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REDUCTION OF WASTE USING LEAN MANUFACTURING TOOLS IN REFERENCE TO THE CERAMIC INDUSTRY

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ABSTRACT
The study aimed to pinpoint areas within the ceramic tile production process requiring enhancement to bolster market competitiveness. The primary issue identified was a notable prevalence of waste, chiefly manifested through high reprocessing rates and prolonged waiting times. Through root cause analysis, the study proposed an improvement framework grounded in Lean Manufacturing principles, comprising two distinct approaches: one targeting process refinement utilizing tools like VSM, and the other focusing on maintenance enhancement through TPM. Given the mixed nature of continuous and non-continuous processes inherent in ceramic tile manufacturing, specific challenges such as downtime, miscommunication, and mishandling were identified as major sources of waste. To address these, the study advocated for the implementation of Lean tools such as Root Cause Analysis, visual factory techniques, and multifunctional employee roles aimed at mitigating downtime, enhancing communication, and improving handling procedures. The research findings underscored the efficacy of Root Cause Analysis in minimizing downtime by eradicating underlying issues causing production failures. Furthermore, the paper provided empirical data elucidating the impact of various Lean practices when applied independently, alongside barriers impeding their adoption within the sector. Despite limited variation observed across certain variables among sampled firms, challenges in accessing requisite data for calculating capacity utilization hindered a comprehensive analysis of its effects.

Keywords: Ceramic industry, Lean Tools, VSM, TPM, Simulation

INTRODUCTION
Ceramic products hold significant importance in the global construction sector, playing a vital role in infrastructure development [1]. With India emerging as the largest exporter, 521,400 tons of ceramic products were exported worldwide in 2018 [1]. Notably, the Peruvian construction sector has experienced a modest 0.03% growth rate in recent years, driving a remarkable 22.2% increase in ceramic production, given its pivotal role in construction activities [2]. Within this sector, approximately 27% of ceramic manufacturers produce a staggering 957,451 tons annually, amounting to a substantial market movement of around $31.6 million [3]. Despite the sector's significance, small- and medium-sized enterprises (SMEs) in the ceramic industry encounter numerous challenges [4]. These include inefficient furnace operations, reliance on unsuitable fuels, subpar product quality, excessive waste generation, and ineffective operational processes. Addressing these difficulties is imperative for enhancing the competitiveness and sustainability of SMEs in the ceramic sector. India has undergone rapid urbanization, with the urban population reaching approximately 36% in 2022 and projected to rise to 40% by 2030, totalling around 600 million urban dwellers. This urbanization trend primarily stems from city expansion and population migration. Significant investments have been directed towards various urban development sectors including housing, road infrastructure, transportation, water supply, power systems, smart city initiatives, and urban governance. Consequently, the demand for residential and commercial construction has surged, propelling the growth of the Indian ceramic tiles market. The country's urban landscape is experiencing an absolute increase in population, driven by rising middle-class incomes and a stable democratic framework. Moreover, annual rural-to-urban migration further contributes to the formation of new cities with burgeoning populations. Lean manufacturing (LM) aims to enhance responsiveness to customer demand by minimizing waste in human efforts, inventory, time-to-market, and manufacturing space, all while ensuring the production of quality products efficiently. Initially embraced by the automobile industry, LM has since been adopted across various sectors including textile, construction, medical, food, electrical & electronics, furniture, and services. The integration of

