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Evaluation of Production Efficiency in Asphalt Mixing Plant Using Lean Concept Based on TIMWOOD

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ABSTRACT

This study aims to assess the effectiveness of the lean concept in improving production efficiency in an asphalt mixing plant. The research emphasizes the need to reduce waste by applying the TIMWOOD principles, which target minimizing transportation, inventory, motion, waiting, overproduction, overprocessing, and defects. By identifying and eliminating non-value-adding activities, this study seeks to enhance overall production efficiency and resource utilization. The findings reveal significant efficiency improvements, with a 50% reduction in average processing time and a 46.14% decrease in total processing time after implementing the lean concept. These results demonstrate that the lean approach enhances productivity by optimizing production time, reducing operational waste, and improving workflow efficiency. Furthermore, the research underscores the practical implications of adopting lean principles, suggesting they can be a sustainable strategy for asphalt plants to boost operational efficiency, decrease production costs, improve resource allocation, and strengthen competitiveness in the industry. This study provides actionable insights for industries aiming to implement lean manufacturing concepts effectively.

Keywords: Asphalt Mixing Plant; Lean Concept; Production Efficiency; TIMWOOD; Waste Reduction

INTRODUCTION

In recent years, the need for efficient and sustainable production processes in the construction industry has gained significant attention, particularly in the asphalt manufacturing sector. As the demand for road infrastructure grows, especially in countries like Indonesia, Asphalt Mixing Plants (AMPs) play a crucial role in producing Hot Mix Asphalt (HMA), a key material for road construction. However, despite its importance, the production processes at AMPs often face challenges such as inefficiency, waste, and high operational costs. This is especially relevant in developing countries where resource management, logistics, and production systems are constantly under pressure (Duffield et al., 2019; Suryanto, 2020). The inefficiencies in the asphalt production process, coupled with escalating costs, hinder the industry's potential to meet the increasing demand for road infrastructure.

The application of lean concepts, specifically through the Transportation, Inventory, Motion, Waiting, Overproduction, Overprocessing, and Defects (TIMWOOD) framework, offers a promising solution to these challenges. Lean concepts focus on eliminating waste, optimizing processes, and improving overall productivity (Dennis, 2015). Previous studies have demonstrated the effectiveness of Lean in various industries, including construction and manufacturing, by reducing operational waste and enhancing production outcomes (Dennis, 2015; Gupta & Jain, 2013). For instance, lean practices have been shown to significantly reduce operational costs in manufacturing environments, which could directly translate to improvements in asphalt production processes, including time and material management (Gupta & Jain, 2013).

However, there remains a lack of research on the application of Lean in AMPs, particularly in tropical and developing countries like Indonesia. Existing studies have focused primarily on environmental sustainability and material efficiency, with limited exploration of how Lean can enhance production speed, reduce costs, and improve worker safety in this context (Gruber & Hofko, 2023; Vilventhan et al., 2019). In particular, the integration of Lean Safety practices—critical to reducing workplace accidents and improving employee well-being—is underexplored in the AMP industry. This research aims to bridge these gaps by exploring how Lean principles, specifically the TIMWOOD approach, can be applied to optimize AMP operations in Indonesia.

This study seeks to fill this gap by investigating how lean concepts, specifically the TIMWOOD approach, can be applied to the production processes of AMPs in Indonesia. The purpose is not only to explore how Lean can optimize time and material management but also to examine its potential to enhance workplace safety and environmental sustainability. By integrating Lean Safety practices with traditional Lean tools, this research will also provide a holistic approach to improving production efficiency and safety standards (Gupta & Jain, 2013; Alzahrani & Jazieh, 2018).

The primary objective of this study is to analyze the impact of applying lean concepts on time savings in the production cycle of HMA at AMPs in Indonesia. This includes evaluating the reduction in process time and assessing the potential for improving overall production speed and efficiency. Additionally, the study examines the effects of lean concepts on material management within AMPs, with a particular focus on inventory control, waste reduction, and the optimization of material usage. By employing Lean methods, particularly the TIMWOOD framework, the study aims to determine how material wastage can be minimized and cost-effectiveness enhanced.

