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Enhancement of Maintenance Efficiency for Liquefied Natural Gas Plant: Operation Factors, Workforce and Productivity Control

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Abstract

Nowadays, to survive in the highly competitive industries, organizations require adapting to the rapid changes in the industrial environment to deliver the products or services with high quality in accordance with the consumer's expectation. In order to achieve maximum efficiency, organizations endeavour to enhance their asset integrity, reliability, availability, productivity, maintenance practice, and concentration on safety and product quality. It is also vital to ensure the highest maintenance efficiency practice in organizations to achieve the best efficiency practice.

Therefore, this paper aims to identify the most influential factors that impact workforce productivity's Wrench Time (WT). Understanding the impacts of these factors on the WT and identifying their causes will provide a clear vision of how the management can allocate the necessary resources to eliminate these impacts.

As a methodology, random sampling is used to determine the sample of observations from a given population. This sample is then used in the pilot test that is conducted to test the reliability of the data collection method. The Day In Life Of (DILO) approach is used to collect data as an observation method that involves the supervisor's participation with the technicians throughout the whole working day. A case study based on one of the largest LNG plants in the Middle East is conducted to verify the achieved maintenance efficiency.

As a result, workforce productivity has increased to 38.1% by changing the monthly workforce plan, leading to a future roadmap to enhance maintenance efficiency by considering more related factors.

Keywords: Maintenance Efficiency, Workforce Plan and Productivity, Wrench Time, DILO.

1. Introduction

Organizations endeavour to enhance their assets' integrity, reliability, availability, and productivity and become more conscious of the product's safety and quality. This improvement leads organizations to achieve maximum performance efficiency and efficient maintenance practice. A market competition force stimulates the organization to close to decide the competitive advantages in every process [1,2].

Generally, maintenance goals in the manufacturing process contribute in several areas [3]. These goals include the plant life's accomplishment, the plant functionality, the environment and safety, the cost-effectiveness of the conservation works, and the efficiency of utilizing the resources.

In most organizations, insufficient capabilities in managing the maintenance will directly affect the company's activities by decreasing productivity, creating overstock inventory which result in inefficient performance [4,5], and [6]. Therefore, improving maintenance efficiency is vital and required by organizations to achieve the best practice of their productivity and performance with less afforded maintenance costs. As one of the maintenance measurement criteria, Wrench Time (WT) is a maintenance criterion used to measure how much time maintenance technicians spend doing actual work assignments [5]. The maintenance cost is also an important criterion [6], and it must be prioritised and minimised [7].

Improving maintenance efficiency in the power industry has been investigated in some recent literature including, but not limited to [8] who developed an improved mathematical model that evaluates the economic efficiencies of the integrated energy system, considering new constraints for maintenance including electric generation, transmission subsystems and the ability to produce and transport a variety of primary energy sources. The Analysis Of Variance (ANOVA) technique was used to analyse the effect of climate conditions on different gas or electricity transmission regions. Authors in [9] used a

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quantitative approach followed by analysing secondary data of all the plant failures and stoppages during plant operation to improve maintenance strategies by examining the efficiency of the thermal power plant. [10] presented an empirically grounded research agenda for smart maintenance that reflects the heterogeneity in industrial adoption and performance of Smart Maintenance to achieve novel perspectives from strategy, organization, economics and sociology. [11] presented the power plant maintenance scheduling and particle swarm optimization (PSO) technique to ensure economical and reliable operation of the power system. Power plant maintenance scheduling of a power system based on minimization of the objective function has been proposed considering a power system's economical and reliable operation while satisfying the crew/workforce and the load demand. [12] Investigating maintenance's role in energy-saving and available maintenance approaches for energy consumption reduction. Various literature and publications on the research areas were reviewed and summarized to show the importance of maintenance and approaches commonly used for energy efficiency. [13] applied the lean maintenance techniques based on a previously developed multicriteria decision-making process that uses why Fuzzy is not part of the acronym? example: FAHP methodology to carry out diagnosis and prescription tasks. That methodology allowed the prescription of the appropriate learning techniques to resolve the primary deficiencies in maintenance efficiency.

