized. Methodology selection illustrates how data was collected to design the simulation model. The data analysis section mainly focuses on the test results of the simulation model, and a discussion has been presented based on it. Furthermore, line balancing and Pareto analysis were conducted to validate the study findings. Apart from that, root causes were identified by following cause and effect analysis. Based on simulation study findings and validated facts, study conclusions were made and organized as the final chapter of this paper.

Literature review

Solid tires manufacturing process

Solid tires manufactured in Sri Lanka can be classified into three categories, namely resilience tires, press-on tires, and non-marking tires. Resilience tires are used for heavy trucks, military vehicles, and construction machinery; press-on tires are widely used in airport ground support equipment; non-marking tires are used for pharmaceutical, food, paper, and textile manufacturing facilities (Bandara et al., 2021). Resilience tires consist of three rubber compound layers: base, cushion, and tread (Premarathna et al., 2021). The inner base layer is made of a hard rubber compound that improves the grip contact between the tire and the rim. The outer tread layer is made of an abrasion-resistant rubber compound that enhances tire durability and traction. The middle cushion layer is made of a soft rubber compound to absorb shocks and manage heat build-up (Premarathna et al., 2021; Sri Lanka Export Development Board, 2022). Press-on-band tires are made by bonding and pressing rubber compounds to a mild steel band to fit the wheel (Wattegedara & Egodage, 2018). Two classifications of Press-on-band tires, namely, smooth tires and traction tires, can be identified in the global market (Newsmantraa, 2022). Due to the carbon black used in the rubber compound mixing, black tires cause ground marks. As a solution, white, grey, and green non-marking tires are produced without using carbon black (Thombert, 2010). Therefore, non-marking treads are filled with silica fillers instead of carbon black (Gunasekara, 2017).

Solid tire manufacturing is a complex multi-step process consisting of various materials and processing steps (Srivastava & Bhuyan, 2018). The tire manufacturing process, in general, consists of five sub-processes. The "mixing process" for combining different raw materials, the "material manufacturing process" for creating tire components like the carcass, belt, bead, and tread, the "building process" for putting the tire components together to create the green tire (raw tire), the "vulcanization process" for applying pressure and heat to the green tire in order to ensure the rubber's elasticity, and the "inspection process" for the last inspection of the finished tire product (Chuang et al., 2015). While selecting the raw material for tire production, its size, colour, and purpose of using the tire are taken into consideration. According to the adopted specifications, the relevant ingredients should be measured correctly, and the components related to the type of tire should be used accordingly (Gupta et al., 2018). Rubber compounds are formulated for the tire manufacturing process with greater concern for the overall properties, performance, and life of the tire (Bandara et al., 2021). The Banbury mixer is used to manufacture various rubber compounds by combining natural rubber, synthetic rubber, and various chemicals in the appropriate proportions to meet the qualities required by the tire model (Krishnan et al., 2018). The rubber compounds prepared for the tire manufacturing process are piled and kept at room temperature for about two days. Properties such as viscosity and processability of compounds change with time, and these compounds are warmed for a specific period of time using warm-up mills before being used for tire production (Bandara et al., 2021). To make a bead ring, rubber is glued to a steel wire that has been covered in copper. On a drum specifically designed for the purpose, tires are made only by assembling all of the component parts, including the rubber compounds (Krishnan et al., 2018). In the process of curing the tire, the tire is loaded into a mould, and the final shape and tread pattern of the tire is obtained by chemical cross-linking of rubber and vulcanizing materials on the heat and pressure of the mould (Stîngă et al., 2020). After curing, the tires unloaded from moulds are sent to the final inspection, where defects like incomplete mould fill, exposed cords, blisters, blemishes, etc. are detected (Krishnan et al., 2018).