Furthermore, this research seeks to develop a model for the implementation of lean concepts based on the TIMWOOD framework, tailored to the specific needs and challenges of AMPs in Indonesia. The proposed model will serve as a practical guide for AMPs in applying Lean principles effectively to improve operational efficiency, reduce costs, and enhance product quality. By addressing these objectives, the study aims to provide valuable insights into the practical application of lean concepts in the Indonesian AMP industry, contributing to both operational efficiency and sustainability. The following sections of this paper will review the relevant literature, outline the research methodology, present key findings, and offer recommendations for future practices and policies in the asphalt production sector.

LITERATURE REVIEW

Lean Concept

The lean concept is a management philosophy that focuses on reducing waste in production processes and enhancing value for customers. Initially developed by Toyota through the Toyota Production System (TPS), Lean has been widely adopted across various industries globally. Lean aims to create operational efficiency by identifying and eliminating activities that do not add value, often referred to as waste. According to Dennis (2015), waste is any activity that consumes resources but does not contribute value to the customer.

The core of Lean is its focus on continuous improvement and eliminating inefficiencies across the value chain. Liker and Meier (2006) stress the importance of fostering an organizational culture that encourages stopping production to fix problems in real time, ensuring high-quality outputs from the start. This is achieved through deep leadership, where leaders not only understand the technicalities of the work but also teach and instill the company's philosophy throughout the organization. Tools such as 5S, Total Productive Maintenance (TPM), and Poka-Yoke are widely used to support Lean in the production environment. For instance, 5S is employed to create and maintain an organized and clean work environment, laying the foundation for efficiency and workplace safety (Feld, 2001).

Lean in the Context of Asphalt Mixing Plants (AMPs)

AMPs play a critical role in the production of HMA, which is used for road construction and other infrastructure projects. However, AMPs often face challenges related to inefficiencies in material handling, waiting times, and overproduction. The application of Lean principles, particularly TIMWOOD, can significantly improve the efficiency and quality of AMP operations.

Sivilevičius et al. (2008) highlighted that AMPs frequently suffer from issues such as inefficient inventory management, prolonged waiting times, and suboptimal use of materials. By applying Lean principles, especially TIMWOOD, these issues can be minimized, leading to improved resource utilization and enhanced production efficiency. In the context of AMP, the primary focus of Lean is on reducing material waste, improving process flow, and ensuring high-quality output, all of which are critical for reducing production costs and enhancing the overall efficiency of the plant.

According to Gupta and Jain (2013), lean manufacturing techniques have been successfully applied in various industries, leading to reductions in operational costs and improvements in product quality. The same principles can be adapted to AMP, where eliminating unnecessary processes or waste can streamline operations and enhance the quality of asphalt production.

Process Activity Mapping (PAM) for Time Optimization
PAM is a valuable tool in Lean methodology that helps visualize and analyze process flows. It is particularly useful in identifying bottlenecks, inefficiencies, and non-value-adding activities within a process. In AMP, PAM helps identify steps in the asphalt production process that do not add value, allowing for their elimination or improvement.

Using Bizagi Modeler, PAM allows AMPs to visualize their production processes, track time spent on each activity, and identify critical points where time is wasted. Juran and Godfrey (1999) argue that mapping out these activities is essential for streamlining production. By focusing on reducing unnecessary waiting times, motion, and inefficiencies, PAM directly supports Lean principles that prioritize the optimization of production cycles (Jacka & Keller, 2009).

For example, in AMP, PAM can help identify and eliminate wasteful steps, such as long waiting periods for materials, inefficient equipment usage, or redundant steps in the process, all of which contribute to extended production times and higher costs.

Material Variance Analysis (MVA) for Cost Control
MVA is a crucial tool for managing material costs within the Lean framework. MVA compares the actual cost of materials with the budgeted cost, helping companies identify variances and their causes. This analysis is key to controlling material waste, optimizing inventory, and improving overall cost management in AMP. MVA involves calculating Material Price Variance (MPV) and Material Quantity Variance (MQV). MPV measures the difference between the standard price and the actual price paid for materials, while MQV tracks differences between the expected and actual quantities of materials used in production (Kaplan & Atkinson, 1998). MVA allows AMP to identify inefficiencies in material purchasing or usage, offering opportunities to reduce costs and improve the overall efficiency of material handling.

