AN INVESTIGATION INTO STOCK CAPACITY UTILIZATION OF A MANUFACTURING LINE AT A CATALYST MANUFACTURER

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AN INVESTIGATION INTO STOCK CAPACITY UTILIZATION OF A MANUFACTURING LINE AT A CATALYST MANUFACTURER

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ABSTRACT

Bottlenecks in a manufacturing line are the fundamental reason that obstructs productivity. Accurately and effectively recognizing bottleneck areas, can improve the use of limited assembling resources, increment the framework throughput, and limit the complete expense of production. This article focuses on improving the throughput of a manufacturing line in an automotive component supplier plant. The project aims to develop a solution to increase the capacity of the production system by following an adapted design thinking method to approach the problem. The first step in the process is to Underline (Emphasize), followed by Define, Research, Analyse, Ideate, and Conclude with Testing and Verification. Tools used in this project are Process mapping, Genchi Gembutsu, Time studies, Ishikawa diagrams (Root cause analysis), and five why analysis. Insight was gained in the Emphasize phase using Gemba walks and observation.

Keywords: root cause analysis, productivity, efficiency

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1 INTRODUCTION

This project was conducted at the powder manufacturing unit of an automotive catalyst manufacturer that supplies high-value catalysts to the industry. Although the organisation's fundamental goal is to produce catalysts, the powder manufacturing unit directly impacts the finished good products and ultimately the company's profit margins. The automotive industry is exceptionally competitive; therefore, an increase in capacity output and meeting customer demand whilst also building a satisfactory buffer/ safety stock variation will benefit the company. The powder manufacturing line is accountable for manufacturing approximately 25 different types of powders in different batch quantities, this process forms part of a five-step process to achieve the finished good. Therefore, whilst trying to increase the capacity output of the powder manufacturing line by looking at the process capacities, the project strives to maintain the high-quality standards that the company instils not only into its products but also in each member of the company and upholds the company ethos.

1.1 Background to Study

This project involves mapping, evaluating, and analyzing the current process of the company's Powder manufacturing system. The Powder system meets the demand with additional labour hours as the system capacity is balanced with demand without taking unplanned events into account. Powder short supply does occur very rarely however the production plan has to then immediately be changed to counteract any potential line stoppage. Multiple powder models are planned for the week depending on the production plan. These plans must be adjusted to not create a capacity constraint on the line. These adjustments result in some weeks having to run a seven-day, three-shift operation which places a major constraint on equipment. The powder manufacturing process has a four-step process: a wet powder(slurry), a microwave process, a calcination oven, and milling.

1.2 Research Problem Statement

Company ABC's powder production demand is not consistently met by the company's powder manufacturing line capacity. This leads to the need for additional production planning and amendments to the original plan during a production week, thus increasing costs (material and labour costs).

1.3 Research Aim

This study aims to develop a solution to meet customer demand whilst keeping adequate safety stock levels by increasing powder capacity output and improving profit margin.

1.4 Research Objectives

The objectives to achieve the project aim have been defined as:

- To determine the main contributors to capacity constraints by conducting a root cause analysis.
- Determine improvement methods for the powder production system.
- Design an improved manufacturing system.
- Establish the new system's impact on the production system.

1.5 Research Questions

Considering the research objectives described above, this research seeks to address three research questions stated below:

- What strategies can be used for the improvement of low-capacity manufacturing volumes at company ABC?
- What best-suited strategy and performance measures will improve the throughput of capacity as well as customer order satisfaction?

- Can an agent-based inventory management model mimic and unveil the execution of the selected integrated-inventory management strategy to be proposed in this study for company ABC?

2 METHODOLOGY

Figure 1 outlines the adjusted planned thinking that was followed to move towards approaching the problem. This strategy will be clarified extensively in this part.

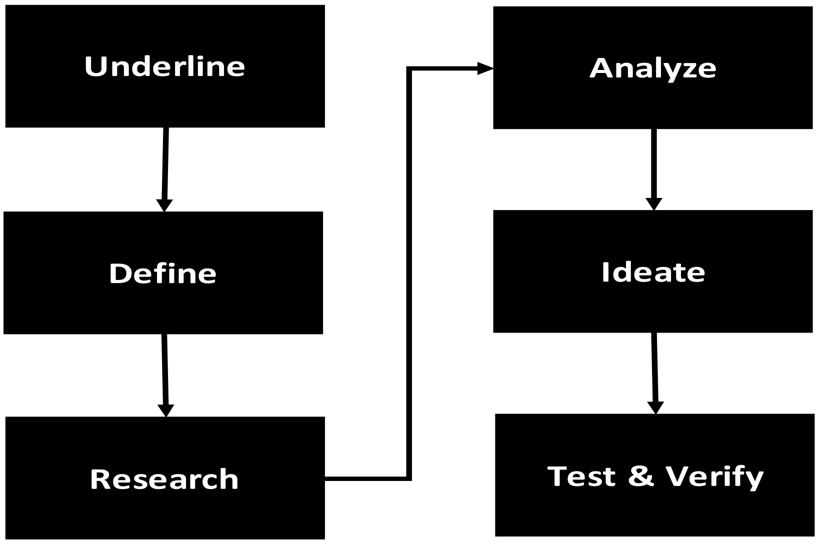

Figure 1: Method Followed to address the problem

In the underline stage, knowledge was acquired about the organization and its tasks through Gemba strolls and observation of the line. Key factors were additionally recognized during this stage.

During the Define phase, the powder system process was mapped by using a process flow diagram. A needs analysis was conducted during this phase to define the company's system requirements, which resulted in the identification of the manufacturing capacity not fully utilized.

In the Research stage, a writing study was directed on the problem statement, on subjects that emerged from this undertaking, and on different writers that have considered or tackled comparable issues, the problem of the manufacturing line not being fully utilized and creating bottlenecks in the overall production process at company ABC can relate to a Theory of constraint issue.

In the Analyse stage, the speculation that the Powder production was not effective was tried by investigating various factors such as overtime required each week. Referring to company ABC's historical production data that the Powder line was not effectively productive as it was initially designed to be, a present status examination was finished, and the main investigation was directed by joining two designing instruments, an Ishikawa graph and a 5 Why examination.

In the Ideate stage, a limit adjusting technique was picked to foster further developed system idea plans. The upgraded configuration intends to improve the system's limits, thus reducing additional mistakes in the system and less time worked.

In the Testing and Verification phase, the final design was tested to ensure that the system was improved. The system was tested by running a simulation multiple times with the new system design and comparing the improved system results to the old system results as well as historical data.

3 LITERATURE REVIEW

Different philosophies and strategies were considered and discussed with the problem encountered within this project, by conducting this literature review we will attempt to discover the gaps within previous research conducted on the issue and put forward possible problem-solving approaches.