Bottleneck identification and elimination

Manufacturing firms always focus on enhancing the production process by adopting different adjustments at different stages. Such adjustments are required in today's manufacturing processes due to shortened product life cycle driven by intense competition and changing consumer requirements (Kikolski, 2016). Bottlenecks can be identified as one of the major causes of these limitations (Chiang et al., 2001). A large chain with numerous subsystems can be used to represent a complex manufacturing system. The maximum capacity that the weakest subsystem (link) of a system (chain) can withstand determines the strength and performance of the system (chain). So, a subsystem that limits the capacity of the entire system is referred to as the bottleneck in a manufacturing system (Tang, 2019).

A bottleneck is a significant limitation of the functioning of a complex system as a whole (Goldratt & Cox, 1990). Baldwin (2015) defined a bottleneck as a 'critical part of a technical system that has no or very poor alternatives at the present time'. The overall performance of a process chain depends on the capacity of the machines operating in that process chain, and machines that affect and limit the overall performance more than other machines are called bottlenecks (Tang, 2019; Roser et al., 2001). One of the main causes of ineffective processes is bottlenecks. By correctly allocating resources, increasing throughput, and lowering production costs, bottlenecks that are quickly and accurately identified can yield significant gains (Kahraman, Rogers, & Dessureault, 2020). The presence of bottlenecks creates limitations in product output as well as the large presence of non-value-adding machines in the process chain (Li, 2018). Bottlenecks are generally identified as some resources or utilities that severely limit the performance of a production system. The average waiting time and capacity workload (utilization) are measured in detecting bottlenecks (Wang et al., 2005). Urban and Rogowska (2018) have introduced two types of bottlenecks that can occur in the production process. The first type goes over the utilization level of performance limits and slows down the flow of goods and materials, generating performance limits for the entire production system. The second kind involves using all of a given resource and threatens production effectiveness.

Identifying a bottleneck is the first and most crucial step in improving business productivity (Urban & Rogowska, 2020). Also, it is important to mention that the identification process requires a vast number of real-time production data and integration of factory physics knowledge (Lai et al., 2021). Firms are following various methods to identify bottlenecks which cause a significant impact on production efficiency. According to the available literature, three different bottleneck detection methods can be identified by using three methods: analytical, simulation-based, and data-driven (Chiang et al., 2000; Lai et al., 2021; Li et al., 2008).

Simulation modelling is one such method that has been used successfully to study the performances of various production scenarios (Darayi et al., 2013). According to Velumani and Tang (2017), the complexity of batch processes in production and the associated bottlenecks can be analyzed by introducing a simulation-based approach. Further, the applicability of simulation modelling has been evidenced by related studies focusing on discrete decision simulation modelling, introducing a decision support tool integrated with multi-criteria decision analysis (Brito et al., 2010), analyzing bottlenecks (Sharda & Bury, 2010), introducing a new approach to simulating complex production systems for an assembly station (Schroer & Tseng, 1987), and studying a material handling system in an assembly line (Hao & Shen, 2008). Also, several applications promote bottleneck reduction, such as workload balancing, scheduling, material flow support, production changeovers, machine control etc. (Velumani & Tang, 2017).

With the advancement of technology, computer-aided simulation became the most valued component in production management due to its applicability to all complex production floor issues. The ability to tackle increasingly complicated production challenges as soon as possible without a delay and its' applicability without a firm or process profile are caused by the popularity of simulation technology among industries. Among the software available for creating simulation models, ARENA software can be identified as one of the most flexible and powerful tools (Rahman & Sabuj, 2015). ARENA simulation techniques have been applied in different scenarios to identify and improve bottlenecks. A pneumatic tire manufacturing plant (Krishnan et al., 2018), a warehouse loading and unloading system (Liong & Loo, 2009), a patient visit process in an emergency department (Wang et al., 2009), and a paper package factory (Kasemset et al., 2014) are some of the examples for such applications. The main challenge linked with simulation modelling is the construction of the simulation model, which requires a lot of information about the real process. A simulation allows for a multi-criteria analysis and the testing of several scenarios while ensuring a comprehensive, complicated view of the process under study (Siderska, 2016).