As Drury (2012) notes, controlling material costs is fundamental to profitability, and MVA provides a diagnostic tool that helps businesses optimize material use and reduce waste. By regularly analyzing material variances, AMP can take corrective actions, such as renegotiating supplier contracts or adjusting production processes to minimize material waste and improve cost efficiency.

TIMWOOD: Identifying Waste in AMP Production
TIMWOOD is a fundamental concept in Lean manufacturing that helps identify and eliminate seven major types of waste in production processes. Each type of waste significantly affects AMP operations, leading to increased costs and lower product quality. Transportation waste occurs when materials or products are moved more than necessary, either within the facility or during distribution. Optimizing facility layout and material flow can help reduce unnecessary transportation time and costs (Feld, 2001). Inventory waste arises from excessive stock, which ties up capital, increases storage costs, and heightens the risk of spoilage or obsolescence (Pascal, 2015). Motion waste refers to inefficient movements by workers or machines that do not add value to the product, which can be minimized by optimizing workflows and arranging tools and materials for easy access (Liker & Meier, 2006). Waiting for waste results from workers or machines being idle due to delays in receiving materials, equipment, or information and can be mitigated by synchronizing operations (Pascal, 2015). Overproduction waste occurs when products are manufactured beyond customer demand, leading to surplus inventory and unnecessary storage costs (Liker & Meier, 2006). Overprocessing waste arises when additional steps are performed in the production process that does not contribute value, which can be addressed by simplifying workflows and eliminating

unnecessary procedures (Feld, 2001). Lastly, defect waste leads to rework or scrapped products, increasing both time and cost. Lean manufacturing emphasizes strict quality control and continuous process improvements to minimize defects (Pascal, 2015). By systematically addressing each of these waste types, Lean practices enhance efficiency, reduce costs, and improve overall product quality.

RESEARCH METHOD

The initial step in this research involves identifying problems through interviews with the plant manager and field observations, which help gather data on material issues and operational inefficiencies. The outputs from this stage include stock quantities and time-related data. Primary data is collected through direct observations, questionnaires, and interviews, while secondary data includes material usage records and relevant SOP documents.

Data analysis is conducted using PAM to evaluate time-based inefficiencies in the production cycle and MVA to compare planned material usage with actual consumption, highlighting material waste. These methods provide insight into areas for improvement in both time and material usage.

Once inefficiencies are identified, the TIMWOOD approach is applied to categorize waste into seven types: Transport, Inventory, Motion, Waiting, Overproduction, Overprocessing, and Defects, helping pinpoint root causes of inefficiency. Lean concept principles, particularly the 5S concept (Sort, Set in Order, Shine, Standardize, and Sustain), are then implemented to improve organization, cleanliness, and efficiency, reducing waste and optimizing the work environment. The study concludes with recommendations for implementing lean concepts at the AMP to enhance efficiency, reduce waste, and improve safety, ultimately contributing to the plant's success and profitability.

RESULTS

Process Activity Mapping (PAM)

The PAM compares the time efficiency of various activities in the As-Is and To-Be processes within the AMP operations. Lean optimization techniques have been applied to streamline operations, resulting in significant reductions in cycle time and total production time. This analysis highlights the areas where Lean practices have had the most impact, specifically targeting bottlenecks and inefficiencies in the production workflow.

In the As-Is state, the total production time was 477.13 minutes, with an average cycle time of 24.9 minutes per production cycle. After applying Lean practices, the total time for the To-Be process was reduced to 256.98 minutes, with an average cycle time of 12.95 minutes. This reduction in total and average cycle times indicates a 46% improvement in operational efficiency, equating to a time savings of 220.15 minutes per production cycle.

The table below compares the individual times for each activity between the As-Is and To-Be processes, providing a detailed view of the time savings and efficiency improvements. The Difference column highlights the reduction in time for each task, while the Percentage Improvement shows the relative gain in efficiency after Lean optimization.