3.1 Strategies to improve manufacturing capacity

In the journey to further develop production execution, various extensive ways of thinking have been proposed in research and are being carried out practically. It is broadly held that the fruitful execution of these methods of reasoning requires system thinking in which one sees things holistically, including the many variations of relationships between the diverse elements of a complex system. Functional integration in which supplier processes meet the requirements of customer processes in terms of cost, availability, and time, and lastly, we consider flatter organizational structures which elevate each employee's tasks within the plant and eliminate excess management layers to improve coordination and communication [1]. We can now delve further into the philosophies applicable to the problem being addressed in this project.

3.1.1 Theory of Constraints

The Theory of Constraints (TOC) is a moderately new administrative way of thinking that has been consistently advancing since the mid-1980s. This framework-based way to deal with management, principally credited to Eliyahu M. Goldratt, looks to comprehend the basic cause-and-effect connections that are liable for an association's performance [2]. Utilizing the five-step measure that Goldratt introduced, the TOC way to deal with limitations of management will be utilized as a system to direct the improvement of the system as company ABC look to make their association more receptive to client requests in a serious and dynamic commercial sector. The five stages look to:

- Recognize the system constraint.
- Exploit the constraint.
- subordinate the non - constraints.
- Elevate the constraint.
- Return to step 1

3.1.2 Total Quality Management

One technique for “extending quality is through Total Quality Organization (TQM). “TQM is detailed organizational thinking that relies on guidelines and practices that lead to further development of business execution [3]. Many situation-oriented surveys or surveys provide evidence that maintains TQM achievements in terms of money-related results, job execution, and customer and worker satisfaction. TQM execution redesigns an association's image and further creates delegate satisfaction and quality care. Similarly offered some evidence for a productive result of TQM practices on market course and organization quality in the Malaysian production industry [3]. [4] found that three TQM factors (supplier quality organization, measuring the board and quality data, and uncovering) add to achieving the practical goals. Therefore, by utilizing TQM standards there can be a potential increase in productivity on the Powder line.

3.1.3 Queueing theory

Queueing hypothesis is a high-level numerical displaying strategy that can appraise holding up occasions [5]. As a rule, a queueing framework has two primary parts: clients and workers. On the off chance that a client should stand by in line, it is alluded to as a line. A queueing model can be utilized to decipher the appearance examples and preparing times to appraise significant framework execution measures, for example, the normal client holding up occasions and the probability of an irregular client experiencing zero deferrals, for quite a few workers [5].

3.1.4 Lean Manufacturing Philosophy

According to [6] reported that the Lean Philosophy which originated in Japan has become a worldwide marvel, because of its authoritative advantages for persistent improvement. This brilliant philosophy continued to grow from inception and the conventional term lean manufacturing was promoted by its significant advocates, the Lean way of thinking is portrayed as being founded on five key standards [7], in particular:

(1) Define Value – characterized according to the client's point of view.
(2) Map the value stream – map the arrangement of activities needed to make items or administrations.
(3) Create Flow – After removing wastes from the VSA, ensure the remaining steps run smoothly.
(4) Pull – utilize a drawing framework.
(5) Chase Perfection – consistently make progress toward the paragon of the item/administration.

3.1.5 Six Sigma

All through the development of Six Sigma in industry, according to [8], there have been numerous ways by which Six Sigma has been made sense, nonetheless, for the setting of this paper, we will sum up the definitions and decide how is "Six Sigma" valuable to this project.

Firstly, Six Sigma is a set of statistical tools adopted within the quality management dynamics to build a system for process improvement. The goal is to upgrade the Six Sigma level of performance measures referred to as the critical to quality (CTQ) which mirrors the client prerequisites through a group of tools for the investigation of the information [9]. Measurable tools recognize the major quality indicators which are the Parts Per Million (PPM) of non-adjusting items. Achieving a Six Sigma level means having a process that creates yields with < 3.4 defective PPM.

Secondly, Six Sigma is an operational philosophy of management that can be shared beneficially by clients, investors, representatives, and providers. Thanks to its adaptability, the Six Sigma application isn't restricted exclusively to assembling and can be rolled out to the entire inventory network which incorporates the arrangement of services. It is helpful to implement a more focused approach towards production network undertakings to thoroughly characterize and execute them more [10]. Six Sigma is likewise characterized as a diverse, client-situated, organized tool that accelerates the deliveries of goods and diminishes overall costs.

3.1.6 Value Stream Mapping (VSM)

As per [11], value stream mapping (VSM) achieves the likelihood to distinguish value-adding exercises. At the end of the day, VSM continually seeks the goal of waste reduction intending to increase the value [12]. Likewise, by applying VSM, which could assist with recognizing functional misfortunes, associations will want to dispose of functional misfortunes and advance toward more worth creation for the client [13]. This is the very issue that the current examination endeavours to review and answer in practice [14]. VSM is one of the most valuable and instrumental strategies [15]. VSM is characterized as movements of every kind and occasion (both value-added, and non-value added) that an item or service goes through on its way from provider to client [16]. In organization ABC, these exercises incorporate delivery, waiting, (in stock, in a line to be handled), packaging, examination, revision, and both manual and robotized handling [17]. VSM can't be utilized straightforwardly for exceptionally complex assembling processes with merging flows [18].

3.1.7 Statistical Process Control (SPC)

The control “graph method is viewed as one of the significant apparatuses in factual quality control [19]. A primary goal of control graphing is to distinguish any crumbling in quality so the remedial move can be made before delivering a huge number of nonconforming things. The idea of the control diagram was first presented by [19]. Shewhart control diagrams are more productive in identifying huge changes in measure boundaries, as they rely just upon the data in the last example perception. Therefore, these charts are imperative to prevent problems before they occur, its flexible enough to be used on any process line.

3.2 Performance Measurements

The current powder manufacturing processes within the company are audited by their performance effectiveness, therefore in this section, we will discuss the various applicable Key Performance Indicators [20].

3.2.1 Throughput

According to [21], it is observed globally, that delivery lead time and reliable delivery are of critical importance to a manufacturing industry's capacity to compete more effectively in both the domestic and export markets. Industries are reputed to have a poor delivery performance record, but very little research has been performed to ascertain the causes of this problem. However, [22] states research has been reported on the possibilities of using various heuristic priority rules to sequence batches through a job shop. The SPT (Shortest Priority Time) heuristic, or modifications to it, has been proven useful in many studies. The simulation model has been utilized to test the impact of notable priority rules of delivering groups into the shop arranged by diminishing expected throughput time. The significant impact of this "phase release" of batches is to build the level of batches conveyed in completed parts on time, especially for the situation where priority rules were being used which could somehow have brought about unfortunate conveyance. This has significant repercussions for the executives because it implies that by "phased" release of batches in the manner discussed, a large proportion of batches will be delivered on time whatever priority rule is in operation in the shop.

