Optimizing Efficiency and Safety in Industry: The Power of Industrial Engineering Techniques for Waste Identification and Productivity Improvement

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Abstract. The present research aims to identify the critical issues of plant inefficiencies caused by plant wastes and safety issues. The study was conducted at a medium-scale cement refractory manufacturing special application cement. The research involved waste identification, waste analysis, and waste elimination solutions. The wastes were identified and segregated based on the 8 lean manufacturing wastes. The issues of worker safety have also been identified and documented. The analysis was performed on the man-machine utilization using the man-machine charts. This resulted in a reduction in the idle time of the operator by 32% and led to the optimization of the workforce. The types of waste have been analyzed and improvements in productivity, waste minimization, worker utilization, and worker safety solutions have been proposed. The study uncovers worker underutilization, which led to suggestions for improvement in working conditions and material handling processes to improve the overall plant's productivity and sustainability.

Keywords: Productivity Improvement · Waste Identification · Manpower Utilization · Safety · Optimization

1 Introduction

1.1 Background

This paper presents a field study conducted at a medium-scale cement refractory unit that specializes in manufacturing high-quality refractory cement for specialized applications. The company is focused on increasing production and reducing waste across the entire plant, and it plans to do so by identifying and eliminating sources of waste. The study was carried out at a cement refractory industry located in Nagpur, India, which has been operational for the past two decades. The company is committed to reducing waste and improving safety parameters to increase the effectiveness of production, as directed by its top management.

The prime objective of this research is to identify and reduce lean manufacturing wastes by maximizing the efficiency of utilization of the workers and improving safety

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standards. The research focuses to identify the wastes, mapping them with lean manufacturing wastes, analyzing the causes of wastes, and providing the solutions which would lead to enormous amplification in the reduction of wastes at the plant and would help to understand the causes and develop the safety benchmarks for the refractory. This could be achieved by segregating the refractory wastes into the 8 lean manufacturing wastes. In the absence of an efficient production system and hazard-free workplace, the plant moves towards the creation of waste and develops inefficiencies. Furthermore, it may result in optimization in the utilization of the resources (manpower, machine, material, etc.) and reduction in activities leading to the cost of the refractory.

The paper is organized as follows: Sect. 1 includes the introduction, which consists of the background and literature review related to the research. Section 2 includes the research methodology used in this study, we mapped the waste identified according to the 8 lean wastes and developed the analysis based on the collected data from the refractory. Section 3 presents the conclusion of this study.

1.2 Literature Review

Industrial Engineering (IE) has developed as an essential component of contemporary manufacturing and production systems. IE focuses on increasing the productivity, safety, and efficiency of industrial processes via the use of diverse techniques and approaches. The power of IE approaches for waste identification and productivity enhancement in the industry is investigated in this study.

Many researchers have recently emphasized the advantages of IE approaches for industrial operations. Several measures to reduce manufacturing wastes and costs have been implemented throughout the past three decades, including lean manufacturing [1]. The primary goals of this effort are waste reduction and increased efficiency. The authors of [2] attempt to examine the potential use of the seven-waste concept in the context of office work activities, despite its typical association with manufacturing processes. The results of a lean assessment of a laboratory for chemical analysts training in a higher education institution that sought to understand lean maturity and identify the key categories of waste produced regularly revealed that wastes were primarily caused by transportation, waiting, and defects [3]. According to research findings of a small-medium enterprise (SME), waiting, wasteful inventory, and wasteful defects were the main sources of waste in the production process [4]. Every organization may use the Lean philosophy of eliminating waste, but it is crucial to identify and address waste to provide value to the consumers of the end process [5]. The study showed reduced waste output through novel agriculture production applications inspired by lean manufacturing wastes [6].

Organizations experience waste that encompasses actions that do not add value and hazardous work conditions. That can result in discontent among customers, employees, the organization itself, and environmental degradation [7]. They contend that IE approaches may assist in the identification of waste and inefficiencies in industrial processes, resulting in increased productivity, safety, and profitability. Moreover, IE approaches can help to increase the sustainability of industrial operations, for example, showing that IE approaches may be utilized to lessen the environmental effect of industrial operations.

The assessment of the literature emphasizes the importance of IE approaches for waste detection and productivity enhancement in the sector. To reduce the lead time for manufacturing, businesses must recognize value-added activities on goods and decrease non-value-added activities [8]. IE approaches may aid in the optimization of operations, the improvement of safety, and the reduction of non-value-added activities. According to [9], the use of industry 4.0 tools in the manufacturing segment to increase worker knowledge, skills, and competencies as well as their capacity to reduce operator motion wastes influences the social elements of production.