Table 1. Comparison of As-Is and To-Be Process Activity Times in AMP Operations

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Activity	As-Is Time (min)	To-Be Time (min)	Difference (min)	Percentage Improvement
Process AMP	24.9	12.95	-11.95	48% reduction
Weighing of Empty Truck	3.35	1.35	-2.00	60% reduction
Truck Enters Parking Area	2.2	1.2	-1.00	45% reduction
Loader Takes Aggregate from Stockpile	1.02	0.52	-0.50	49% reduction
Loader Fills Aggregate into Cold Bin	0.35	0.35	0	No change
Drying Process in Dryer	0.35	0.35	0	No change
Material Screening	1.02	1.02	0	No change
Material Mixing in AMP	1.18	1.18	0	No change
Weighing Truck After Filling	3.5	1.5	-2.00	57% reduction
Covering the Bin with Tarpaulin	2.33	2.33	0	No change
Liquid Asphalt Metering	0.97	0.97	0	No change
Filling Hotmix into Truck	10.38	3.38	-7.00	67% reduction
Coarse and Fine Aggregate Metering	0.97	0.96	-0.01	1% reduction

Key observations in Table 1 reveal significant improvements in several activities following Lean optimization. The filling hot mix into truck activity saw the most notable reduction, with time decreased by 67%, from 10.38 minutes to 3.38 minutes, due to optimized filling processes and better equipment coordination. Similarly, the weighing truck after-filling process was reduced by 57%, from 3.5 minutes to 1.5 minutes, likely through the introduction of faster or automated weighing systems. The weighing of the empty truck process also improved by 60%, from 3.35 minutes to 1.35 minutes, reflecting enhanced speed in truck handling, possibly through automation. the loader takes aggregate from stockpile activity was reduced by 49%, from 1.02 minutes to 0.52 minutes, indicating better material handling and coordination. Additionally, the truck entering parking area time was reduced by 45%, from 2.2 minutes to 1.2 minutes, likely due to improved scheduling and traffic management. Some activities, such as loader filling aggregate into the cold bin, drying process in the dryer, material screening, material mixing, and covering the bin with tarpaulin, did not experience significant changes, as they were already operating efficiently.

Material Value Analysis (MVA)
Table 2 presents an analysis of the financial impact of leftover materials in HMA production. Using monthly production data of 9,000 tons and material composition, the analysis calculates the amount of material used and the leftover stock for each material, including Coarse Aggregate, Medium Aggregate, Fine Aggregate, Asphalt, and Filler. The total value of unused materials amounts to IDR 781,432,500, with Fine and Medium Aggregates contributing the largest share of the leftover stock, indicating inefficiencies in stock management and material usage.

Table 2. Material Value Analysis

Material	Available (Tons)	Leftover (%)	Used (Tons)	Leftover (Tons)	Unit Price (IDR/Ton)	Financial Value of Leftover (IDR)
Coarse Aggregate	1,350	46.5%	722.25	627.75	200,000	125,550,000
Medium	2,430	46.5%	1,303.35	1,126.65	250,000	281,662,500

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Aggregate						
Fine Aggregate	5,040	46.5%	2,695.20	2,344.80	150,000	351,720,000
Filler	180	25%	135	45	500,000	22,500,000
Asphalt	558	0%	558	0	N/A	0
Total	-	-	-	-	-	781,432,500

Asphalt does not have leftover material due to the implementation of a Just-In-Time (JIT) inventory system, which ensures that asphalt is ordered and delivered precisely when needed, eliminating surplus production and storage. This system minimizes waste by closely aligning the delivery and use of asphalt with the production schedule, thus preventing any unused material from accumulating at the end of the production cycle. In contrast, materials like Fine Aggregate and Medium Aggregate exhibit significant leftover stock, highlighting inefficiencies in forecasting, stock planning, or material consumption. This suggests the need for more accurate planning and better coordination between material requirements and actual production needs to optimize resource utilization and reduce waste.

TIMWOOD on Efficiency

The application of Lean principles, particularly the TIMWOOD framework, has significantly enhanced operational efficiency at the AMP. Through the use of MVA and PAM, various inefficiencies were identified and systematically addressed. Transportation waste was reduced by streamlining material flow, as MVA and PAM revealed unnecessary movement of materials and trucks, leading to improved resource utilization. Inventory waste, particularly the excessive stockpiling of Fine and Medium Aggregates, was mitigated through the JIT approach, which MVA and PAM highlighted as essential in reducing storage inefficiencies and associated costs. Motion waste, caused by unnecessary worker and machine movement, was minimized by optimizing workflows, resulting in improved productivity. Waiting waste was significantly reduced by enhancing scheduling and aligning material availability with production needs, as identified during key processes such as truck weighing and hot mix filling.

