AN OPTIMIZATION MODEL FOR EVALUATING PERFORMANCE RATES USING LEAN MANUFACTURING PRINCIPLES IN LEBDAH CEMENT FACTORY

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Received 17 April 2025, revised 5 May 2025, accepted 11 May 2025

الملخص

تناقش هذه الورقة تطبيق نظام التصنيع الرشيق في الشركات الصناعية الليبية، وخاصة في مصنع لبدة للإسمنت (LCF)، حيث يواجه تطبيق نظام التصنيع الرشيق (LMS) داخل منظمات الإنتاج الليبية العديد من التحديات المتمثلة في تنظيم عملية الإنتاج والتنسيق بين مختلف عمليات الإنتاج، والوقت المهدور بسبب عمليات المناولة، لذا تم تصميم نموذج محاكاة للتحقق من الوضع الحالي لمدى تطبيق مبادئ التصنيع الرشيق، مع التركيز بشكل خاص على تقليل الأنواع السبعة من الهدر. تم استخدام برنامج FlexSim في عملية المحاكاة لنمذجة الخط الإنتاجي لمصنع لبدة للإسمنت من لحظة وصول المواد الخام إلى الحصول على المنتج النهائي. حيث تم تقسيم عملية المحاكاة إلى أربع مراحل لتسهيل العملية، مما يتيح تتبع عملية الإنتاج وتقييم أي تأخيرات قد تحدث في الخط الانتاجي. وقد كشفت النتائج التي تم الحصول عليها من نموذج المحاكاة عن عدم استخدام الوقت والموارد على النحو الأمثل، مع وجود كمية هدر كبيرة ناتجة عن معالجة المواد الخام. كما تم تنفيذ عدد من سيناريوهات التصنيع الرشيق أدت إلى تحسين خطوط النقل وإدارة المخزون، وإلى زيادة الإنتاج السنوي بنسبة 10% وانخفاض المنتجات المعيبة بنسبة 37%.

ABSTRACT

This paper discusses the application of the lean manufacturing system in Libyan industrial companies, especially in the Lebdah Cement Factory (LCF). The implementation of the lean manufacturing system (LMS) within Libyan production organizations faces many challenges such as challenges in organizing the production process and coordination between the various production processes, and the time waste due to handling operations. A simulation model has been developed for investigating the current state of implementation of lean principles, with a particular focus on the minimization of seven types of waste. FlexSim is used in the simulation process to model the production line at LCF from the arrival of raw materials to the final product. The simulation process is divided into four stages to facilitate the process. This enables tracking the production process and evaluating any delays that may occur. The results obtained from the simulation model revealed that time and resources have not been employed in an optimal manner, with a notable amount of waste occurring during the processing of raw materials. The implementation of lean manufacturing scenarios, including an optimization of conveyor lines and inventory management, resulted in a 10% increasing of the annual production and a 37% reduction in defective products.

KEYWORDS: Lean Manufacturing System; Lebdah Cement Factory; Performance; Production processes; Simulation model; Seven types of waste.

INTRODUCTION

Lean Manufacturing System (LMS) is a way that can be used to eliminate waste and improve the efficiency in a manufacturing environment, thereby reducing costs and maintaining product quality [1, 2]. In order to implement LMS, a variety of tools are employed among which simulation emerges as one of the most effective approaches. The modelling process involves a series of steps through which a system is imitated during a specific period of time and the required results from the process demonstrated [3, 4]. With the scientific development in the field of industry and the apparent increase in the complexity of production processes, there are many problems facing organizations in Libya. These challenges include waste and losses in the production process, and the need to develop the administrative process within organizations, whether industrial or service-oriented. The main objective of implementing a lean philosophy within organisations is to improve the flow- rate of materials by eliminating or minimising the wastes and non-value added activities. These wastes are overproduction, transportation, waiting, inventory, motion, over-processing and defects [5]. The simulation process can be considered as one of the most efficient solutions to address these issues. By studying the system, identifying its requirements, and subsequently organizing and developing it in terms of administrative and service functions; the performance rates of production processes can be evaluated. The main objective of this study is to identify the shortcomings and weaknesses inherent in the industrial operations currently in LCF by developing a simulation model, thereby providing scenarios for the proposed improvement.