On the other hand, Pareto Analysis is another unique tool used to identify bottlenecks in process chains, and this tool has been used to confirm and validate the results obtained from ARENA simulation (Krishnan et al., 2018). The Pareto analysis ranks data classification in descending order from the highest to the lowest frequency of occurrence. Frequencies are equated to 100%, with "vital few" items representing 80% of the cumulative occurrence percentages and "useful many" occurrences representing the remaining 20% (Karuppusami & Gandhinathan, 2006), which allows understanding significant causes for an issue. Similarly, the cause-effect diagram has been used to identify problems related to workers, work methods, procedures, and equipment handling which cause slowness or blockage of operations (Tague, 2005). A cause-effect diagram is an effective and simple tool that can be employed to list all the possible causes of a barrier after identifying the bottleneck (Ilie & Ciocoiu, 2010).

A bottleneck in a production system limits the capacity of the overall design, and eliminating bottlenecks can improve system efficiency (Tang, 2019). Material, machinery, and labor must be thoroughly investigated in the process of eliminating bottlenecks (Üstün, 2005). The bottleneck elimination process can be classified into two categories analytical and simulation-based. Analytical methods are less suitable for short-term studies, and simulation-based methods are often used in experimental studies (Li et al., 2007). Line balancing is also a bottleneck-eliminating procedure frequently practised on the production floor (Govender & Dewa, 2022). It assures the smooth functioning of the production by adjusting the operating times of service centres to match the required cycle time as closely as possible (Kitaw et al., 2010).

Methodology

As an initial step, the solid tire manufacturing process was extensively studied for this experimental research design, and the process of building resilience tires is shown in Figure 1. Following the completion of an in-depth analysis of the manufacturing process, time studies were carried out to generate an accurate time estimate for each of the functions involved in the manufacturing process. The simulation model was designed using the ARENA simulation to obtain data in time studies. The simulation results were analyzed to determine where the bottleneck was, and then line balancing and Pareto analysis were used to confirm the findings. Further, to identify the root causes for the identified bottlenecks, a cause-effect analysis was carried out. Considering the identified causes, practical recommendations were made to eliminate the blockages and optimize production.

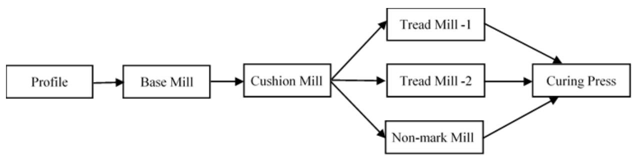

Figure 1. Resilience tire building process in plant
Source: own processing

Data collection and analysis

In order to provide an accurate estimation of the total amount of time required for the manufacturing process of solid industrial resilience tires, time studies are carried out. Data collection was done by profile making time, profile arrival time, and service time (tire layers building times) of all these five mills. One hundred data for each mill were observed in seconds using a stopwatch.

With the observed data, the service distributions (Tire building distributions) were analyzed using the Input Analyzer of the ARENA software. Tire building times were entered into the ARENA Input Analyzer to get statistical probability distributions. Then the identified distributions were considered for designing the ARENA model.

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Table 1. Tire building rate distributions of the resilience tire building process

Operation	Distribution	Expression
Base building	Gamma	28 + GAMM(38.7, 1.31)
Cushion building	Weibull	31 + WEIB(62.8, 1.09)
Tread building (Mill 01)	Weibull	52 + WEIB(90.1, 1.11)
Tread building (Mill 02)	Beta	49 + 432 * BETA(0.612, 1.53)
Non-Mark	Beta	98 + 110 * BETA(0.485, 0.826)

Source: own processing

The ARENA model for the resilience tire-building process was developed using the identified statistical probability distributions. The developed ARENA model for the tire building process is shown in Figure 2. According to the observed data, creating a profile takes about one minute, so profiles were considered to arrive at the base mill once a minute randomly. Also, changing drums takes an average of 42 seconds, and there are about 224 tire-building drum changes per day. Therefore, after allocating times for drums changing and allowances, the machines were considered to work for twenty hours per day. After wrapping the cushion layer, the tire split to the treadmill ratio was calculated according to the maximum tire target. The rates of distribution of tires to treadmill 01, treadmill 02, and non-mark mill are 58%, 27%, and 15%, respectively.