While overproduction and overprocessing were not major concerns, Lean practices ensured that production remained aligned with demand, thereby preventing unnecessary production and processing inefficiencies. Additionally, defects were minimized through the application of Lean principles, with MVA and PAM contributing to improved process consistency and material handling, ultimately ensuring higher product quality. The integration of the TIMWOOD framework with MVA and PAM successfully reduced waste, optimized material usage, and enhanced workflow efficiency, leading to substantial cost savings, better resource allocation, and increased overall productivity at the AMP.

Enhancing Efficiency with 5S Methodology

To enhance operational efficiency and streamline processes at the AMP, the lean concept principles, particularly the 5S methodology, were implemented. The 5S approach aims to create a more organized, clean, and efficient work environment by addressing both physical and procedural inefficiencies in the production process.

Sort (Seiri) – Eliminate Unnecessary Items

The first step in implementing 5S at AMP was to Sort the workspace by eliminating unnecessary items. The focus was on retaining only the essential tools, materials, and equipment. This phase helped reduce clutter in the work area, making it easier for workers to access the materials they needed without wasting time searching for tools or supplies. As a result, this practice significantly minimized downtime, improved the flow of operations, and contributed directly to reduced activity times in the production process.

For instance, in the AMP process, activities like material handling and weighing could be optimized as unnecessary materials were removed, reducing confusion and delays.

Figure 1. Existing Work Area

Set in Order (Seiton) – Optimize Layout and Material Flow

Once unnecessary items were removed, the next step was to Set in Order the remaining materials and equipment. By carefully designing the layout of the plant, storage areas, and material flow paths, AMP could optimize the arrangement of tools and materials, ensuring that everything was in its place for easy access. This organizational change aimed to reduce the amount of time workers spent moving between different areas of the plant. The time savings in retrieving materials can be seen in the significant reduction in the time it takes for activities such as weighing empty trucks (60% reduction), loading aggregates (49% reduction), and filling trucks with hot mix (67% reduction). Improved material flow not only optimized space utilization but also enhanced worker efficiency and minimized waste during transitions.

Figure 2. Future State Map

Shine (Seiso) – Maintain Cleanliness and Equipment Condition

The Shine phase emphasized maintaining cleanliness and orderliness throughout the plant. This involved introducing a regular cleaning schedule to ensure that both the work environment and machinery were well-maintained. Clean work areas promote safety, reduce the risk of equipment failure, and prevent defects caused by dirt or poorly maintained machines. Additionally, well-maintained equipment ensures higher uptime and better performance. By focusing on cleanliness, AMP helped prevent potential production delays, leading to better overall operational efficiency and fewer interruptions during production.

Figure 3. Maintain Cleanliness and Equipment Condition

Standardize (Seiketsu) – Implement Standard Operating Procedures (SOPs)
To ensure consistency and reliability, the Standardize phase introduced the creation and implementation of SOPs. These SOPs outlined clear guidelines for both operational and cleaning tasks, and they were followed across all shifts to ensure that processes were uniform. Standardized procedures minimized variability in work quality and efficiency, which further helped to streamline operations and reduce unnecessary delays. For instance, with the SOPs in place, activities like the drying process (which remained unchanged) and material mixing could be carried out consistently across shifts, preventing issues from arising due to varying practices.

Figure 4. Implement SOPs

Sustain (Shitsuke) – Ensure Long-Term Adherence and Improvement
The final stage, Sustain, focused on ensuring that the improvements made through the 5S process were maintained over time. This involved continuous monitoring, regular audits, and ongoing training for employees to reinforce the principles of 5S. A culture of discipline and commitment was encouraged, ensuring that the new practices were adhered to by all workers. Regular follow-ups and audits ensured that any deviations were quickly identified and corrected, preventing the regression of improvements. By keeping the 5S principles alive, AMP was able to sustain the efficiency gains made in the previous stages and continue striving for further operational improvements.