3.2.2 Change Over Time

Accomplishing "production greatness" is fundamental for the endurance and monetary development of any country in this period of globalization. The "mechanical age" of the last century has offered a way to the "data age" which in assembling terms upgrades capacity and lessens item process durations, thus changing Cycle Times (CTs). The advancement of innovation, complex high-creation frameworks, and mechanical production systems has introduced another period in assembling [23], notwithstanding To contend in this ceaselessly evolving climate, these organizations should search out new strategies permitting them to stay serious and adaptable and, all the while, empowering their organizations to react quickly to new requests [23] accordingly single minute exchange of die (SMED) is a significant lean instrument to decrease squander and further develop adaptability in assembling measures and assembling stream enhancements. single minute exchange of die (SMED) lessens the non-useful time by smoothing out and normalizing the activities for trade instruments, utilizing basic procedures and simple applications. We can see that In the single-minute exchange of die (SMED) technique, arrangement exercises are partitioned into inward and outside exercises. Outside exercises can be done during the ordinary activity of the machine, when it is yet running, for instance, preparing the hardware for the arrangement activity should be possible before the machine is closed. Inside exercises can be performed just when the machine is closed, for instance, appending or eliminating the dies. The interior and outer arrangement exercises contain various activities like planning, after-measure change, checking of materials, mounting, and eliminating devices, settings and alignments, estimations, preliminary attempts, changes, and so on [24]. A few techniques can be applied to diminish the length of exercises. A few alternatives like utilizing useful cinches, executing equal tasks, lessening acclimations to least, and planning successful instruments are recommended [24] however theoretically the change over time is inversely proportional to the problem of capacity utilization of the Powder manufacturing line.

3.2.3 Planned Maintenance

According to [25], It is imperial to support capacity, and in this manner with regards to the upkeep that companies have developed. The far and wide motorization and mechanization have decreased the quantity of manufacturing staff and expanded the capital utilized in the manufacturing gear and designs. In processing plants, for example, it's anything but extraordinary that the upkeep and activities divisions are the biggest, and each contains 30% of the all-out labour. Moreover, close to the energy costs, upkeep expenses can be the biggest piece of any functional spending plan. However, the primary connection looked at by management, regardless of whether its yield is positive, is its commitment to organization benefits.

3.2.4 Overall Equipment Effectiveness

Producers give superb dependability and nature of their equipment at cutthroat costs. “To have exceptionally dependable machines to make smooth assembling measures certain, numerous associations have executed absolute useful upkeep (TPM) as the empowering device to augment the viability of hardware [26]. Upkeep and its administration have moved from being considered a "means to an end" to being of key significance for the most serious associations throughout the planet [27]. Quite possibly the most pivotal and broad applied devices of execution estimation in the assembling business are in general gear viability [53]. OEE is the critical proportion of both TPM and lean upkeep [28]. The OEE uncovers the secret expenses related to the effectiveness of the hardware. OEE is characterized as a proportion of complete gear execution, that is, how much the hardware is doing what it should do [29].

3.2.5 Capacity Utilization

This concept is an idea firmly connected with the thoughts of usefulness and effectiveness. [72] states that "capacity utilization (CU)" in the industry is a much-ignored area and members are still familiar with the sustainable benefits of capacity and effective utilization. Research shows that the estimation of capacity can only be carried out by management in the workplace. To conquer such issues and expand the huge consciousness of the CU idea, the novelty of the current work is to investigate the CU discernment through practicality via the current project outcomes. Research shows the situation with CU across the world and its job in the improvement of efficiency and quality inside the enterprises. Besides, the difficulties looked at in a CU assessment are featured for propelling the industrialist and specialists. CU is directly related to the production level of a production line. CU is a latent ability to perform and produce output without increasing input variables according to [25]. The CU as output could be increased with the full use of all input variables under normal conditions like extending the working hours and considering regular holidays and machine maintenance [25].

3.3 Techniques & Problem-Solving approaches

3.3.1 Total Quality Management (TQM)

TQM decides the general intent to augment the processing plant's execution pointers dependent on the distinguishing proof of production bottlenecks and apparatus [26]. For many quality circles, there has been a struggle, because total quality management has been something to “get around to one day” and continuous improvement has just been another expression for total quality management. As indicated by [27] there is no widespread agreement meaning of TQM, and various gatherings including academicians, researchers, experts, designers, and others have thought of different definitions. For example, [28] characterized TQM as a business cycle zeroing in on working on hierarchical viability, proficiency, and responsiveness to client needs by effectively affecting individuals in process improvement exercises. According to [29] past researchers have shown that TQM is an administrative practice that can work on the nature of an item or administration. It is in this critical manner to find and distinguish a specific quality and its suggestion. Quality can be characterized distinctively since individuals could see quality comparable to contrasting rules considering their singular jobs in the production chain, based on broad surveying of the TQM writing [30]. It has also been observed that there are seven significant classifications of practices estimated in past examinations, to be specific administration, key preparation, client concentration, data and examination, human resource management (HRM), and supplier management [31]. These practices, excluding supplier management, are consistent with the criteria that are used in TQM [32].

3.3.2 Simulation Approach

Simulation is defined as the process of model designing of a system as well as the conduction of experiments using this model to 1) understand the system behaviour and 2) evaluate different strategies for system operation. The behaviour of the model should be consistent with the response behaviour of the system in reaction to the event happening over a period according to [2]. It was elucidated by [32] that simulation models are flexible, although a closed form of solutions (e.g., queuing) is not provided. The goal of simulation includes the retrieving of supplementary information on the performance of the models that are proposed [32]. A simulation was used by several researchers to analyse waiting time [33], test the scheduling heuristics performance, and compare the performance of simple scheduling rules within a system [34]. The implementation of simulation optimization offers improvements, however small the impact is.

3.4 Implementing the Improvement

Based on certain restrictions from higher management at company ABC, only two possibilities for improvement were allowed to be put forward, one being advancing the current equipment and the second being installing new machinery, the possibility that will be chosen for implementation would ultimately be based on reducing the low volume capacity that the powder manufacturing line is currently experiencing.

3.4.1 Advancing Current Equipment

By redesigning the equipment, the bottleneck could be decreased, bringing about higher throughput, which will empower the interaction to satisfy reliability. This conceivable arrangement will be generally moderate as no foundation changes will be required except if the upgrades are done outside of working hours.

3.4.2 Adding New Equipment

By adding new equipment, factors such as equipment installation time as well as cost factors will have to be greatly scrutinized, although changes will happen within the plant’s layout, the bottleneck constraints will be enormously relieved.

The two above-mentioned improvement possibilities were used as the foundation for further design and improvement concepts and investigations in the further part of the project.