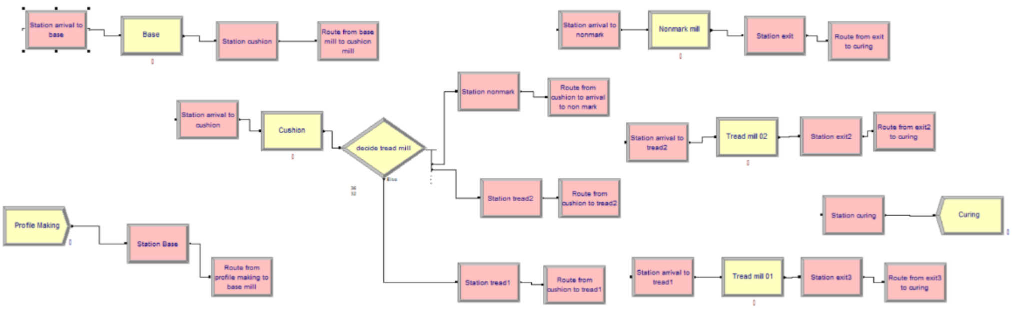

Figure 2. An ARENA simulation model of the resilience tire-building process

Source: own processing

Results and discussion

Simulation results

According to the results of Table 2, 13 tires were waiting in the cushion mill, and it was observed that the longest waiting time was in the cushion mill. Consequently, the cushion mill can be identified as the bottleneck. According to the data obtained from the planning department, the maximum resilience tire target in the manufacturing plant was about 762. Based on these results, a target of 1,225 resilience tires per day can be achieved.

Table 2. Output data of simulation model

		Results
Number in (profiles)		1232
Number out (tires)		1225
Tire building %		99%
Waiting time (Seconds)	Base Queue	376
	Cushion Queue	571
	Treadmill 01 Queue	432
	Treadmill 02 Queue	241
	Non-mark mill Queue	78
Number of tires waiting	Base Mill	10
	Cushion Mill	13

	Tread Mill 01	4
	Tread Mill 02	3
	Non-mark Mill	2

Source: own processing

Warm-up mill capacities

The capacities of the warm-up mills in the manufacturing plant were calculated to determine the presence of obstacles to reaching the maximum resilience tire target. According to the results, the warm-up mills seem to have enough capacity to warm the rubber compounds needed daily to build the tire layers. Within 20 minutes, the rubber compounds must be heated and sent to the mills to form the tire layers, so if one of the cushion or tread warm-up mills breaks, an extra mill must be placed to use. But base and profile warm-up mills can be used together.

Table 3. Capacities of warm-up mills

Mill Name	Machine Hours	Feeding Capacity (kg)	Actual Feeding Capacity (kg)	Time per feeding (min)	Needed compound weights per day (kg)	The capacity of the mill (kg)	Free capacity (kg)
Base Warmup	20	100	180	21	6,300	10,286	3,986
Cushion Warm-up	20	75	100	7	12,719	17,143	4,424
Tread Warmup	20	150	150	7	18,706	25,714	7,008
Profile Warmup	12	100	130	26	845	3,600	2,755

Source: own processing

Validation through line balancing & Pareto analysis

The Standard minute value (SMV) for each operation was calculated using the following equation. Here, 12% was reserved for allowances, and operators were assumed to work at 100% efficiency. The number of tires on the day with a maximum tire target was used as the required output. This study was conducted in order to validate the bottleneck identified by the simulation analysis and to find the line efficiency.

$$\text{SMV} = \text{Basic time} + \text{Allowances}$$

Through the analysis, the process of cushion building was identified as the bottleneck. It has been able to produce the required tire output in all operations except the cushion layer-building process. In the process of building the cushion layer, the tire quantity required is 762, and the production capacity is only 727. Therefore, the bottleneck identified from the simulation was validated, and the calculated line efficiency was 95.4%, which renders itself as an excellent value. In practice, a higher SMV should be given for building non-mark tires, but it was reduced in this case because resilience non-mark tires were limited to rim size 12 only.