To enhance operational efficiency, lean concept principles, particularly the 5S concept were implemented at the AMP. The 5S methodology aims to create a more organized, clean, and efficient work environment by addressing both physical and procedural inefficiencies in the production process.

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Figure 5. Ensure Long-Term Adherence and Improvement

DISCUSSION

The implementation of Lean Construction principles, particularly the 5S methodology, at the AMP, resulted in significant improvements in operational efficiency and cost management. Based on PAM and MVA, overall production time was reduced by 46%—from 477.13 minutes in the As-Is state to 256.98 minutes in the To-Be state.

Key activities saw substantial time reductions, such as filling hot mix into trucks, which was reduced by 67%, and weighing empty trucks, which saw a 60% reduction. These improvements were achieved through optimized material handling, improved scheduling, and the elimination of non-value-adding activities, all driven by the application of 5S.

The 5S methodology played a crucial role in enhancing efficiency. The Sort phase helped eliminate unnecessary materials and equipment, reducing clutter and minimizing downtime. The Set in Order phase optimized plant layout and material flow, speeding up task completion, particularly for activities like truck weighing and aggregate loading. The Sustain phase ensured long-term adherence to the new practices through continuous monitoring, audits, and training, which helped maintain the gains achieved.

The MVA revealed significant financial losses due to leftover materials, particularly Fine Aggregate and Medium Aggregate, with unused materials amounting to IDR 781,432,500. While the JIT system for asphalt successfully reduced waste, inefficiencies in aggregate inventory management remain a challenge.

The application of the TIMWOOD framework helped identify and eliminate waste in key areas. For instance, transport waste was minimized by streamlining material flow, and inventory waste was reduced through the JIT system. Motion and waiting wastes were also reduced by optimizing workflows, ensuring materials were readily available, and improving scheduling, especially during truck weighing and hot mix filling.

Overall, the implementation of lean construction principles at AMP led to substantial reductions in waste, improved productivity, and better resource management.

CONCLUSION

The implementation of lean concept principles, particularly the 5S methodology, at the AMP, resulted in significant improvements in operational efficiency and cost management. Through PAM, MVA, and the TIMWOOD framework, several inefficiencies were identified and addressed, leading to a 46% reduction in production time (from 477.13 minutes to 256.98 minutes).

Key improvements included a 67% reduction in the filling hot mix into truck activity and a 60% reduction in weighing empty trucks, mainly due to optimized material handling, improved scheduling, and the elimination of non-value-adding activities.

The 5S methodology played a crucial role, with the Sort phase reducing clutter and downtime, the Set in Order phase improving workflow, and the Sustain phase ensuring long-term adherence to these changes. Additionally, the MVA revealed a financial loss of IDR 781,432,500 due to leftover Fine and Medium Aggregates, highlighting inefficiencies in stock management and forecasting.

The TIMWOOD framework helped address waste in transportation, inventory, motion, and waiting, streamlining processes and reducing waste. The Shine phase contributed to a safer, cleaner work environment, boosting worker productivity and morale, while the Standardize phase introduced SOPs, ensuring consistency and reducing errors.

LIMITATION

One of the key limitations of this study is the upfront investment required for implementing lean concepts at AMPs. The costs associated with purchasing new equipment, upgrading tools, and providing training for employees were substantial. While these expenses were justified by the long-term savings achieved through improved efficiency and reduced waste, smaller plants with limited financial resources may struggle to afford such investments. This financial barrier could hinder the widespread adoption of Lean practices in the industry, particularly among smaller-scale operations that lack the necessary capital.

Another limitation is the generalizability of the findings. Although the implementation of lean concepts at the AMP studied proved to be successful, applying these principles to other plants or industries may present different challenges. Larger or more complex operations may face additional constraints, such as logistical issues, variations in material supply chains, or differences in workforce adaptability. These factors could influence the effectiveness of lean strategies in different settings, requiring further research to explore how lean methodologies can be adapted to various operational environments.

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DECLARATION OF CONFLICTING INTERESTS

The authors declare that there are no conflicts of interest regarding the publication of this paper. The research was conducted independently, and no financial or personal relationships influenced the content or findings of this study.

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