The following research has its focuses on creating a holistic improvement and a very positive impact on the manufacturing plant working and the life of its employees using IE techniques. The relative efficacy of various worker safety and health training techniques that seek to enhance performance and understanding in terms of safety and prevent undesirable effects [10]. Worker ergonomics and other lean manufacturing parameters play an essential role in designing the assembly process [11]. Worker health has always been a prime concern for the management and the processes involved in the plant pose an inherent risk to all the labor on the shop floor. Continuing to enhance material handling might be a catalyst for drastically cutting the overall time and also contribute to improving ergonomics by lessening human effort and, therefore, fatigue [12]. The improvements were mainly focused on productivity, waste minimization, manpower utilization, and worker health. The novelty in this research lies in the comprehensive identification and analysis of plant inefficiencies caused by waste and safety issues in a specific medium-scale cement refractory manufacturing plant. The researchers used lean manufacturing principles to identify and segregate waste and utilized man-machine charts to optimize workforce utilization.

2 Research Methodology

The research identifies plant inefficiencies and safety issues in a cement refractory manufacturing plant and proposes waste elimination solutions. The study improves productivity, waste minimization, and worker utilization while optimizing the workforce. This research can be useful for researchers in identifying plant inefficiencies and safety issues in similar manufacturing plants and proposing solutions to improve productivity and sustainability as the methodology can be implemented in medium-scale industries without any major capital investment. Identifying waste in the plant and acting on improving it is a viable option for increasing production and reducing costs. The wastes have been identified and segregated based on the 8 wastes of Lean Manufacturing and maximizing manufacturing efficiency. The analysis based on the collected data has been performed to plot the process flow chart and man-machine charts to eliminate the wastes present in the manufacturing plant. Based on the analysis, the solutions have been proposed in the waste elimination section.

2.1 Waste Identification

The refractory operations were studied and the activities which led to developing the waste have been identified are segregated as per the 8 lean manufacturing wastes. The eight lean manufacturing wastes consist of Overproduction, Waiting, Transportation, Processing, Motion, Inventory, Defects, and Unused Talent [3]. The existing process has a laborer who is required to pierce a hanger-like instrument in the sack and pull it from a stack of the same onto the ground as in Fig. 1. Then he has to re-pierce the hanger and drag the sack from the stacks to the trunk, which is about 15 m from the stack. In this process because of the piercing, the sack is damaged to a certain extent and hence the lime in it falls on the ground and hence is wasted.

When the raw mix is transported from the BBM machine to the Nodulizer, as shown in Fig. 2, it must be stored once in a WIP stack as a buffer for the Nodulizer and allows quality check. The following raw mix is stored in sacks of about 50 kg. The sacks are sealed with rubber bands, as they must be opened in a few hours at the Nodulizer. The following sacks are placed horizontally in the WIP, and two rows of sacks are placed upon each other. When one sack is placed above the other there are multiple times when the rubber bands of the lower sacks burst open. This causes the raw mix to pour out on the ground and hence be wasted.

When handling the nodules, do tend to fall out of the trolleys at multiple locations. This results in those nodules being crushed under the worker's feet and hence are wasted. This also contributes to the uncleanliness of the shop floor which can be seen in Fig. 3 and requires constant cleaning.

Fig. 1. Carrying the Bags using a hanger

Fig. 2. Raw-Mix bags burst due to excess pressure.

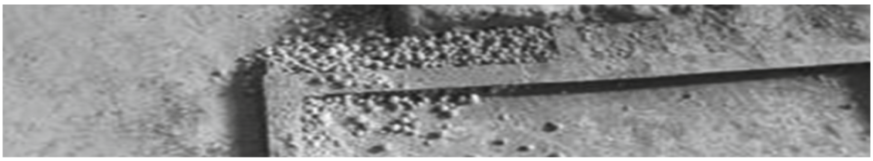

Fig. 3. Nodules being spread on the shop floor.

Fig. 4. Nodules not being dispensed properly into the trolley.

The clinkers are manufactured in the rotary kill. They are thrown out of the trolley because of the inherent force by which they exit the machine which can be seen in Fig. 4. Hence, they fall off the trolley in considerable amounts. The clinkers are the main bottleneck of the plant and hence wastage of this resource is not affordable by the complete process.

The ground clinkers are stored in sacks before being processed further. When it must be used, the sacks are supposed to open, and the powder must be poured into a bigger container to be transported to the BBM machine. The sacks, however, are thrown inside the bigger container as they are very heavy. This generates a huge amount of dust, which is extremely hazardous for the worker's health. Similarly, all the wastes in the refractory were identified and categorized matching the 8 types of wastes in Lean manufacturing in Table 1.

Additionally, the issues of worker safety are highlighted separately in Table 2.