Authors in [14] developed a predictive maintenance planning model using intelligent methods involving five main phases: data cleaning, data normalization, optimal feature selection, prediction network decision-making, and prediction. Authors in [15] presented the concept of Predictive Maintenance 4.0, the building blocks of predictive system architecture, its applications in the electrical sector and its benefits as an innovative technology. [16] proposed a new structure for the Lean Maintenance (LM) process based on a systematic literature review of a significant number of related articles that were published on LM. The process structure is designed based on the five lean principles to guide and support organizations in pursuing maintenance excellence. Authors in [17] conducted a literature review and updated survey on maintenance management of photovoltaic plants, a novel analysis of the current state and a discussion of the future trends and challenges, considering the main faults and degradation mechanisms, including the causes, effects, and the main techniques to detect, prevent and mitigate them. [18] reviewed previous practice of maintenance schedules in the electricity industry to study regulated and deregulated power systems and explore some critical features such as network considerations, fuel management, and data uncertainty.

Although the previous works considered in their maintenance focus on several factors, including energy efficiency, generation, transmission, excellence, strategy, organization, economics and sociology, none-of them investigated other more factors such as operational factors which affect the productive workforce, and this has a direct impact on the maintenance efficiency. Hence, this work aimed to investigate operational factors' impact on the maintenance efficiency rather than focusing on the data collection approach, Day In Life Of (DILO), which was previously used to improve productivity. Other practices of maintenance efficiency improvement are conducted in different industries, including but not limited to Automotive Maintenance Spare Parts [19], reliability-centred maintenance [20], integrated reliability, availability, and maintainability [21].

However, this work aims to understand the factors that impact the WT of the workforce productivity, which directly affects maintenance efficiency. The contributions of this paper are summarized as follows:

- To better understand the WT percentile of the workforce productivity, the maximum WT should be achieved and considered as an indicator used in the industry to illustrate the productivity of the maintenance activities. Measuring the WT is necessary for an organization to define targets and keep track of progress to reduce their value-adding (VA) and non-value-adding (NVA) times.
- To identify different operation factors that impact the WT and reduce the causes to enhance the WT and the maintenance efficiency. Studying the adding and non-value adding factors and developing short- and long-term plans to minimize the non-value adding time.
- To set a roadmap for the maintenance management to utilize their resources to reduce the waste and develop a long-term plan for the maximum performance of WT. Sustaining continuous improvement; developing collaboration among management and workforce, and shortening the distance and behavioural change that can lead to increase of the work productivity.

2. Research Methodology

An operational observation method is used to observe the activities and the time taken by the maintenance workforce during the working day. The continuous observation regarding what the workforce team performed during the day or more, as illustrated in the 1980s by Frederic W. Taylor, pioneered the work sampling practice [22]. Observation practice methods are widely used in research because it provides a vision that might not be accomplished with different methodologies. Many managers and researchers considered observation practice an excellent approach to data gathering compared with other processes like interviews and questionnaires [23]. As shown in Figure 1, the theoretical framework process consists of three main steps. Data input is mainly associated with operational factors that are impacting workforce productivity. Data processing begins by providing a training program to all respondents that cover the process of observation, time recording, and data collection. Data preparation is followed in three steps: identification, training, and data collection.

Furthermore, data analysis and interpretation are conducted to determine the project objectives. A pilot test was conducted with a small group of the targeted respondents to test the reliability of the observation method. The test was performed by collecting five observations per the line management decision to measure the reliability of the observation method with data collocation. The line management accepted and approved the result of the pilot test.

Data output results can be seen as determining the position of the workforce productivity according to the best practices in the industries. It can also provide the management insight to prepare for any necessary resources to enhance or improve the current position by developing an enhancement program, as shown in Figure 1.

Therefore, the research plan execution sequence is created based on the theoretical framework shown in Figure 1 and is categorized into four stages, as shown in Figure 2.

Stage 1 Research Strategy: The research strategy demonstrates the main points of the research process and the direction to achieve the objectives, which consists of nine steps.

Stage 2 Aim and Boundaries: This research aims to enhance maintenance efficiency by increasing the percentage value of the workforce productivity (Wrench Time). The maintenance department of Company A is divided into many sections and sub-section. The targeted population for this project is only the maintenance workforce for assets 1, 2, and 3 under the sub-section of Mechanical, Electrical, Instrumentation, and Control System.

Stage 3 Data Preparation: Data preparation is separated into three steps: data identification, training, and data collection. Data preparation started with identifying the different operation factors that impact workforce productivity. These factors are developed through the involvement of the maintenance senior staff, including the final approval of the line management.