3.5 Literature Review Conclusion

In this literature review, the work of other authors that have solved or researched similar problems was analysed. By using the lean philosophy, Six Sigma, and the Theory of Constraints, strategies for system enhancements were identified. It was observed that integrated philosophies eliminate unnecessary limitations that may lead to a plateau and the depletion of resources in the long term. Different approaches were identified to optimize the entire feed production process. These approaches include the Theory of Constraints and the Simulation approach. The TOC is divided into bottleneck and non-bottleneck machinery. The bottleneck can be elevated by either replacing machinery, adding machinery, or upgrading existing machinery, these restrictions being determined by higher management at company ABC. The concepts in this section will be used as a basis for alternative designs that could solve the problem, as stated in the problem statement.

4 DESIGN INTRODUCTION

This section of the article examines a proposed answer for the problem as far as a calculated plan. The theoretical structure whereupon the arrangement is based, is examined. Potential answers for the customer's necessities as electronic frameworks used to carry out the interaction for observation. Furthermore, whether it is smarter to buy or foster such frameworks in-house is examined. The part is then closed and the importance of the writing concerning the task is examined.

4.1 Design Requirements

The design requirements are based on root-cause analysis. The design requirements should be met for the task to be effective. The design requirements are:

a) The powder interaction should have an overabundance ability to represent changeability.
b) Production yield deficit should be insignificant.
d) Maximum limit increment for the most reduced venture.
e) The final plan should be monetarily achievable for the business.

Figure 2, depicts the Fishbone diagram, followed by Table 1, which is a scoring matrix of all the main causes identified that could be generating the effect. The main causes that are identified, were finalized by company ABC's Engineering department and higher management.

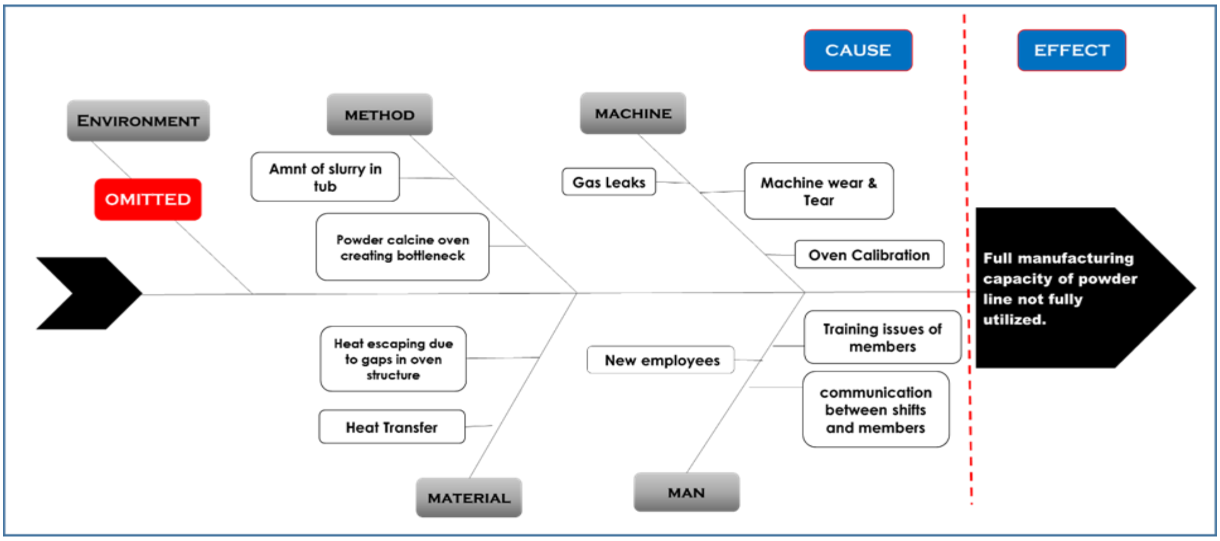

Figure 2: Ishikawa diagram (Root-cause analysis)

Score Rating: > 0 - (Not likely) ⟷ 5 - (Very Likely)		Full manufacturing capacity of powder line not fully utilized.			
4M + E Factor	Cause	Does this problem impact the "EFFECT"	Possibility of achieving positive outcomes once countermeasure is developed?	Risk of creating a line stoppage	Score
Man	Training issues of members	1	0	0	1
Machine	Oven Calibration	1	1	1	3
Machine	Gas Leaks	1	1	1	3
Material	Heat escaping due to gaps in oven structure	0	3	1	4
Method	Powder calcine oven rack not effectively utilized	5	5	1	11

Table 1: Scoring matrix of the Ishikawa diagram's main cause

4.2 Design Decision Criteria

The design criteria are based on the current state and the root cause analysis. The design will be utilized to guarantee that the main system is tended to and that the issue, as characterized in the issue articulation, is settled. The models that will be utilized to assess every idea configuration are:

a) Cost-Effectiveness Short Term
b) Cost-Effectiveness Long Term
c) Investment Short term
d) Investment Long Term
e) Production Increase

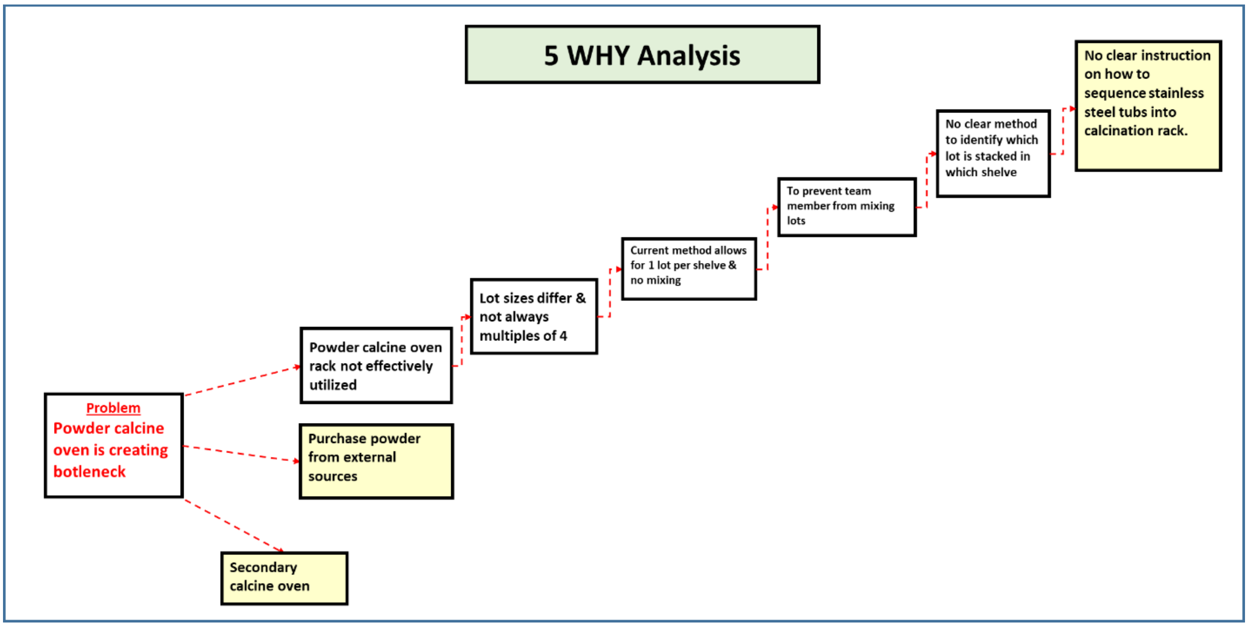

Figure 3: 5 WHY Analysis

Figure 3 represents the 5 WHY analysis that was conducted after the Ishikawa (Fishbone analysis) was completed. Higher management together with engineers at Company ABC determined the constraints of improvement, based on restrictions from company ABC's headquarters in Japan.