Value Stream Mapping tools (VSM and Kanban) has proven effective in waste reduction within textile enterprises, concurrently boosting inventory turnover and operational profitability. However, misapplication of VSM can yield unfavourable outcomes, necessitating careful implementation to avoid technical and financial setbacks. Despite this, VSM exhibits substantial potential for increased productivity and reliability as a lean tool, facilitating systematic diagnosis and identification of lean project opportunities. In the context of the power sector, ongoing reforms and infrastructure expansions have spurred demand for insulators, particularly high-tension variants, with India poised to capture 25-30% of the global electric insulator market by 2019. While LM has found widespread adoption across various manufacturing systems, its implementation in continuous process industries has encountered challenges, partially attributed to industry-specific complexities. Notably, applying LM in ceramic industries, which encompass both continuous and discrete manufacturing processes, presents unique hurdles. Defective ceramic products pose environmental threats, resource losses, and missed opportunity costs due to their non-recyclability and inability to undergo rework. Thus, this study aims to demonstrate the applicability of LM in the ceramic sector, focusing on defect reduction, waste minimization, shortened waiting and processing times, inventory optimization, rejection reduction, and space efficiency. The statement highlights the complexity of Lean Practices (LP) implementation and the diverse range of techniques involved. Researchers have noted that adopting LP in a piecemeal fashion may not effectively enhance operational performance indicators. In fact, implementing a single LP tool in isolation could potentially have a detrimental effect on overall performance. This discrepancy arises because while certain practices may optimize specific operational areas, the localized improvements may not necessarily translate into overall operational enhancement. Therefore, when assessing the impact of LP practices on operational performance, researchers suggest considering various control variables. These variables include plant size, industry type, product characteristics, level of vertical integration, capacity utilization, model mix, automation level, and market requirements. By analysing LP practices in conjunction with these control variables, researchers can better understand their holistic impact on operational performance across different contexts. The rest of the article explores, as in Section II, related work in the ceramic industry using lean tools; in Section III, research methodology for waste reduction; in Section IV, experimental analysis; in Section V, results and discussion; and finally, in Section VI, conclusion.

II. RELATED WORK

The literature review encompassed an examination of papers focusing on Quality Management Systems (QMS), the Six Sigma methodology, Lean manufacturing, and integrated Lean Six Sigma methodologies. This comprehensive review spanned various areas of manufacturing production. Specifically, papers were scrutinized to identify Critical Success Factors (CSFs) crucial for effective Lean manufacturing implementation and to explore Lean Manufacturing applications in Small and Medium-sized Enterprises (SMEs). Additionally, attention was directed towards papers addressing waste reduction strategies essential for successful Six Sigma methodology implementation, along with applications of Six Sigma methodology in SMEs. A diverse array of papers published across reputable sources such as Inder Science, Emerald, Springer, and ScienceDirect were gathered. Emphasis was placed on sourcing the most recent articles and papers published post-2018. Within the scope of Lean Manufacturing, 10 papers were reviewed, alongside 10 papers each for Six Sigma methodology and the Integrated Domain. Integration of Lean-Green Manufacturing with Six Sigma Techniques in SMEs, this conceptual study focuses on integrating lean-green manufacturing techniques with six-sigma techniques in small and medium-sized enterprises (SMEs), emphasizing their combined benefits for society and business improvement [1]. The current study presents an assessment model for Lean Six Sigma (LSS) implementation readiness using fuzzy logic. Drawing from a literature review, researchers combined 48 traits with 5 enablers and 16 criteria to develop the model, which is being applied in a medium-sized Indian hospital [2]. This study employs a modelling approach to determine conditions under which Lean Six Sigma (LSS) project techniques can enhance environmental friendliness by reducing energy consumption, taking into account predicted LSS values and outputs [3]. This research investigates the adoption, advantages, motivations, and challenges associated with implementing lean manufacturing practices in the Indian automotive sector and component manufacturing businesses [4]. Highlighting GLSS implementation trends, this article notes that 80% of GLSS implementations occur in manufacturing and construction, with each sector contributing 40% to the total [5]. Specifically focusing on the Best-Worst-Method (BWM), this study conducts a sensitivity analysis to ensure the reliability of the BWM's rankings of various lean practices [6]. Top management selected critical success factors (CSFs) supporting Strategic Lean Management (SLM) deployment and provided examples for other CSFs, particularly within the Indian automobile industry [7]. A case study demonstrates significant reductions in chemical and energy usage—28% and 21%, respectively—through the application of lean techniques [8]. Implementing lean methods led to a notable increase in production and quality, with production rising by 50.42 units per hour and quality improving from 3.2 to 4.4 sigma [9]. A proposed framework for LSS implementation is tested using data from a Bangladeshi clothing manufacturing company, identifying 10 obstacles through literature review and industry consultation [10]. Utilizing a natural resource-based view, this study evaluates GLSS enablers and outcomes to enhance the environmental sustainability of manufacturing enterprises in both developed and developing countries[11]. Implementing LSS in automotive component manufacturing organizations adversely affects financial performance but enhances other areas such as customer satisfaction, learning, growth, and business process performance [12]. This descriptive study analyses factors influencing MSMEs' motivation to implement Lean Six Sigma and identifies barriers to implementation [13]. The study discovers positive potential in pairing Six Sigma with Industry 4.0 technology, though not all technologies have been fully explored yet[14].Utilizing DMAIC cycle and value stream map (VSM), this case study addresses process improvement to reduce rejection rates in automotive filter manufacturing[15]. Management achieved 20% savings in annual production and overhead expenditures through lean implementation, while suggestions are made to strengthen methodologies for continued use in Industry 4.0[16]. The study contributes to understanding the benefits of Lean Six Sigma methodology in industrial organizations, aiding academics and practitioners alike [17]. By combining Lean Six Sigma principles with supply chain resilience, the maritime industry can design effective continuous improvement strategies, especially crucial during events like COVID-19[18]. A systematic approach is employed to assess Critical Success Factors (CSFs) and develop a structural model for adopting Strategic Lean Six Sigma (SLSS) in healthcare settings [19]. Results from a systematic literature review offer valuable insights into the Green Lean Six Sigma (GLSS) domain, aiding practitioners and consultants in implementing environmental performance enhancements [20]. Through exemplary case studies, this essay illustrates how Lean Six Sigma can drive enterprise-wide changes and enhance value across supply chains [21]. Subject matter experts' insights are gathered through guided interviews, employing content analysis to elucidate how LSS principles aid healthcare organizations, particularly in the context of COVID-19[22]. Results indicate the effectiveness of Lean Six Sigma in pinpointing root causes of issues and facilitating continuous improvement through technology implementation [23]. Reduction in Length of Stay (LOS) using DTAPs. Implementation of defined treatment and admission pathways (DTAPs) based on Lean Six Sigma principles led to a consistent 39% reduction in length of stay for femur fractures [24]. The proposed LESSVSM model aims to reduce energy and waste, promoting sustainable manufacturing practices for both academia and industry professionals [25]. This pioneering study explores the integration of Lean Six Sigma with Industry 4.0 technology, offering managerial and scientific insights for operational excellence research [26]. Utilizing the DMAIC approach and action research, this study presents a case study in the printing sector of a Tier III city, showcasing the application of Lean Six Sigma principles [27]. Through fishbone analysis, non-value-added operations causing delays in the packing process can be identified and addressed for process optimization [28]. This study presents an action-research-case study on shortening lead time for supplier selection using the Lean Six Sigma DMAIC strategy in a multinational healthcare organization's goods and distribution department [29].