Stage 4 Data Analysis: The collected quantitative data are analyzed using MS Excel. The collected data is analyzed to determine the percentage of the workforce productivity (WT), the activities executed and have a value-added or non-value-added to the productivity.

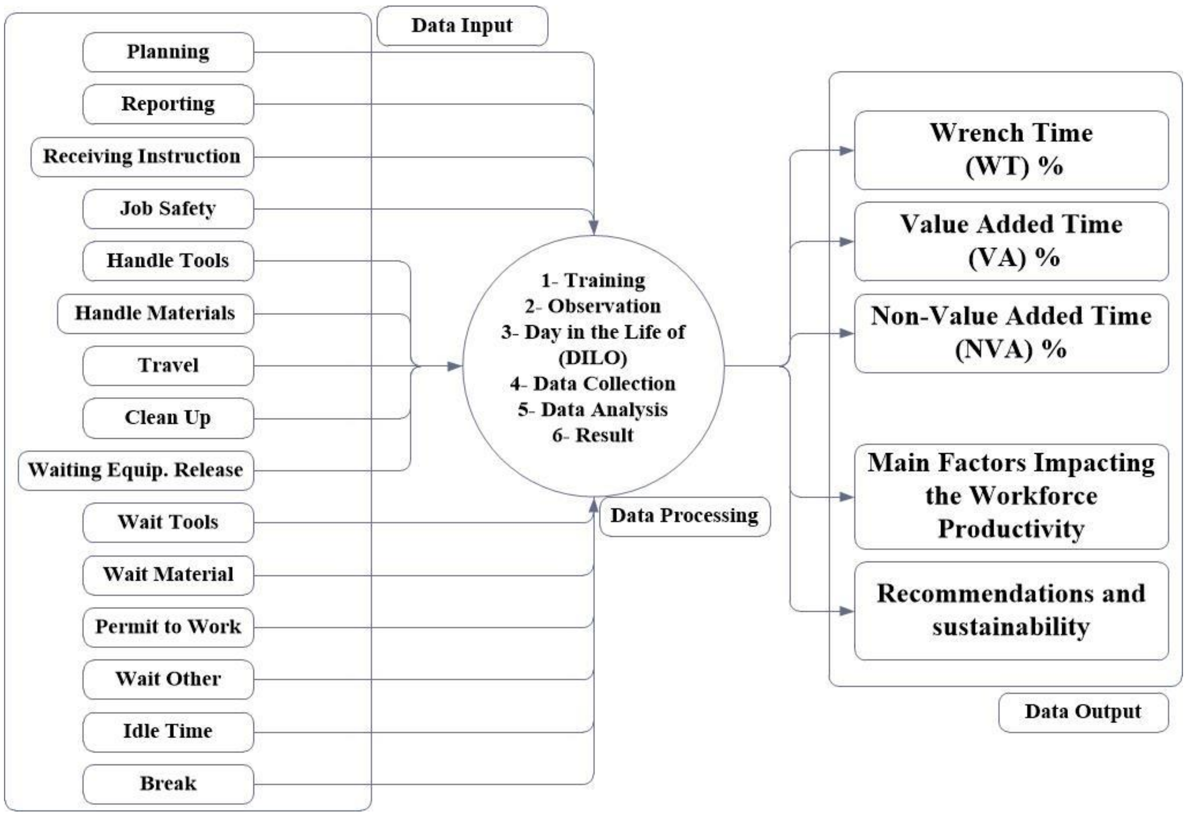

Figure 1. Proposed Research Theoretical Framework Process.