4.3 Factors to consider when developing the final countermeasure

4.3.1 Variables

The variables in the process will result in variation in daily powder production but will not influence weekly production to the same extent. Different powder quantities will cause variation as the microwave timings have different durations from the calcine oven. Also, some powders must be calcined twice, and this may impact the overall capacity output. The variables that we are being considered, are based on the potential countermeasures developed from the 5 WHY analysis. They are stated below as follows:

4.3.1.1 Purchasing of Powder from an external source

Purchasing of powder from the companies' headquarters would alleviate major pressure off from the production line, Powder would be ordered as per customer order and in line with the in-house production sequencing plan. There are however a few negatives to this solution, since the powder will be of high monetary value, importing into the country would pose a few safety hazards, as well as potential contamination of powder as most of the powders, would be shipped rather than arrive via airfreight.

4.3.1.2 Improved oven racking system concept design

An improved oven racking system could be the result of the enhanced bottleneck processing time or because of the improvement of a combination of the bottlenecks in the system. A simulation using excel graphs was developed to allow the various parties concerned, to visually see what the potential improvement could be like. The simulation delivered the current system capacity based on six days with three 6-hour shifts 24-hour cycle workday. The concept design was weighed against the final design requirement.

4.3.1.3 Implementing secondary microwave and calcination oven

A secondary microwave oven could be possibly installed, this would alleviate strain from different powder models having to go through the microwave process, this aids with the theory of constraints theorem with regards to current conditions. Various discussions were held with management as well as the company's headquarters in Japan, a green light was received if this would be the option that best suits the current problem.

4.4 Decision Tree analysis

Decision trees are graphical, simple-to-develop portrayals of the different decision ways inside a task. At their most fundamental level, decision trees can be utilized as a straightforward device to put together groupings of occasions or decisions.

Based on different variables that were developed from the Ishikawa diagram, the 5 WHY analysis was then conducted to produce possible countermeasures, and a decision tree analysis was conducted afterwards. Figure 4 reflects the various factors, their probabilities, and possible monetary values per powder batch.

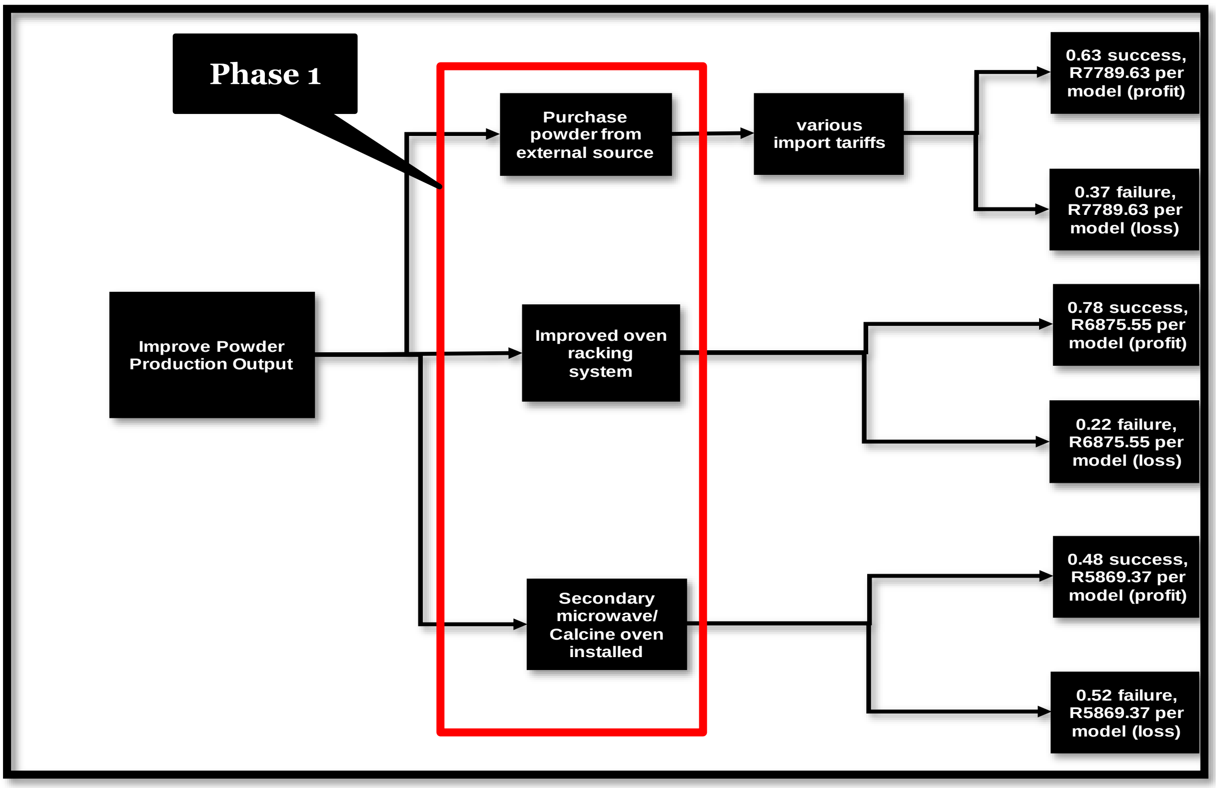

Figure 4: Decision Tree analysis of 3 possibilities

After conducting the tree analysis, the blocks in phase 1 of the analysis demonstrate the possible improvements that could be, and the blocks in phase 3 demonstrate the monetary values regarding one batch of powder as well as the probability factor of success or failure. Phase 3 would indicate the most economical criteria to choose from.

	External Purchase	Improved Racking System	Secondary Microwave and oven
Success	R4 907.47	R5 362.93	R2 817.30
Failure	-2882.1631	-1512.621	-3052.0724
	R2 025.30	**R3 850.31**	**-R234.77**

Table 1: Feasibility options

Table 2 reflects the calculation conducted, the green cells, highlights option 2 as the more applicable countermeasure to implement.