Table 4. Line balancing results

Operation	SMV	Number of tires that can be produced (24h)	Required output
Profile making	1	1440	762
Base building	1.56	923	762
Cushion building	1.98	727	762
Tread building (Mill 01)	3.01	478	444
Tread building (Mill 02)	3.04	473	207
Non-mark	2.62	549	111

Source: own processing

Further, Pareto analysis was used to identify the bottleneck in the solid resilience tire manufacturing process and validate the results obtained from the ARENA simulation. This chart was plotted based on tire building times of four tires in rim sizes 8, 9, 10, and 12. Results from the Pareto Analysis of the processes are similar to results from the ARENA simulation. According to the Pareto principle (80/20 rule), tread building and cushion building can be identified as core problem areas. There are three mills for building the tread layer and one mill for building the cushion layer. In this calculation, the average building times for tire sizes have been used considering all three treadmills. So, cushion building can be identified as the most problematic area and validated as a bottleneck.

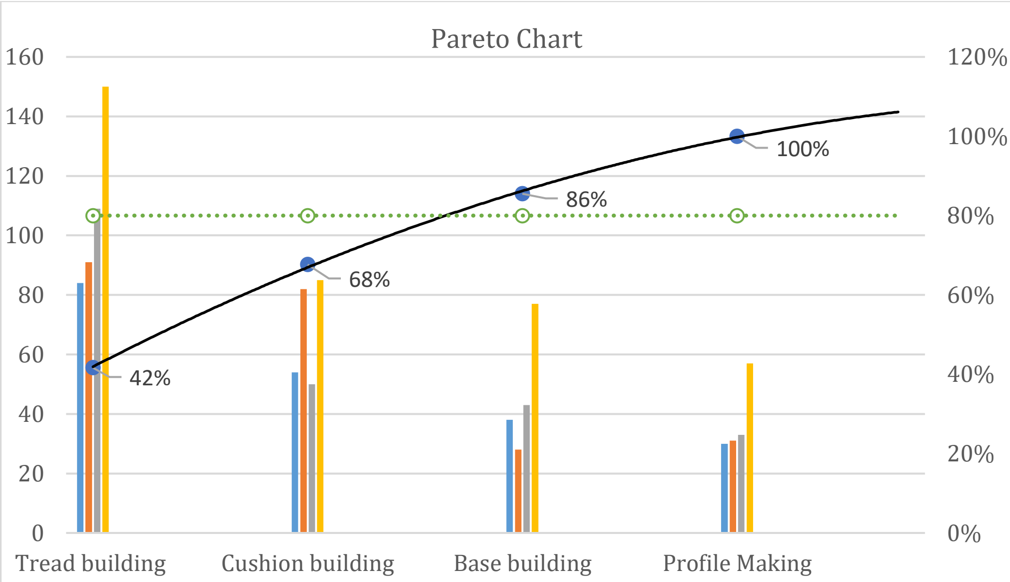

Figure 3. Pareto chart
Source: own processing

Identification of root causes

The cause-effect diagram has been used to identify problems related to workers, work methods, procedures, environment, and equipment handling, which cause the backlog of the maximum target. Figure 4 shows the reasons identified for the backlog of the maximum target.