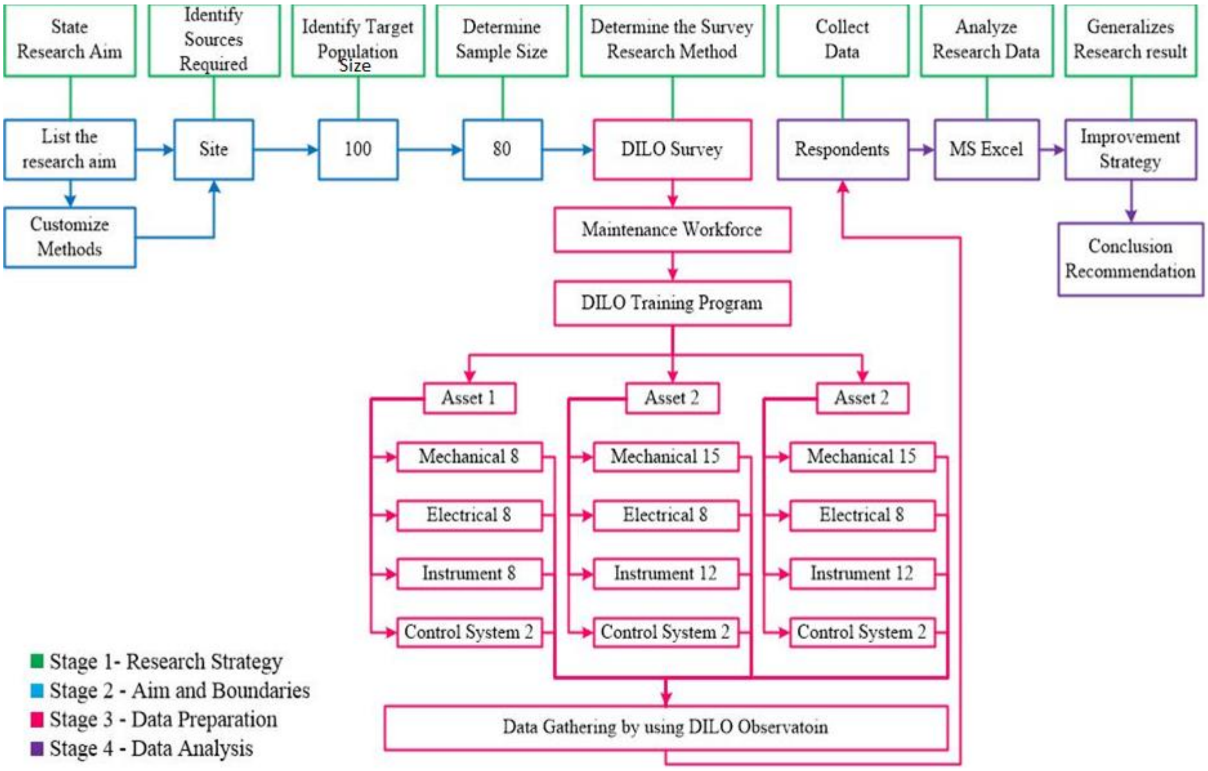

Figure 2. Research Plan Execution Sequence [24]

The operation factors that agreed to measure by observation activity using the DILO observation methods are shown in Table 1.

In order to have reliable, accurate, and trusted data, we decided that the mechanical supervisors would have to observe the instrumentation and control system teams, and the control system supervisors would observe the mechanical teams. Table 2 shows the values of each element of the OCE according to the MEI [25].

Nowadays, many companies started to measure the craft utilization time (WT) to monitor the workforce productivity, efficiency of the planning and scheduling, and other resources. Eliminating waste will enhance the workforce productivity and increase the WT, whereas the typical WT is 40%, and the best is 70%. The element values in Table 2 for craft utilization were adopted as a reference for analysing workforce productivity (WT).

Table1. Operation Factors List

Productivity	**Operation Factors**	
	Value Added (VA)	Non-Value Added (NVA)
Wrench Time	Planning	Waiting Equip. Release
	Reporting	Wait for Tools
	Receiving Instruction	Wait for Material
	Permit to work	Wait for Other
	Job Safety	Idle Time
	Handle Tools	Break
	Handle Materials.	
	Travel	
	Clean Up.	

Table 2. Range of OCE Element Values and OCE(Percentage)

	Range of OCE Element Values		
OCE Elements	Low	Medium	High
Craft Utilization (WT)	**30%**	**50%**	**70%**
Craft Performance	>80%	90%	95%
Craft Service Level	>90%	95%	98%
OCE Factor	22 %	43%	65%

3. Case study

In order to verify the achieved workforce productivity and the operation factors percentage, a case study was used in one of the liquefied natural gas plants based in the Middle East. Mode details about the company will be provided in the following section.

3.1. Company Brief

Company A is an LNG producer in the Middle East that exports the LNG to its client based on a long-term contract. The liquefaction of LNG passes through several processes, such as acid removal, dehydration, mercury removal, pre-cooling, fractionation, liquefaction, and storage. The liquefied natural gas is extracted upstream and then transported to the liquefaction facilities downstream, consisting of the process trains. The LNG is liquefied at -161°C degrees, then exported to the international markets using a fleet of LNG carriers. The LNG business observed a strong development during the previous eras, which caused an increase in the LNG demand worldwide. Therefore, the LNG demand increased from 1990 to 2011 by 190 million tons. This incredible development was mainly due to the world's big traditional gas well [26]. To ensure a continuous operation and production of LNG, it is required to enhance the maintenance process efficiency of the facilities.