Option 2, being the “Improved Racking System” reflects the highest theoretical profit gain based on model costs over a period of 12 months. This will direct the project in developing an efficient and cost-effective mechanism that takes into consideration the ergonomics of members working on the line. The design will need to be easy as well as yield positive feedback from the members who will utilize the improvement in their everyday work.

4.5 Section conclusion

After weighing the 3 different options as stated in the decision tree analysis, the best analysis would be to improve the stacking matrix of the calcination rack combined with a user interface to get the best output from the calcination oven, this would allow for capacity to meet demand more conveniently allowing for flexibility on the line and reduce bottleneck at the PGM Powder area.

5 FINAL DESIGN

The best alternate decision will now be discussed, the improvement will meet the project aim, resulting in an improved stacking matrix, this will also be regarded as the final deliverable of the project and will be a practice of Industrial Engineering improvement tools.

5.1 Improved calcination stacking

The final design entails a new matrix of how production members stack the calcination oven rack, this allows for more tubs to be placed on the rack and ultimately increases capacity output. The sequence stacking will be broken up into horizontal and vertical stacking compared to only vertical stacking methods of the calcination rack. The figure below reflects both horizontal and vertical stacking based on the powder manufacturing method and quantity of tubs.

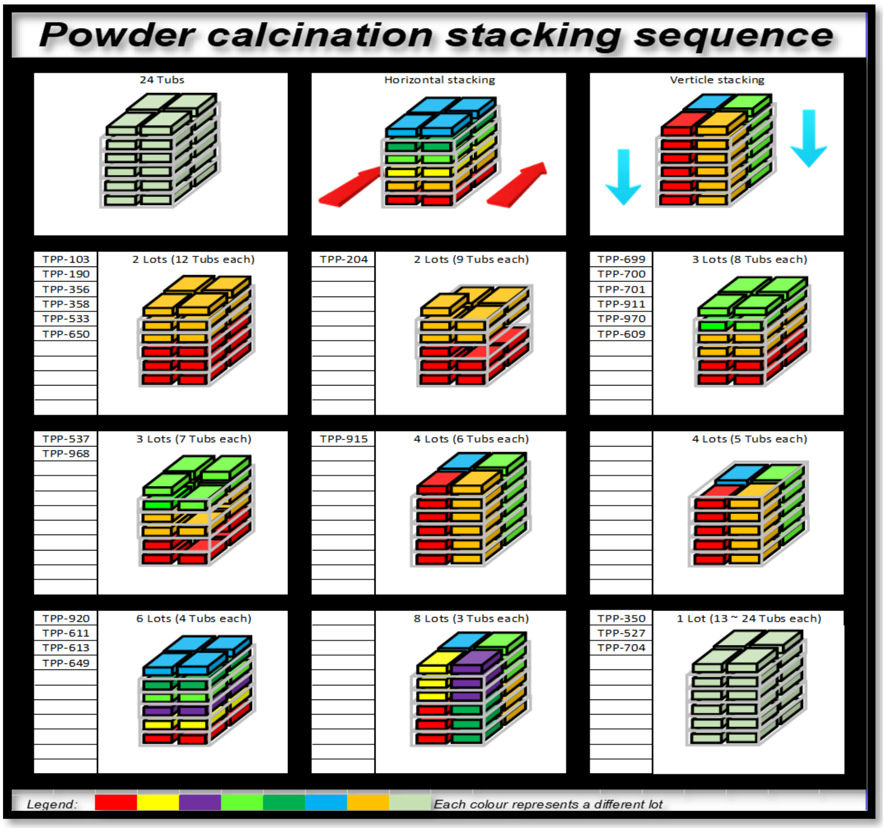

Figure 5: Horizontal & Vertical stacking methods.

5.2 Graphical User Interface development

Using the 4IR thinking, a graphical user interface (Figure 6) will run parallel to the stacking sequence, the member will make use of keyboards and scanners to load data onto the system as he or she loads the powder batch into the oven, the data will be stored and easily accessible to management for traceability purposes as well as eliminating the factor of batch mixing which can lead to contamination and ultimately loss in company profit margins.

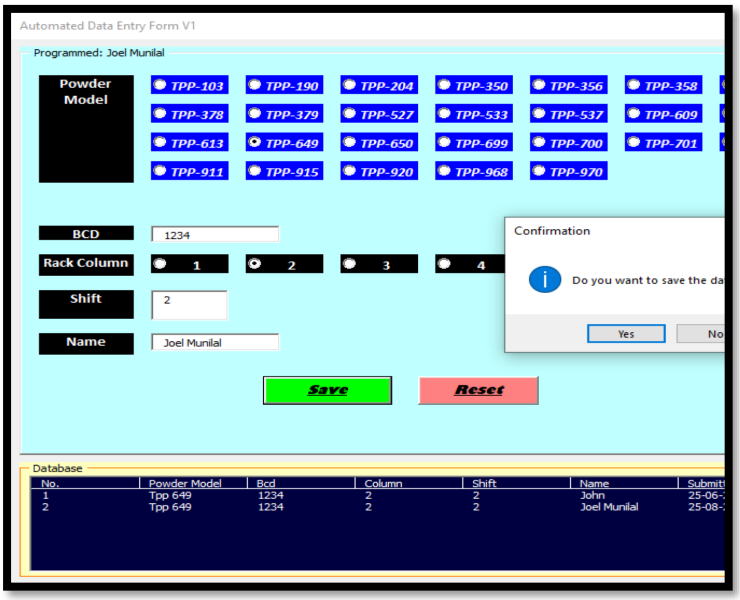

Figure 6:Example of UI (Final Stage)

5.3 Design conclusion

This section concludes with the improved stacking sequence and the graphical user interface that runs parallel to the stacking matrix.

5.4 Evaluation Conclusion

This final design meets the final design requirements. The deliverable of this project is the recommendations as to what areas in the system must be given attention. The recommendation of improving the stacking of the powder oven rack is accompanied by possible tools (stacking matrix chart and user interface) to be used to reach the designed capacities. Company ABC's management was happy with the final design and agreed that it could solve the problem.