AN OVERVIEW OF LMS IN CEMENT MANUFACTURING USING SIMULATION

This section provides a review of studies that adapted the application of simulation in implementing LMS. Previous studies highlight the effectiveness of simulation frameworks, software tools, and techniques for enhancing lean practices, showing their potential to improve manufacturing systems, including the cement industry. The successful application of lean tools and techniques depends on communication, culture, and people [5]. Implementing lean philosophy in cement industry highlights the success of communication, culture, and people in lean application [6, 7]. The proposed transformation steps have been shown to be useful for identifying waste, analysis of relationships and quantification of advantage through all the cement production. They focussed on applying LM principles to identify and reduce the waste in cement production processes and also make them more effective and efficient [5]. Tools such as Waste Relationship Matrix (WRM), Waste Assessment Questionnaire (WAQ), and Value Stream Analysis Tools (VALSAT) can be used to achieve the stated objectives. The researchers found that the three most significant types of waste in the cement production process were defects, overproduction and inventory. Moreover, activities were classified as non-value-adding, although necessary, and low-quality materials were identified as a waste contributing factor [8, 9].

Simulation has been used to evaluate the effect of Lean Manufacturing Systems (LMS) on manufacturing processes. A developed framework includes an integration of a simulation model using LeanSim with a value stream mapping (VSM) was presented. This framework was used in a milk factory. The obtained results illustrate the effectiveness of the simulation framework developed to enhance performance rates [10]. Also, another study examined the effectiveness of the game "The Lean Lemonade Tycoon

2” as a tool for teaching lean principles to undergraduate students. The outcome showed the game’s worthiness in simulating lean principles and impacting the learning, indicating the ability of games and simulations to bridge game-theory and in-practice learning [11]. In addition, simulation models were developed for the assembly line to work with lean concepts. The findings illustrated that simulation models improve efficiency, help to become more responsive and reduce production costs [12].

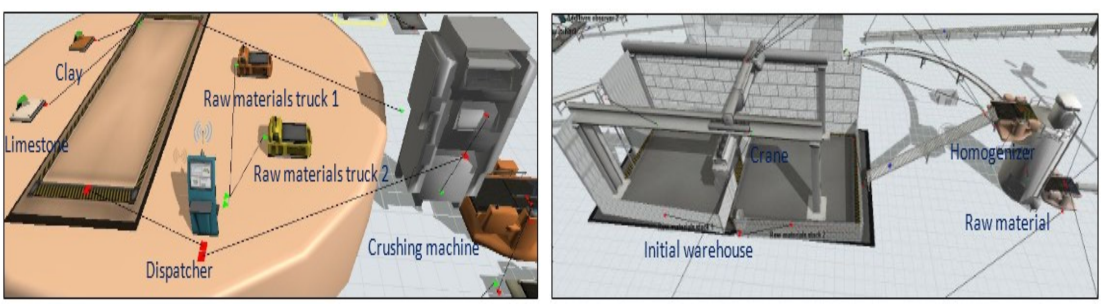
According to the literature review of the study about lean manufacturing, it can be stated that there is a gap in the research studies that deal with the extent of lean manufacturing system applications in the cement industry through adapting simulation models which is the primary contribution of the study.

METHODOLOGY & MODEL DEVELOPMENT

The methodology adopted for this study begins with an understanding of the simulation process in all its details from a theoretical point of view, followed by field visits to the concerned factory to study and evaluate its current status, to represent the simulation process in accordance to reality. Data was gathered by conducting field visits to the factory for a full working day; then the developed model is practically presented using FlexSim to imitate the current status of the factory, in order to increase its performance rates.

LCF was inspected with its machinery and equipment. It produces ordinary Portland cement in both bulk and packaged forms, with a design capacity of up to 1,000,000 tons/year, while the actual production capacity does not exceed 500,000 tons/ year [13]. The simulation process of LCF was conducted from the beginning of the raw materials arrival to the final product process using the FlexSim 3D simulation tool. FlexSim is a robust simulation software solution widely used for various projects, including modelling, analyzing, and improving complex systems [14].