Understanding the current maintenance process leads to identifying the process's shortcomings, and accurately interpreting the data collected and creating an accurate analysis. Observation comprises time recording of the conservation works activities executed by the maintenance technician from 7:00 am to 4:00 pm using a Day in the Life of (DILO) method. The process sequences during the working day consist of the following steps:

- The meeting started in the early morning,7:00 am, in the workshop yard. The supervisors and their team received instructions with a quick brief from the foreman regarding maintenance tasks.
- Collect the necessary documents and drawings and reserve the spare parts if required from the warehouse.
- The supervisors gathered the team with contractors and collected the required standard tools. Occasionally, they collected a special tool from the tool container if required.
- Arrange services/support requirements from electrical, instrumentation, control system, mechanical, and logistics disciplines.
- Transportation from the maintenance building to the control room uses a pick-up car (contractors use a personal tricycle or bicycle).
- Toolbox talk (TBT) meetings are led by the supervisor, explaining the safety precautions that should be considered during the job execution.
- The supervisor picks up the permit to work (PTW) document from a control room in the morning, which has a pick-up time, as all employees are in the PTW room to get the permit to work documents.
- The night shift production supervisor approves PTW documents being ready for the next day. The day production supervisor will check for safety and hazardous requirements, including the supplementary documents. Sometimes, the production day supervisor will discuss the safety and hazard issues with the maintenance team before signing the PTW when clarification is needed.
- Once the day shift production supervisor approves the PTW, the maintenance team will move with the field operator to perform a final check and hand over the machine to maintenance.
- Upon completion of the maintenance jobs, the maintenance supervisor has to sign the PTW with the field operator prior submitted to the production supervisor. If the job is not completed, the maintenance supervisor must report that the work status will be completed by the next day.
- If a job is not completed before lunchtime (12:00 pm - 1:00 pm), the maintenance team must stop and resume it after lunch.
- Before 3:00 pm, the maintenance supervisor has to go back to the office to write the daily report, complete the work order with technical findings, and write in SAP.

3.2. Data Collection

Data Collection was conducted in Company Ain assets 1, 2, and 3 as described in the research boundaries. The collection started from 7:00 am to 4:00 pm using the day in the life of (DILO) method. The data collection was divided into three stages: part of the data was collected in July, the second in August, and the third in September 2014. The data is divided into three stages to examine the operation factors that impact workforce productivity. Four observers (Supervisors) collected data from different disciplines (Mechanical. Electrical, Instrumentation, and Control systems) each month by supervising and monitoring the technicians throughout the whole working day, including monitoring and recording the tasks carried out and the time taken to complete them.

In order to have reliable, accurate and trusted data, the instrument and control system teams and supervisors will observe the mechanical teams. The observers collected the total number of observations was 80 during the three months based on the population and sampling size rules. The data collection was done based on the developed plan for each discipline every day. See Table 3 for the workforce plan and 3-5 for the monthly observation plan.

Table 3. Workforce Plan for Observation(Values)

Discipline	Population	Sample Size	July	August	September
Mechanical	38	31	31	31	31
Instruments	32	26	26	26	26
Electrical	24	20	20	20	20
Control System	6	3	3	3	3
Total DILO	100	80	80	80	80

Table 4 shows the number of conducted observations by each discipline for the three months of July, August and September, and the final participant result was 100% achievement.

Table 4. Monthly DILO Plan (Values and Percentages)

Crew	July	August	September	Percentage
Mechanical	10	10	10	100%
Instruments	9	9	9	100%
Electrical	6	6	6	100%
Control System	2	1	2	100%
Total DILO	27	26	27	100%

The observation plan table shows how many observations were planned for everyday to be collected by the observers. See Figure 3 for the observation plans for September.

3.3. Data Analysis

Data analysis will concentrate on the workforce productivity (WT) and determine percentages of the activities that are executed but do not have an added value to the productivity, and this can be transferred to either value-added or non-value-added time. The collected quantitative data are analysed by using the statistical methods analysis software. An MS Excel software is used to analyse the collected data using the DILO observation method. Figure 4 shows the productivity and non-Productivity tasks.