II. RESEARCH METHODOLOGY

The proposed methodology for tiles production in the ceramic industry involves implementing Value Stream Mapping (VSM) tools to improve the production process. VSM is a lean manufacturing technique used to analyse, design, and manage the flow of materials and information required to bring a product or service to a consumer. Figure (1) likely illustrates the entire production process, detailing how waste reduction is integrated into each stage. This could involve identifying and eliminating various forms of waste such as overproduction, waiting times, unnecessary transportation, excess inventory, unnecessary motion, defects, and underutilized talent. By using VSM tools, the ceramic industry can streamline its production processes, reduce costs, improve efficiency, and enhance overall quality. It's a systematic approach that aims to optimize every aspect of the production flow, from raw materials to finished products, ultimately leading to better resource utilization and customer satisfaction.

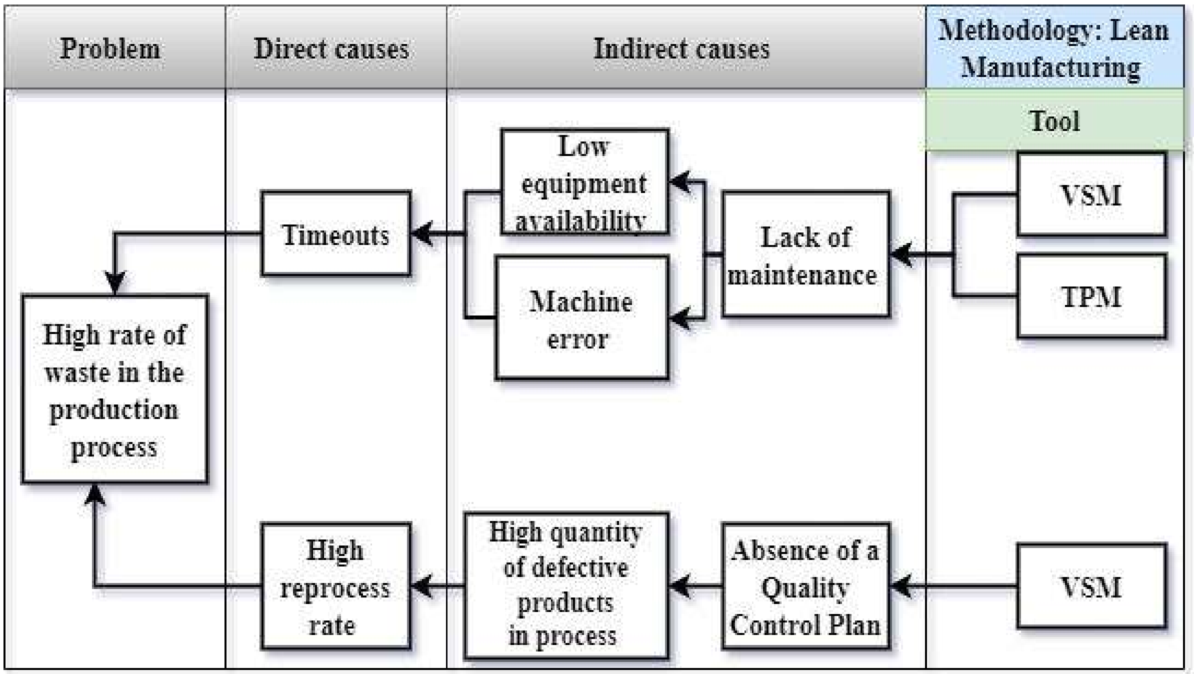

Figure 1: process of proposed methodology for the production of ceramic industry

The VSM methodology is renowned for its efficiency, primarily targeting the flow of operations. It comprises a suite of techniques aimed at visually representing the movement of materials and information throughout the manufacturing process. Its core objective is twofold: identifying opportunities for enhancing value addition while concurrently eliminating or minimizing non-value adding activities. VSM stands as an integral component within the arsenal of lean manufacturing tools, hailed for its capacity to streamline operations. The most effective VSM implementations typically involve the collaboration of a cross-functional team, comprising individuals representing various activities within the value stream under evaluation. Furthermore, the development of VSM is often integrated into training initiatives, fostering a deeper comprehension of lean concepts. Value Stream Mapping (VSM) is deeply rooted in the fundamental principles of Lean Manufacturing. This tool empowers organizations to slash lead times, minimize inventory, enhance quality, and achieve superior on-time deliveries, thereby optimizing resource utilization. By curbing non-productive activities—commonly referred to as waste—resources are conserved, allowing for their reallocation towards improving throughput and bolstering profitability. Figure (2) provides a visual depiction of the concept of VSM. The process of crafting a value stream map unfolds in two key stages: firstly, the Development of the Current State, followed by the delineation of the Future State [5].