The model for cement manufacturing simulation has four main stages to improve the flow as well as understanding. The first step is the arrival of raw materials such as clay and limestone to the main crusher, which has the capacity to run 10 hours daily and produce 500 tons/ hour. The transportation of raw materials to the main crusher is shown in Figure 1(a). The crushed material is subsequently followed, elevated to a primary warehouse and is then forwarded to the raw materials mill, where the rate of continuous operation is 220 tons/ hour, as shown in Figure 1(b).



(a) (b)

Figure 1: The first stage: (a) main crusher; (b) initial warehouse and raw material mill.

The second stage requires the transfer of additives (gypsum and iron) to the warehouse and a crusher, which is represented in Figure 2.

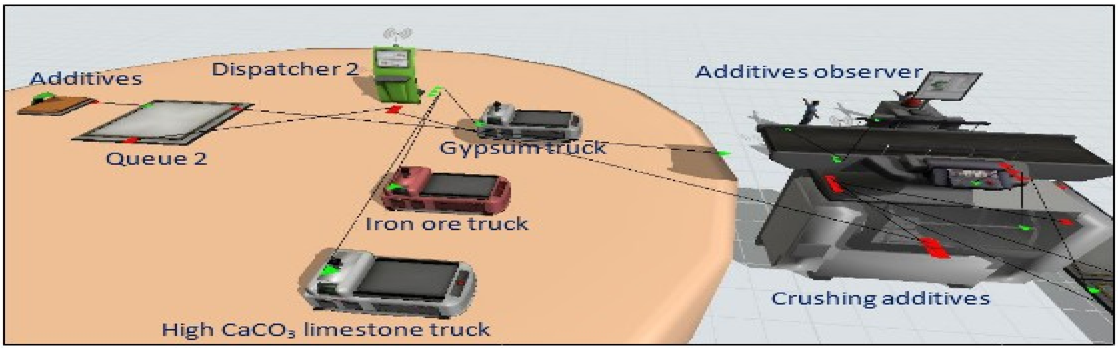
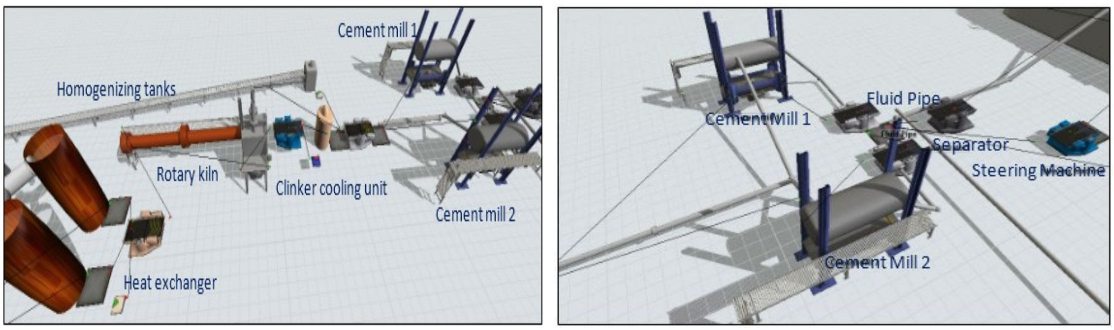


Figure 2: The second stage.

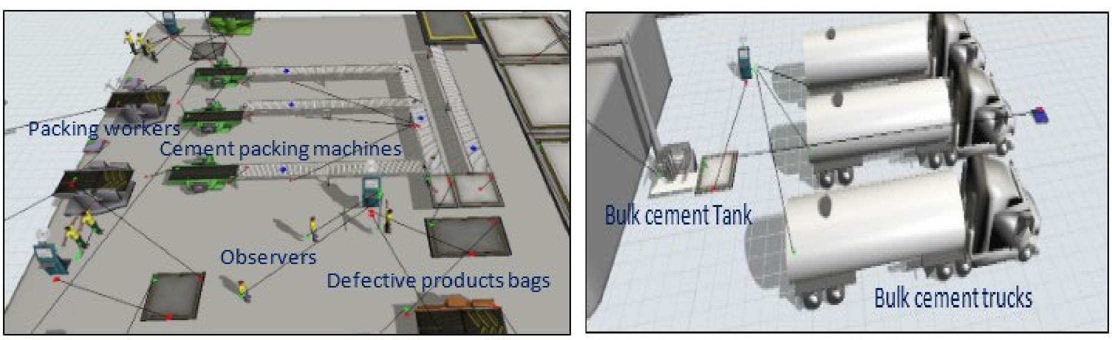
In the third stage, materials are transferred to homogenizing tanks and then to a rotary kiln, producing clinker with the remaining slag getting disposed of. The clinker is transported to the final mills shown in Figure 3 to be grinded with gypsum.