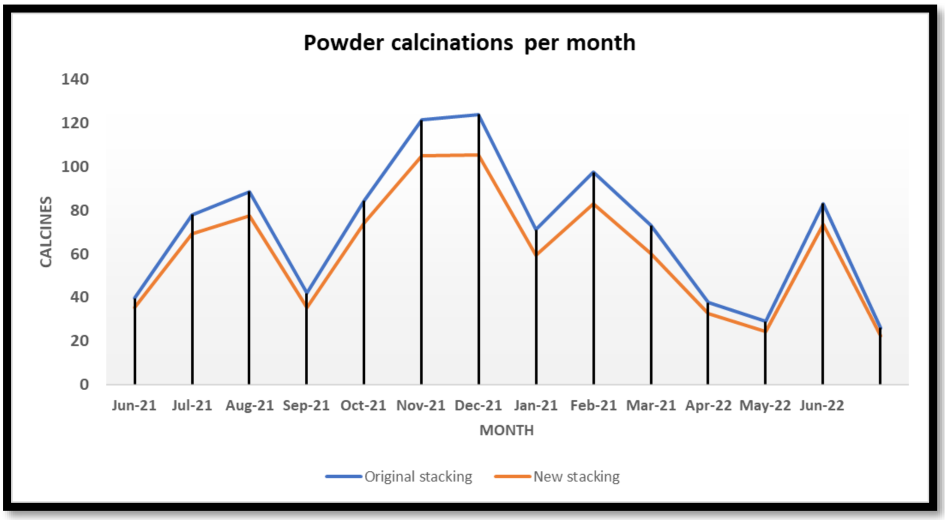

Figure 7: Original vs Improved stacking

Figure 7 reflects the originally planned calcination between June 2021 to June 2022, this datum is reflected on the blue line. The improved calculations are reflected on the orange line, the is an evident gap between the blue and green lines, thus reflecting an improvement in the calcination oven and proving the improved stacking method to be true. Before further approval from management was received, extensive trial tests had to be conducted using different analysis methods from production, after weeks of running trials on different powder models, the results returned positive and the green light was given from production, Figure 8 reflects data on one of the powder models at company ABC, the powder model is called (TPP – 920) that had been run on a trial to determine if the improved stacking method of the calcine rack affects the integrity of the powder. It is evident that the results fall within the tolerance range, thus maintaining the integrity and quality of the powder.

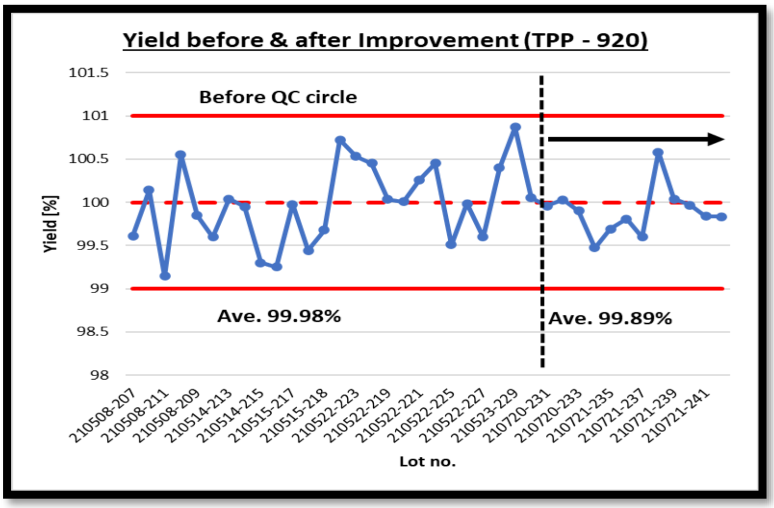

Figure 8: Trial analysis for TPP - 920

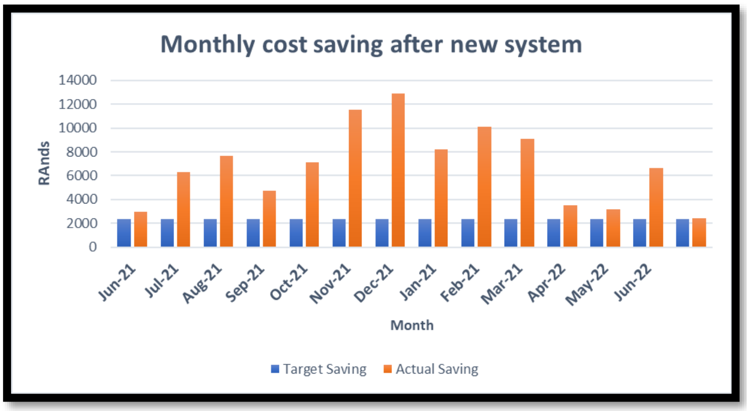

Figure 9: Cost Saving of improvement

Figure 9 reflects the theoretical cost-saving improvement that will be achieved after the new sequence method., the target saving was based on the average calculations that can be done on the line, however, based on different model runs, the orange bar reflects the actual savings to be achieved.

6 CONCLUSION

The final system design results were compared to both the current state simulation and the current state data from the past. This comparison displayed an immense increase in system capacity, resulting in a much larger system capacity than there is a demand in the current system. The final design and recommendations were delivered and were accompanied by a high-level implementation plan. The project aim and objectives were delivered on time. The problem statement is addressed, and the required deliverables are delivered.

7 RECOMMENDATIONS FOR THE SYSTEM

The powder production system does not group the same powder models to increase production efficiency. Implementing a new stacking matrix to increase volume going into the oven to improve production efficiency is highly recommended. Also, implement 2D barcode labels for each stainless-steel tub going into the oven, this allows for better traceability and not mixing lot numbers up.

7.1 Recommendations for Future Studies

Develop new universal stacking matrix methods to accommodate for instances such as the problem stated in this project. As well as develop a universal method for planning production based on a pull-forward method.

Understanding how to improve the greenhouse effect, based on reducing gas consumption in the automotive industry.

8 REFERENCES

[1] Gerber, H.U. and Shiu, E.S.W. (2005), “On the time value of ruin in a Sparre Andersen model”, North American Actuarial Journal, Vol. 9 No. 2, pp. 49-84.

[2] Kirkley, J., Paul, C.J.M. and Squires, D. (2002), “Capacity and capacity utilization in common-pool resource industries”, Environmental and Resource Economics, Springer, Vol. 22 Nos 1–2, pp. 71-97.

[3] M. Bengtsson, L. Andersson, and P. Ekström, "Measuring preconceived beliefs on the results of overall equipment effectiveness – A case study in the automotive manufacturing industry", *Journal of Quality in Maintenance Engineering*, vol. --, no. --, 2021. Available: 10.1108/jqme-03-2020-0016 [Accessed 3 June 2021].

[4] Bhat, K.S. and Rajashekhar, J. (2009), “An empirical study of barriers to TQM implementation in Indian industries”, The TQM Journal, Vol. 21 No. 3, pp. 261-272.

[5] K. Thampi and M. Jacob, "On a class of renewal queueing and risk processes", *The Journal of Risk Finance*, vol. 11, no. 2, pp. 204-220, 2010. Available: 10.1108/15265941011025206 [Accessed 6 May 2021].

[6] Castro, H., Putnik, G. and Shah, V., 2012. A review of agile and lean manufacturing as issues in selected international and national research and development programs and roadmaps. *The Learning Organization*, 19(3), pp.267-289.

[7] Chowdary, B.V. and George, D. (2011), “Improvement of manufacturing operations at a pharmaceutical company: a lean manufacturing approach”, Journal of Manufacturing Technology Management, Vol. 23 No. 1, pp. 56-75.