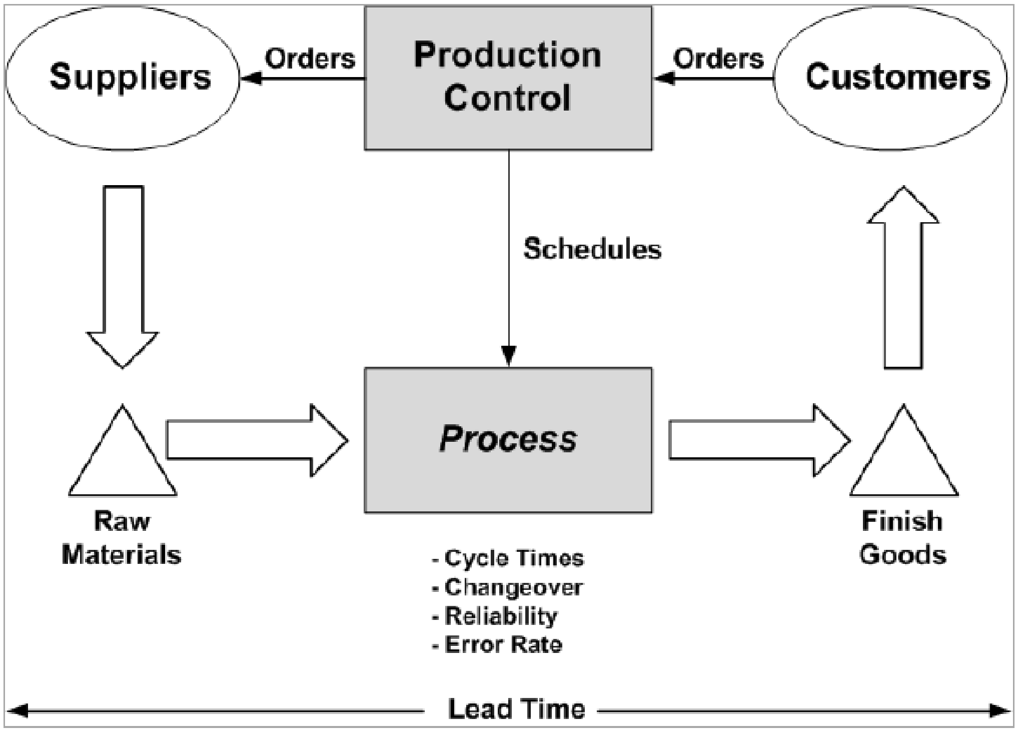

Figure 2 value stream Map

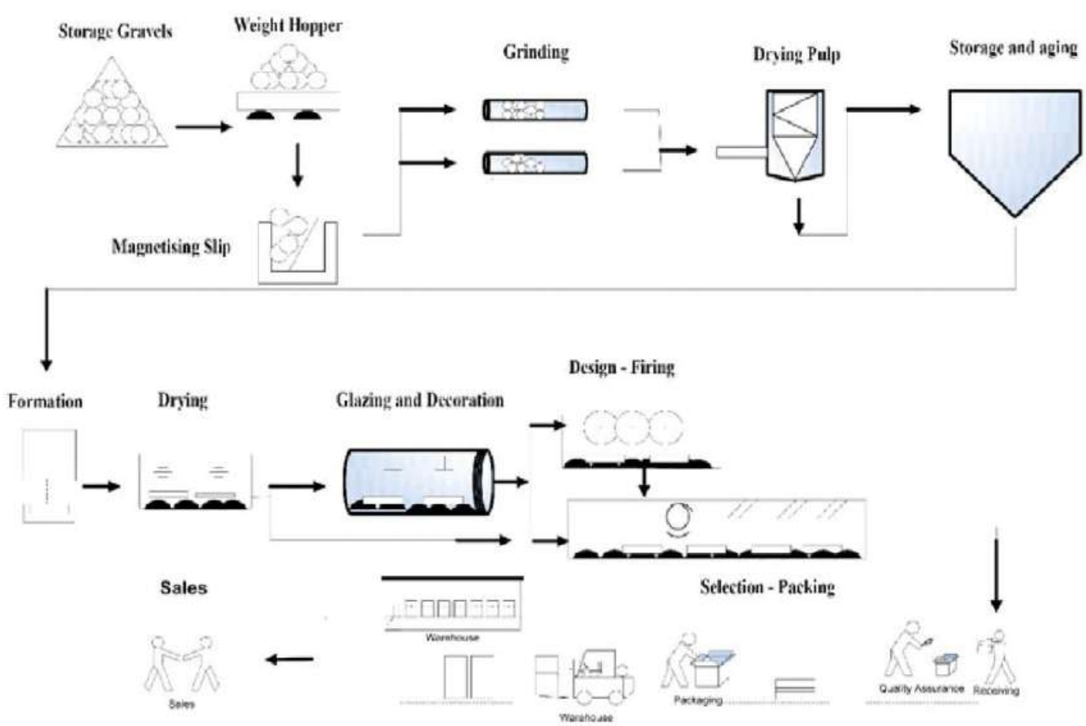

Figure 3 production process of tiles in ceramic industry

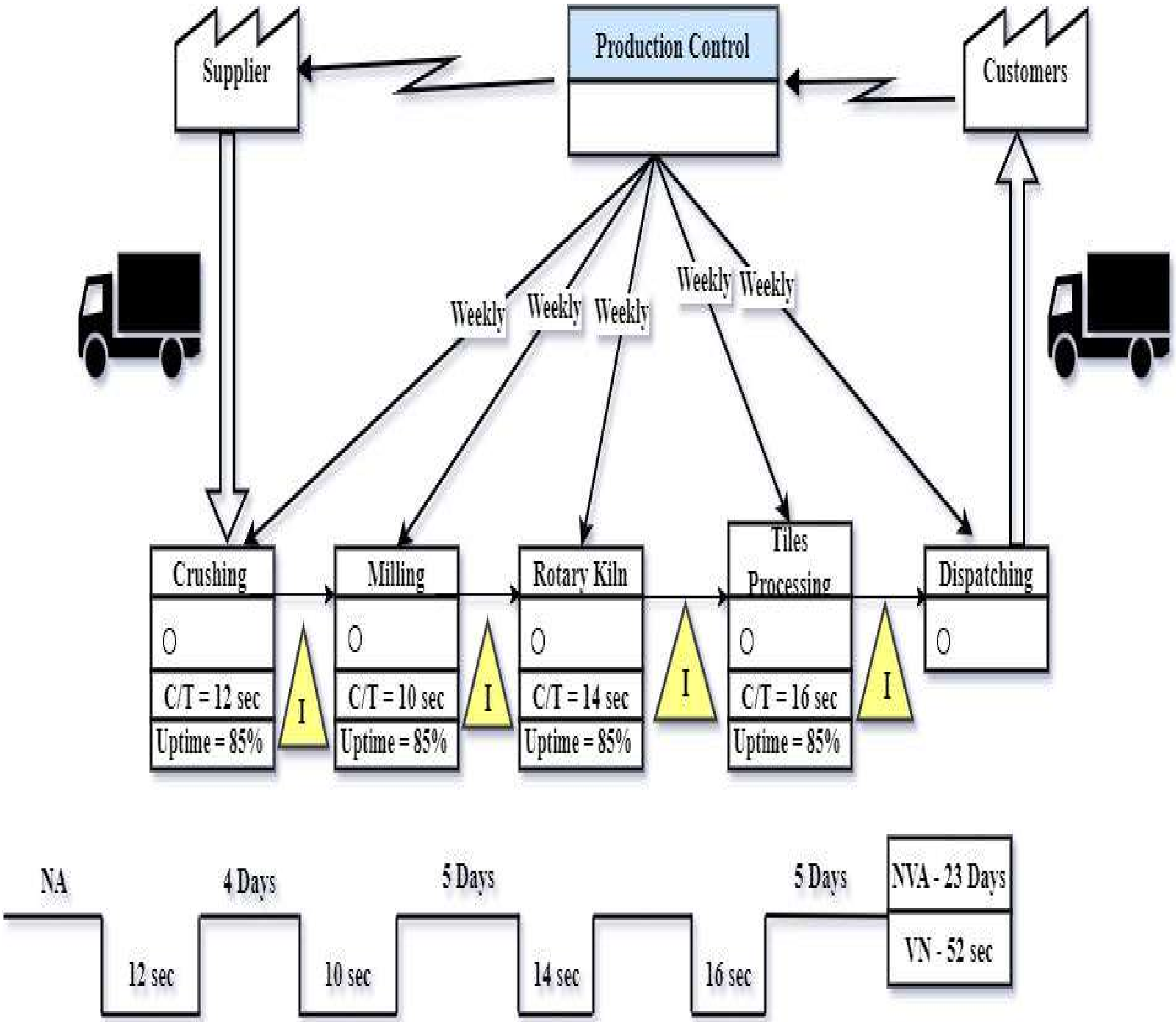

Figure 4 Current value stream mapping

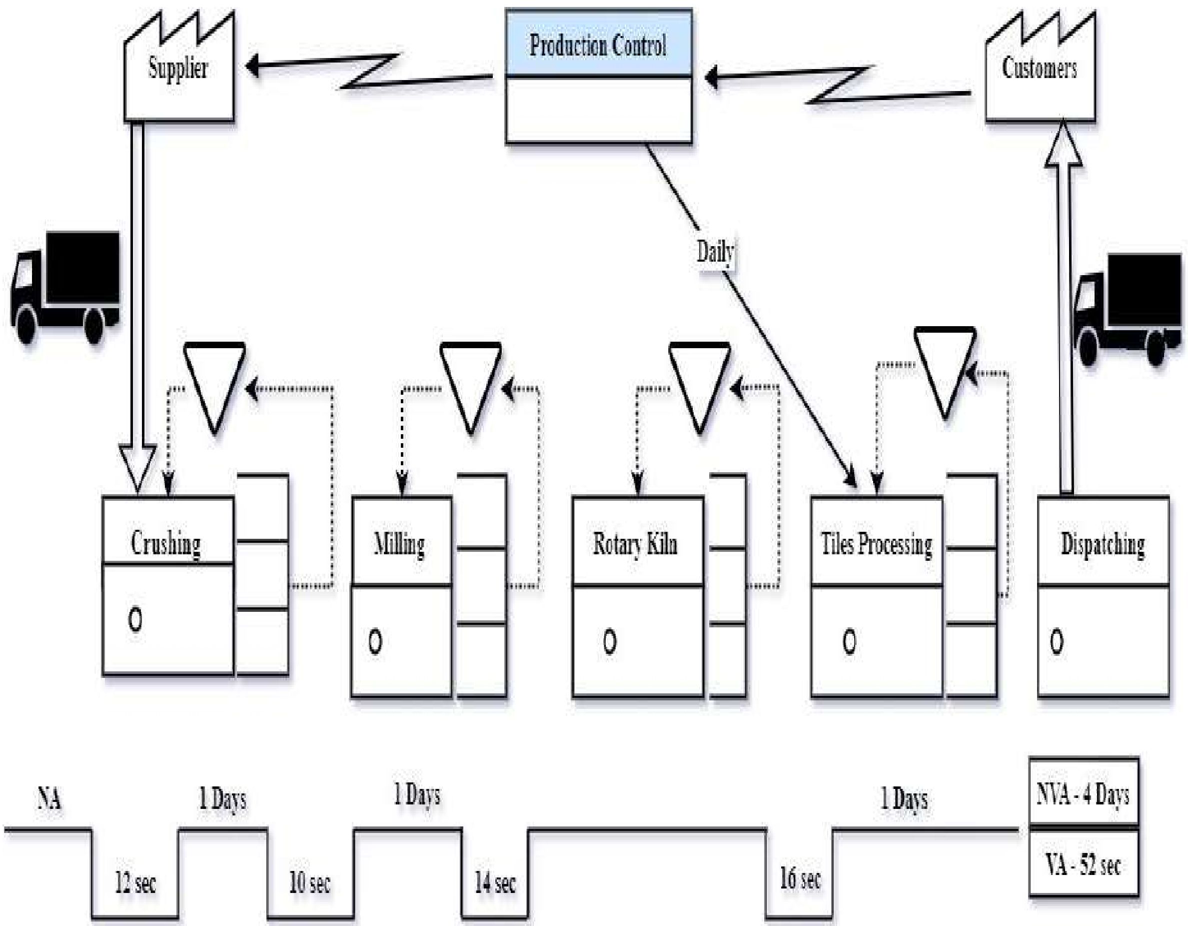

Figure 5 Proposed VSM future state

TPM Methodology

The implementation of Total Productive Maintenance (TPM) entailed standardizing both corrective and preventive maintenance processes, alongside checklist procedures, which were delineated through comprehensive flowcharts. This standardization facilitated the acquisition of detailed breakdown insights, pinpointing the primary causes for each occurrence. Simultaneously, it aimed to enhance oversight of the maintenance activities undertaken for each machine. For instance, fault summaries revealed that grinding and extrusion