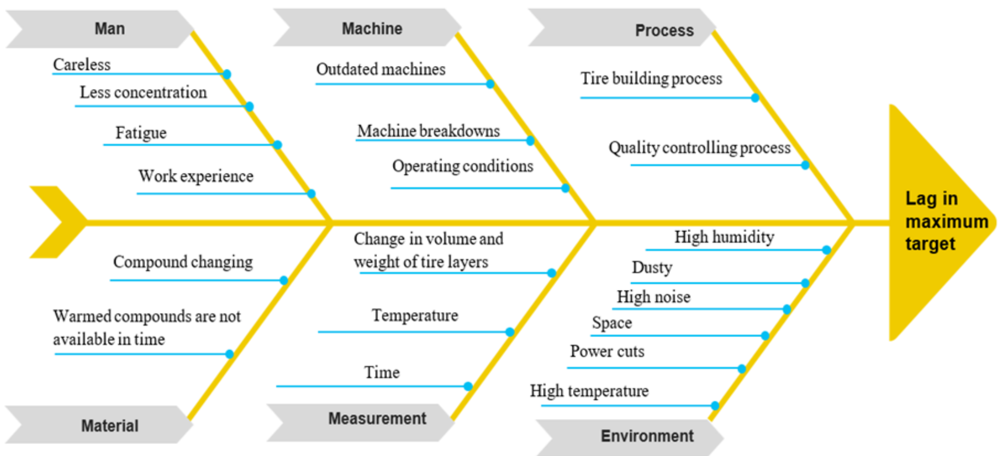

Figure 4. Cause and effect diagram
Source: own processing

The 5WHY analysis was conducted to study the main reasons for the difficulty in achieving maximum tire targets. The responses for this study were obtained from work floor employees in the manufacturing plant. Designed questions to identify root causes are the following:

Q: Why is it difficult to achieve a maximum tire target?
A: Returning tires sent to the curing presses.
Q: Why are tires returning?
A: Because the tires are not at the right temperature.
Q: Why does the temperature of the tires decrease?
A: Due to power cuts or machine breakdowns.
Q: Why do machines break?
A: Because the machines are outdated.
Q: Why are there outdated machines?
A: Because preventive maintenance is not done.

According to the results of the 5WHY analysis, the main reason for not achieving the maximum tire target was the presence of outdated machines that were improperly maintained.

Discussion

Bottlenecks are the major difficulty in streamlining and improving the efficiency of manufacturing processes. Therefore, manufacturing firms are continuously monitoring the production process to detect bottlenecks andidentifying and analysing bottlenecks is one of the fundamental restrictions facing modern manufacturing firms (Kikolski, 2016). This study provides an example of identifying bottlenecks using simulation modelling and validating procedures of identified issues that limit production capacity.

A commonly used simulation software for bottleneck detection is the ARENA software (Alzubi et al., 2019). By simulating the data, the issues with the current system, such as the emergence of bottlenecks and waiting times, could be identified (Rasib, 2021). Previous researchers have used Pareto Analysis and Line Balancing to confirm and validate the results obtained from the ARENA simulation (Krishnan et al., 2018; Yemane et al., 2020). In this study also, the bottleneck has been identified using ARENA simulation and the bottleneck has been validated using Pareto Analysis and line balancing. According to the study, building the cushion layer was identified and validated as the bottleneck in this manufacturing process. Rahman and Sabuj (2015), Liong and Loo (2009) have suggested that adding an additional resource person to the process is an option to eliminate the bottleneck successfully. In practice, however, adding a third resource person to the cushion mill is inappropriate since two employees can manage the required functions without delay. Heshmat, El-Sharief and El-Sebaie (2013) have suggested installing an extra mill to eliminate the bottleneck in their study. Thus, the installation of another cushion mill may be an option to eliminate the identified bottleneck in this study. Considering this option, an ARENA simulation analysis was performed, and it was found that treadmills pose the most significant bottleneck. Then, additional capacities should be sought to eliminate bottlenecks on the treadmills. But this is not a practical solution due to lack of space. According to the results obtained from the simulation and line balancing, the efficiency of the tire building process was about 95%, indicating a sound efficiency level. Therefore, the bottleneck in the tire building process does not affect the inability to reach the maximum tire target.

Nevertheless, according to the results obtained from the ARENA simulation, it was found that the maximum tire target given by the planning department of 762 tires can be increased to 1,225 tires. According to the results obtained from line balancing, the maximum number of tires that can be produced is 727.