[8] Mangaroo-Pillay, M. and Coetzee, R., 2020. A systematic literature review (SLR) comparing Japanese Lean philosophy and the South African Ubuntu philosophy. International Journal of Lean Six Sigma, ahead-of-print(ahead-of-print).

[9] N. Vamsi Krishna Jasti and A. Sharma, "Lean manufacturing implementation using value stream mapping as a tool", *International Journal of Lean Six Sigma*, vol. 5, no. 1, pp. 89-116, 2014. Available: 10.1108/ijlss-04-2012-0002 [Accessed 20 July 2021].

[10] Nakhai, B. and Neves, J., 2009. The challenges of six sigma in improving the service quality. *International Journal of Quality & Reliability Management*, 26(7), pp.663-684.

[11] Pacheco, D., Pergher, I., Antunes Junior, J. and Roehe Vaccaro, G., 2019. Exploring the integration between Lean and the Theory of Constraints in Operations Management. *International Journal of Lean Six Sigma*, 10(3), pp.718-742.

[12] Pepper, M. and Spedding, T., 2010. The evolution of lean Six Sigma. *International Journal of Quality & Reliability Management*, 27(2), pp.138-155.

[13] A. Dadashnejad and C. Valmohammadi, "Investigating the effect of value stream mapping on operational losses: a case study", Journal of Engineering, Design and Technology, vol. 16, no. 3, pp. 478-500, 2018. Available: 10.1108/jet-11-2017-0123 [Accessed 21 August 2022].

[14] D. Matt, "Adaptation of the value stream mapping approach to the design of lean engineer-to-order production systems", Journal of Manufacturing Technology

[15] H. Singh and A. Singh, "Application of lean manufacturing using value stream mapping in an auto-parts manufacturing unit", *Journal of Advances in Management Research*, vol. 10, no. 1, pp. 72-84, 2013. Available: 10.1108/09727981311327776 [Accessed 6 May 2022].

[16] M. Suarez-Barraza, J. Miguel-Davila, and C. Vasquez-García, "Supply chain value stream mapping: a new tool of operation management", International Journal of Quality & Reliability Management, vol. 33, no. 4, pp. 518-534, 2016. Available: 10.1108/ijqrm-11-2014-0171 [Accessed 21 August 2022].

[17] N. Sangwa and K. Sangwan, "Leanness assessment of a complex assembly line using integrated value stream mapping: a case study", The TQM Journal, 2022. Available: 10.1108/tqm-12-2021-0369 [Accessed 22 August 2022].

[18] N. Vamsi Krishna Jasti and A. Sharma, "Lean manufacturing implementation using value stream mapping as a tool", *International Journal of Lean Six Sigma*, vol. 5, no. 1, pp. 89-116, 2014. Available: 10.1108/ijlss-04-2012-0002 [Accessed 20 July 2021].

[19] M. Alsaid, R. Kamal and M. Rashwan, "The performance of control charts with economic-statistical design when parameters are estimated", *Review of Economics and Political Science*, vol. 6, no. 2, pp. 142-160, 2020. Available: 10.1108/reps-05-2020-0055 [Accessed 9 May 2021].

[20] C. C. New and M. T. Sweeney., 2007. Delivery Performance and Throughput Efficiency in UK Manufacturing Industry.

[21] C. C. New and M. T. Sweeney., 2007. Delivery Performance and Throughput Efficiency in UK Manufacturing Industry.

[22] Wu, L., Chan, F., Niu, B., and Li, L., 2018. Cross-trained worker assignment and comparative analysis on the throughput of divisional and rotating seru. *Industrial Management & Data Systems*, 118(5), pp.1114-1136.

[23] Ekincioğlu, C. and Boran, S., 2018. SMED methodology is based on fuzzy Taguchi method. *Journal of Enterprise Information Management*, 31(6), pp.867-878.

[24] Singh, J., Singh, H., and Singh, I., 2018. SMED for quick changeover in manufacturing industry – a case study. *Benchmarking: An International Journal*, 25(7), pp.2065-2088.

[25] Wakjira, M.W., and Singh, A.P. (2012), "Total productive maintenance: a case study in manufacturing industry", Global Journal of Researches on Engineering & Industrial Engineering, Vol. 12 No. 1, pp. 25-32.

[26] Muchiri, P. and Pintelon, L. (2008), "Performance measurement using overall equipment effectiveness (OEE): literature review and practical application discussion", International Journal of Production Research, Vol. 46 No. 13, pp. 3517-3535.

[27] P. Tsarouhas, "Improving the operation of the croissant production line through overall equipment effectiveness (OEE)", *International Journal of Productivity and Performance Management*, vol. 68, no. 1, pp. 88-108, 2019. Available: 10.1108/ijppm-02-2018-0060 [Accessed 6 June 2021].

[28] S. Benjamin, M. Marathamuthu and U. Murugaiah, "The use of 5-WHYs technique to eliminate OEE's speed loss in a manufacturing firm", *Journal of Quality in Maintenance Engineering*, vol. 21, no. 4, pp. 419-435, 2015. Available: 10.1108/June-09-2013-0062 [Accessed 12 June 2021].

[29] Ylipaa, T., Skoogh, A., Bokrantz, J. and Gopalakrishnan, M. (2017), "Identification of maintenance improvement potential using OEE assessment", International Journal of Productivity and Performance Management, Vol. 66 No. 1, pp. 126-143.

[30] Cândido, C.J.F., and Santos, S.P. (2011), "Is TQM more difficult to implement than other transformational strategies?", Total Quality Management and Business Excellence, Vol. 22 No. 11, pp. 1139-1164.

[31] N. Bouranta, E. Psomas and A. Pantouvakis, "Identifying the critical determinants of TQM and their impact on company performance", *The TQM Journal*, vol. 29, no. 1, pp. 147-166, 2017. Available: 10.1108/tqm-11-2015-0142 [Accessed 4 June 2021].

[32] N. Mahmud and M. Hilmi, "TQM and Malaysian SMEs Performance: The Mediating Roles of Organization Learning", Procedia - Social and Behavioral Sciences, vol. 130, pp. 216-225, 2014. Available: 10.1016/j.sbspro.2014.04.026 [Accessed 21 August 2022].

[33] Rich, E. (2008), "Management fads and information delays: an exploratory simulation study", Journal of Business Research, Vol. 61, pp. 1143-1151.

[34] Verein Deutscher Ingenieure VDI (2014), "Simulation of systems in materials handling, logistics and production: fundamentals", VDI Standard issue 3633, December 2014, Beuth Publishing, Berlin.

[35] Zeigler, B.P., Praehofer, H., and Kim, T.G. (2010), Theory of Modeling and Simulation. IntegratingDiscrete Event and Continuous Complex Dynamic Systems, Nachdr. (ed.), Vol. 2, Academic Press, Amsterdam.