machines experienced approximately 42 and 20 hours of downtime, respectively, over a one-week period. Grinding machine failures included issues like hammer overheating, conveyor belt wear, main shaft overheating, and bearing and screen wear. Meanwhile, extruder malfunctions encompassed deceleration of the cutting shaft, engine overheating, and wear on pistons, pinion teeth, and belts. Identification of these faults enabled the planning of requisite preventive maintenance activities for each machine. Maintenance planning was categorized into mechanical, electrical, lubrication, and other domains, with each activity coded for enhanced tracking and control. The overarching objective of TPM was to heighten equipment availability, performance, and quality, with a focal point on the specific components of each machine, given their substantial influence on process operations.

IV. EXPERIMENTAL ANALYSIS

The production process underwent simulation to forecast the key outcomes anticipated from implementing TPM and VSM tools over a three-month period. Specifically, for the grinding process, the simulation factored in preventive maintenance schedules and downtime reduction measures, notably addressing issues like the presence of a metal detector in the conveyor belt. This inclusion resulted in augmented availability time for milling operations, thereby enhancing both efficiency and productivity. Similarly, in the extrusion process, the simulation accounted for preventive maintenance schedules and measures aimed at minimizing machine downtime, including visual inspections. This proactive approach led to increased availability time for the extruder, consequently bolstering its efficiency and productivity levels.