(a) **(b)**

Figure 3: The third stage: (a) rotary kiln; (b) cement mills.

In the last stage, shown in Figure 4, cement is packed into bags and silos which accounts for 70% and 30% respectively. Both forms of packing are automatically done. Important production system dynamics were captured by running the simulation 25 times for a simulated workday, as the system's waiting and interaction time, material flow, and discharge volume changed cyclically over a workday.



(a) **(b)**

Figure 4: The fourth stage: (a) packing section for bagging cement; (b) bulk cement filling trucks.

RESULTS ANALYSIS AND DISCUSSIONS

The findings obtained from the simulations contain an analysis of the waste quantity in the production process. Also, the impact of each type of seven types of waste on performance rates. These findings will be presented as follows.

Motion

Figure 5 shows workers in the cement bagging stage, which displays them as active for 38% of the time. This consists of 11% empty bag carrying, 13% returning to the site of work, and the remaining waiting time is due to workers not having access to the filling machines.

Figure 5: The specific tasks assigned to production line workers and operators.

Transportation

Material handling processes were implemented using two types of trucks as shown in Figure 6. type 1 was used to handle primary raw material, whereas type 2 was used to handle the other material additives. It is clear that type 1 has a transit time of 49% of the total time, while type 2 has a considerable short transit time of 1%. In this figure, the last row contains the time required to handle cement bags using robotic arms, which takes 25% of the total time each arm.

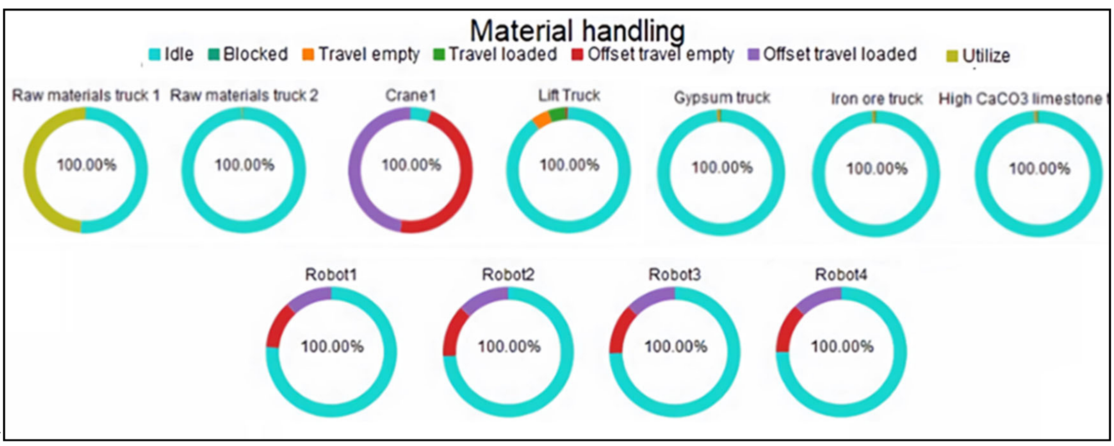


Figure 6: The time taken to transport materials.

Waiting Time

Figure 7 demonstrates the time processing of raw materials using machines used in the factory. The Crusher works for 12 hours a day and processes 49% of raw materials. Quality laboratory 1 suffers a waiting time of 36% of the whole time because of the quality observer's delay. The test process takes 5% of the total time, while quality laboratory 2 suffers a time loss of 4% due to late sample arrivals.