2.2 Waste Analysis

After identifying and segregating the wastes and safety issues, the problems causing the wastes and safety negligence were detected as provided in Table 5. The analysis was carried out to determine the workers' utilization; we observed that the workers were not properly utilized. At the Batch Ball Mill machines, two operators were assigned the same task, which was not necessary at all. When we analyze Man-machine charts on Batch Ball Mill machines, we have found the results shown in Table 3.

From Table 3. It was observed that the average idle time of the operator working on a single machine is 40.5 min in each cycle of the batch, whereas his/her working time is just 17.5 min. Thus, we have plotted a Single Man Multi-Machine chart to see if a single operate both machines. Plotting the Single Man Multi-Machine chart from Table 4, the idle time was reduced by 32% based on the observations and man-machine charts, also an extra operator that can be utilized for other tasks.

2.3 Waste Elimination Solutions

The solutions provided in Table 5 to the problems identified is presents various suggestions to reduce waste and improve efficiency in the cement manufacturing process. The

Table 1. Waste Identification

Type of Waste	**Description**	**Refractory**
Overproduction	Producing more than is needed or producing it too soon	Producing more raw mix than necessary
Waiting	Idle time due to delays in production	Idle time of operators at the BBM machines
Transportation	Unnecessary movement of materials or people	Dragging lime bags with a hanger, transporting nodules on trolleys
Processing	Unnecessary processing, overprocessing	Wastage of clinkers due to falling off the machine, grinding excess clinkers
Motion	Unnecessary movement of people	Operators at the BBM machines moving between two separate machines
Inventory	Excess inventory or unnecessary inventory	Stacking raw-mix bags on top of each other, having too many nodules on a single trolley
Defects	Rework, scrap, or incorrect output	Wastage of lime due to spilling on the floor, nodules falling out of trolleys
Unused Talent	Underutilizing people's skills and abilities	Assigning two operators to the same task at the BBM machines

Table 2. Worker's Safety Issues

Type of Issue	**Description**
Worker Safety	Lack of safety gear for workers, leading to potential harm from dust particles, noise, and machinery

Table 3. Results of Single-Man Single-Machine chart

Time activity chart each batch cycle (in minutes)		
	Operator	**Machine 1**
Average Idle time	40.5	16
Average Working time	17.5	42

suggestions were identified through a careful analysis of the process, including observing the flow of materials and the activities of workers. These suggestions serve as an initial point for implementing lean manufacturing principles in the cement industry.

Table 4. Results of Single-Man Multi-Machine chart

Time activity chart each batch cycle (in minutes)			
	Operator	**Machine 1**	**Machine 2**
Idle time	27.5	10.5	18
Average Working time	30.5	48.5	38

Table 5. Summary of Lean Manufacturing solutions for reducing waste and improving efficiency in the cement manufacturing process.

Problem	Solutions
Raw material wastage due to torn sacks during loading and unloading activity	Using pallet jacks or hand trucks may also be used depending on the size of the sack for transportation. Store sacks on wooden platforms.
Raw material wastage due to horizontal storage	Store sacks vertically to reduce wastage. Storing cement sacks vertically would insert less pressure on the openings section of the sacks as in Fig. 2.
Nodule wastage during storage	Lay industrial plastic on the floor with a funnel-like shape to contain the nodules.
Inefficient clinker poured into Nodulizer	Install a hydraulic lift to reduce travel time.
Clinker wastage during collection	Install a funnel metal plate on the collection container to reduce wastage and improve worker safety.
Time-consuming trunk movement	Fit wheels to the trunk to reduce cycle time.
Dust and wastage during ground clinker powder sack handling	Reduce the sack capacity to half to make it lighter and easier to handle.
Inefficient labor usage on BBM machines	Have one operator handle both BBM machines to increase productivity and save on labor costs. There is a significant amount of idle time for the worker working on the BBM machine as shown in Table 3.

3 Conclusion

In this research, we have successfully identified lean manufacturing wastes and worker safety issues to improve the plant's productivity. Eliminating the wastes identified will enable the plant to run more effectively and boost general output. The reduction of accidents and injuries would also assist to boost productivity by lowering lost time and accident-related expenses. Addressing worker safety concerns will also help to reduce accidents and injuries. The underutilization of workers was addressed using man-machine charts which led to a reduction in the idle time of the operator by 32%. The solutions proposed would significantly reduce the waste in the refractory.

4 Future Scope

Future work will work on developing a heuristic technique for reducing waste in lean manufacturing. While data sets from various plants could support the proposed waste recovery technique. Statistical methods such as Moving Average or ARMA could analyze the impact of idle time reduction on productivity, and experimentation could determine the most effective approach for improving productivity.

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