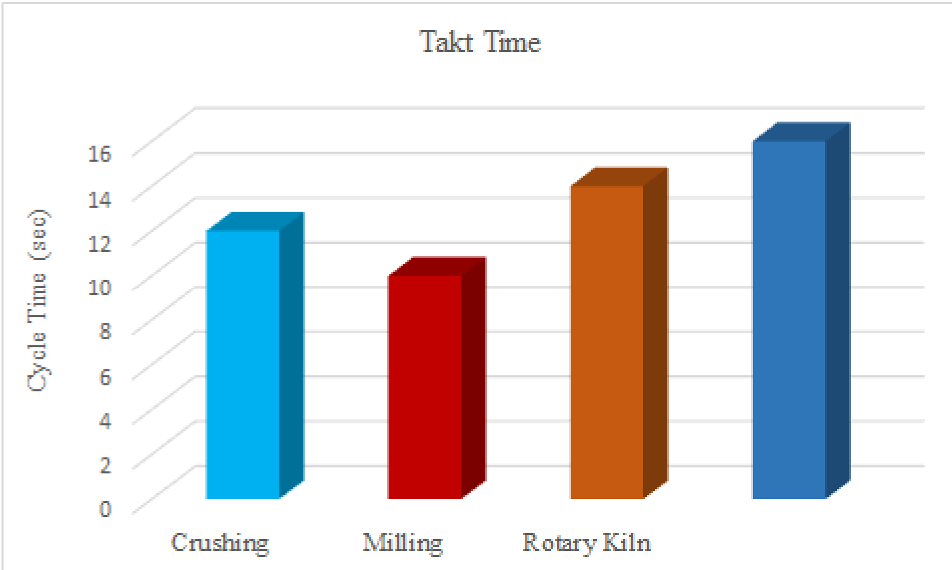

Figure 6: Tiles production line balancing and using crushing, milling, rotary kiln, tiles processing.

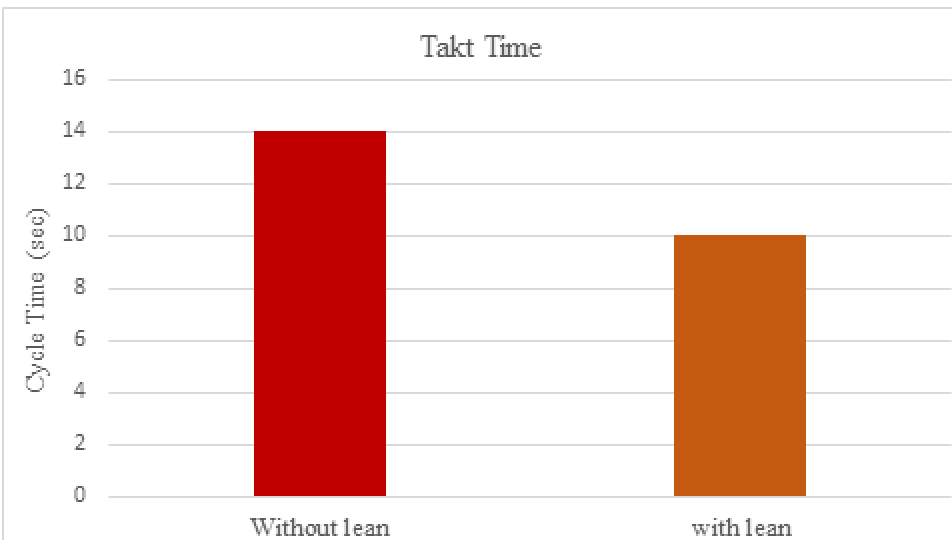

Figure 7: Without lean and with lean.

VI. CONCLUSION & FUTURE WORK

To mitigate waste in the production process of ceramic tiles, a focused approach on identifying root causes, implementing corrective measures, and continuous monitoring is imperative. In our study, the efficacy of Lean Manufacturing tools such as VSM and TPM was demonstrated in reducing losses within the production processes of small and medium-sized enterprise (SME) companies. The implementation of these tools yielded significant enhancements in Overall Equipment Effectiveness (OEE) for grinding and extrusion machines, marking the principal achievement of our research. Specifically, OEE for the milling machine surged from 38% to 67.30%, while for the extruder, it rose from 31% to 46.85%. Economically, this translated into a substantial increase in the company's gross margin, escalating from 15% to 37.7%. Such outcomes bear immense significance for the company's sustainability and competitiveness within the market landscape.

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