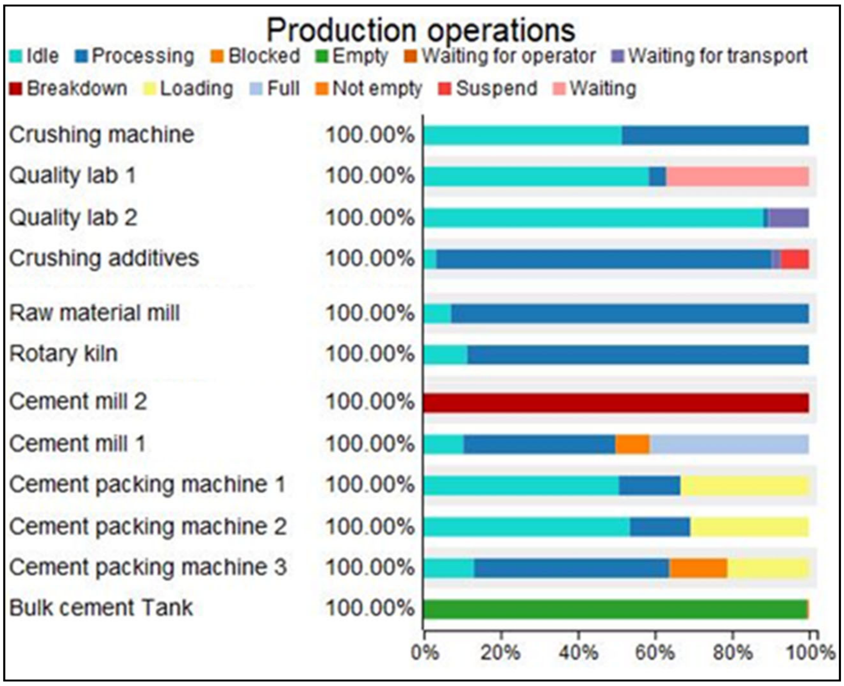


Figure 7: The specific tasks assigned to production line workers and operators.

Overproduction and Overprocessing

Figure 8 illustrates the productivity of the factory machines. The crusher processes 5,880 tons of material daily, while the additive crusher only produces about 290 tons, or 5% of the raw material input. The raw materials mill handles 6,270 tons, including re-ground materials due to quality issues. Also, the kiln processes 4,620 tons, and the cement mill produces around 1,436 tons. Additionally, the packing machines collectively produce 448.45 tons/ day.

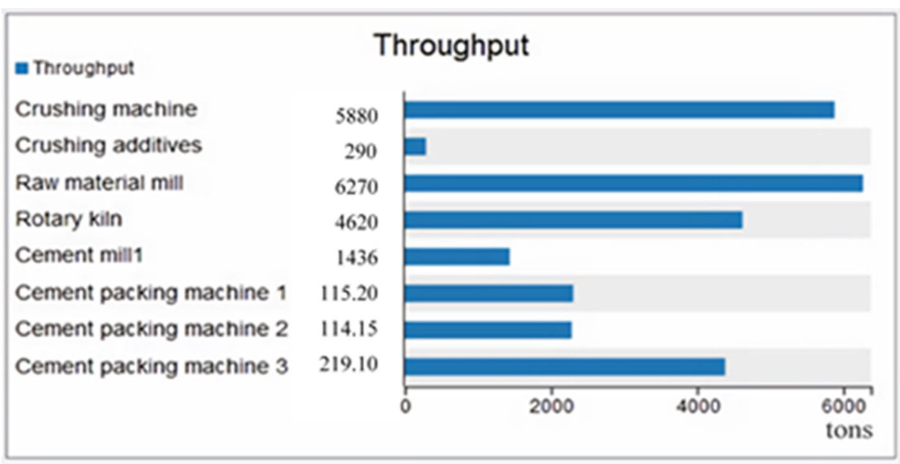


Figure 8: The amount of materials processed by machines in the production line

However, the examination time is 2% which is little, since assessing components of the mixture takes a short time. Mill 1 works for about 40% of the total time, whereas due to material accumulation, its efficiency is reduced to a 9% blockage, which doubles milling time. For packing machines 1 and 2, bag stabilization stands at 33% with a packing time of 16% and 33%. The third packing machine displays breakdowns and interruptions in stabilization.

Inventory

Figure 9 illustrates the relationship between Work in Progress (WIP) and time concerning main raw materials. As time progresses, a semi-linear pattern is observed. The peak proportion ratio of the material consumed compared with the stored volume of materials reaches 38% per day.