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According to the cause-and-effect diagram and 5WHY analysis, machine breakdowns and power cuts are the main reasons for the difficulty in achieving a maximum tire target. The fact that production lines are inherently variable makes it more difficult to identify the bottleneck. This variation may be the result of arbitrary events like machine failures (Sengupta, Das, & Vantil, 2008). Improperly maintained and outdated machinery generates frequent breakdowns. Before loading a tire into the press for vulcanization, the temperature of the base layer should be between 85-110 degrees Celsius, and the cushion and tread layers should be between 90-110 degrees Celsius. Tires must be rebuilt due to temperature drops during the time it takes to repair broken-down machinery or turn on generators during a power outage. The rebuilding process is a waste of time, effort, and money. Therefore, by minimizing and managing these situations, the efficiency and effectiveness of the production process can be increased.

The tire target can be increased by paying particular attention to outdated machines and properly maintaining them. As a result of power failure, time wastage can be identified since it takes longer to turn on with the generator support as those machines restart step by step. Since the temperature can be maintained uniformly for about half an hour after tire building, such issues can be avoided if there are known scheduled power cuts, and this can be reached through rigorous planning. Also, by maintaining good communication and a relationship between the electrical and production departments, it is possible to understand when the generator is turned on and off and when the tires should be produced.

Conclusions

This study presents the analysis and assessment of the chosen production process. In operation perspective, bottlenecks are the key issues many operational firms encounter when targeting optimum output. The purpose of this study was to find out production bottlenecks by applying simulation modelling. Further evaluation methodology was designed to validate the identified bottlenecks and to identify root causes for the issues. The resilience tire-building process was selected, and the simulation model was developed by examining actual workstation loads. Pareto analysis and line-balancing techniques were used to validate the simulation findings and to identify root causes.

By performing ARENA simulation modelling, the cushion layer-building process was recognized as the bottleneck which limits designed tire targets. It obstructs the flow of the entire process, forcing some centres to go idle and some to block the whole process. This was the main objective of this study, and the results confirmed the possibility of performing simulation modelling in bottleneck identification. Also, findings were further confirmed by the Pareto analysis. Moreover, while validating the identified bottleneck, performed line balancing was denoted opportunity to improve the efficiency level further. Through the 5WHY analysis, the main reason for not achieving the optimum production was identified. According to this case study, the presence of improperly maintained outdated machines and frequent power failures were the main causes of the production delay. This implies the requirement of solid infrastructure facilities within the production floor to optimize production. A conclusion was reached that outdated machines should be maintained to increase the tire target as there is good efficiency in the tire building process. By answering these issues at the cushion layer-building process (bottleneck), the production capacity of the whole process can be improved. Further, this facilitates reducing the idle times at treadmills and the curing press process and allows it to function smoothly.

Therefore, the performed study confirms the possibility of applying simulation modelling and other validating techniques to identify and improve production processes. Thus, the method followed in this case study can be employed in any sector and any complex production floor in order to optimize the production process. Also, the methodology adopted in this study can be considered as a good example when firms are looking to understand production efficiency. Also, it is important to mention that the whole analysis will depend on the production data collecting for this purpose. Therefore, factory management should implement a proper mechanism to obtain real-time production data among all sections. Management can focus more and more on new technological applications in such implementations. With the advancement of the production process, more carefully crafted and integrated studies on bottleneck identification may be required to develop, especially when studying some specific production domains. As stated by Kikolski (2016), the success of the application depends on the accurate design and the proper execution of the simulation model.

Recommendations

It should be highlighted that the analysis was just intended to serve as an illustration of how simulation models might be used to pinpoint bottlenecks in an industrial production process. According to this case study, it is recommended to develop an appropriate program for regular preventive maintenance, and maintenance department personnel can be assigned to maintain machinery in each department. Furthermore, new machinery should be installed as much as possible to replace obsolete machinery. Tire building times and scheduled power cut times should be managed to improve efficiency.

Limitations and further study

In this study, only the resilience tire-building process was considered a point of focus. Therefore, future studies can take into account the press-on band tire-building process (POB). And further extensive analysis can be conducted to find the whole process of tire production of all types of resilience, POB, and flap. Various methods can also be used to identify bottlenecks in the production process. Also, different productivity improvement techniques can be employed in future studies to validate identified causes.

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