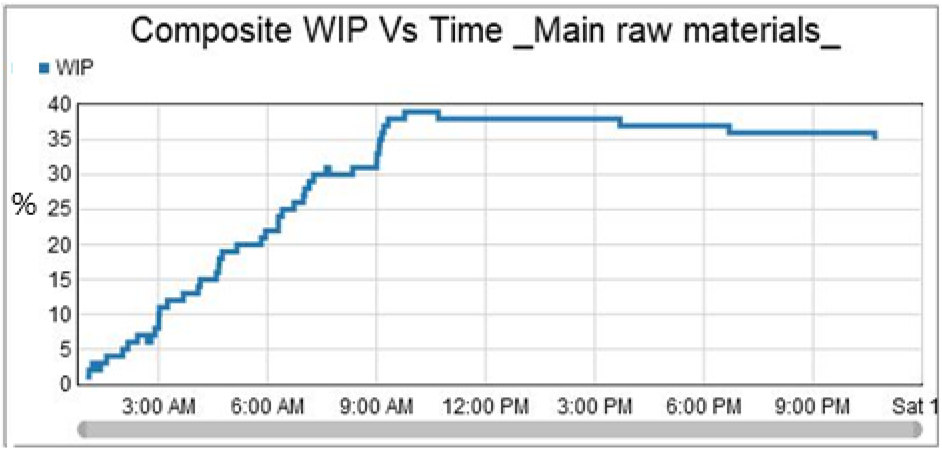


Figure 9: Composite WIP vs time (main raw materials).

Defects

Figure 10 shows the losses sustained during the process of the factory's production. Burning losses are the single greatest percentage loss accounting for 1,202 tons of impurities, in addition to slag resulting from the rotary kiln lost per day. Also, this figure illustrates that 0.4 defective tons are torn apart during the belt movement every day.

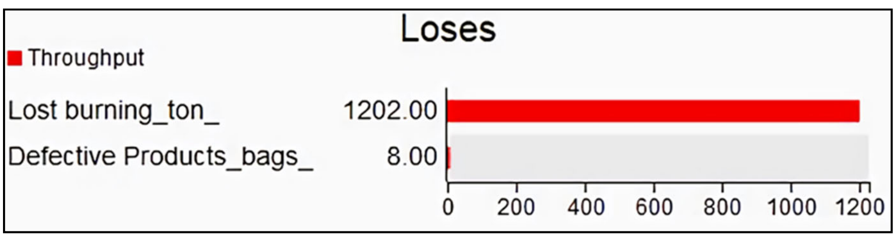


Figure 10: The amount of daily losses during the production process.

Figure 11 illustrates the daily production quantities of the plant. The first row shows the amount of cement produced 1203 packages, which weighs 30 bags of 50 kg each. The second row indicates that roughly 428 tons of bulk cement are produced a day.

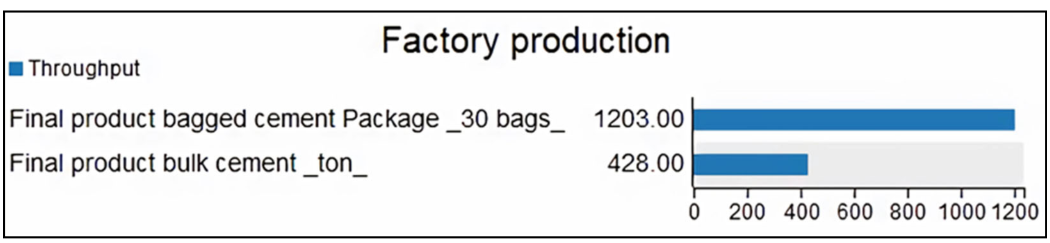


Figure 11: The daily production volume of the factory.

Bagged cement production is expressed in tons rather than units. To determine the average production per year, the value of total production is divided by the number of working days. The production is then calculated by multiplying the hourly average productivity by the number of hours worked in a year:

$$\frac{2{,}232.5}{24} \times 5{,}375 = 499{,}987\ ton/\ year$$

OPTIMIZATION SCENARIOS

A number of scenarios were applied to determine the impact of the seven types of waste in the Lean Manufacturing framework and assess their effect on the LCF production process, in order to find possible optimization opportunities.

Motion Scenario

This scenario shows the impact of motion on the time it takes from the workers to carry out their tasks. In this scenario, the percentage of time (bag transfer and return) decreased by about 20% for the workers responsible to packing cement bags. This can be achieved due to the coordination improvement between operators in the packing department, by setting a specific time to install cement bags on the packaging machines at the same time, and changing the bags when they finish packing instead of the concerned worker to minimize the wasted time, thus increasing the operating time of the operators to about 40%.

Transportation Scenario

In this scenario, it was supposed that all tasks related to the transportation stage to be equally shared among the raw material transportation trucks to enhance the smoothness of the transportation stage without overloading the truck. It was also proposed that for the transportation of bagged cement, the number of trucks was reduced from 6 to 5 and for the bulk cement filling was reduced from 3 to 2. This is a 33% reduction in the number of transportation processes.

Waiting Time Scenario

This scenario provides coordination between the production processes from crushing raw material until obtaining the finished product. However, the bad communication between the observers at the factory leads to additional waiting time. As the production process has been started, machines are firstly to be set up before each shift begins. This reduces the processing time and the incidence of sudden stops, thereby accelerating the production process. By coordinating between workers in the packing department, it can be seen that the loading time is reduced by 15% due to the simultaneous installation of all cement bags in the packing machine.

Overproduction and Overprocessing Scenario

This improvement scenario results a 10% reduction in the daily consumption of raw materials. To this end, increasing in-between batch time of material additives so that final volume of additives per day is minimised, while ensuring that the production is carried out in a manner such that no processed material is stored in warehouses in bulk, which may cause degradation of quality. This results in the mill required to process the materials on more than one occasion to achieve the necessary degree of smoothness.

Inventory Scenario

In this scenario, it was proposed that the cement mill uses the clinker immediately after it comes out of the cooling unit and stores the surplus quantity. Therefore, the relationship becomes linear and without clinker accumulation in the warehouse, similar to the current situation in the factory, and reducing the storage percentage to 15%.

Defects Scenario

Due to the occurrence of defective products of bagged cement in terms of the occurrence of rupture of some bags as a result of the poor design of the belts, it was proposed in this scenario to make a change in the design of the belts to be curved instead of straight where rupture occurs due to the sharp angles connected between the belts, if the belts are curved, these angles are avoided, thus reducing the percentage of torn bags, which is approximately 3 bags over 24 hours instead of 8 bags, reducing the defective products percentage by 37%.

By applying all the previous scenarios, the factory's daily production volume increased as shown in Figure 12. The production volume of bagged cement per pack reached 1371 packs, each containing 30 bags weighing 50 kg per bag, while the daily production volume of bulk cement did not change.

Figure 12: The daily production volume of the factory after the seven-waste scenario.

Upon converting to tons, the resulting production quantity is 556,424 tons/ year. Therefore, the annual production volume increased by 10%.

Based on the findings obtained by implementing the seven types of waste scenarios, it is clear that Lebdah Cement Factory's production processes can improve their performance.

CONCLUSIONS

This study presented the impact of lean manufacturing principles on performance rates within Lebdah Cement Factory by adapting a simulation model. FlexSim was used in the simulation process to model the LCF production line. By simulating the production process for a period of day, the findings illustrated that the production quantity during this time period is 499,987 tons annually, which is within the limits of the actual production capacity of the factory. Furthermore, a series of scenarios was conducted to evaluate the potential impact of the seven types of waste identified within the Lean Manufacturing framework on the LCF production process. The implementation of these scenarios increased the production by 10% of the annual production and reduced defective products with a rate of 37% as well, which has led to significant improvements in the efficiency of production processes in LCF. For further research, the authors recommend another lean manufacturing tool such as 5S. The theory of constraints (TOC) could be used to continuously improve the performance rates for the purpose of increasing the overall effectiveness of production processes in LCF. Also, extending the simulation period for more than one workday could provide deeper insights into system dynamics and variations in performance over time. In addition, training programs, which include the implementation of lean manufacturing and organizational cultures, could be adopted, in order to improve the factory performance.

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