The analysis focuses on the WT, value-added time (VA), and non-value added time (NVA). Data analysis is divided into three parts; part one will analyse the collected data using MS Excel to identify the major percentile of operation factors related to each month (July, August, and September) and then interpret the variation between each one. This will provide insight and recommendations for question two. Along with this analysis, determine the percentile of WT, value-added time and non-value added time. This leads to accomplishing question number one. The last part of this study concentrates on the program development to monitor the improvement of the workforce productivity by establishing a roadmap plan for observation methods to be applied at different intervals to appraise the result deviations.

The data collected through the observation by the observers were 80 DILO for each month, based on the population and sample size as described in Table 5.

4. Result

Data analysis of the maintenance process observation of the workforce team activities is conducted in July, August, and September, as presented in Table 6 and Figure 5.

Table 5. Workforce Plan for Observation (Values)

Discipline	Population	Sample Size	July	August	September
Mechanical	38	31	31	31	31
Instruments	32	26	26	26	26
Electrical	24	20	20	20	20
Control System	6	3	3	3	3
Total DILO	100	80	80	80	80

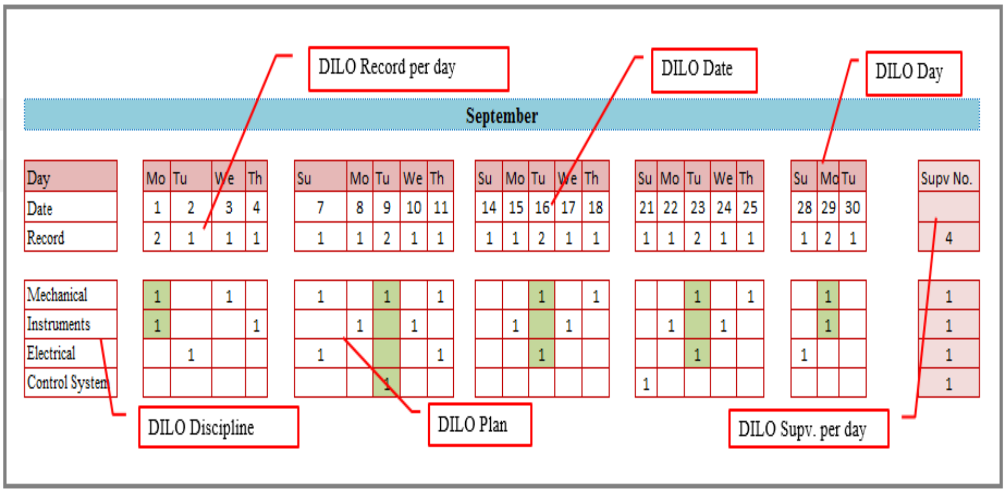

Figure 3. Observation Plan (Values)

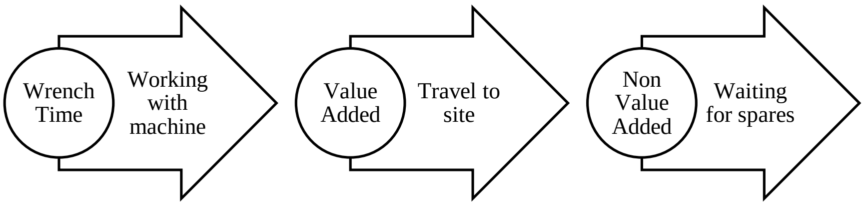

Figure 4. Productivity and Non-Productivity Tasks

Table 6. Accumulative Observation Result (Percentage)

Accumulative Observation					
Operation Factors	% Jul	% Aug	% Sep	% Avg.	Productivity
Wrench Time	37.0%	38.0%	39.2%	38.1%	38.1%
Planning	7.7%	7.4%	7.3%	7.4%	
Reporting	4.6%	4.6%	4.7%	4.6%	
Receiving Instruction	2.4%	2.6%	2.4%	2.5%	
Job Safety	2.6%	2.8%	2.7%	2.7%	
Handle Tools	2.3%	2.8%	2.5%	2.5%	
Handle Materials.	2.8%	2.3%	3.2%	2.8%	
Travel	13.1%	12.7%	12.2%	12.7%	
Permit to Work	5.4%	5.6%	5.9%	5.7%	
Clean Up.	2.1%	2.3%	2.4%	2.3%	43.1%
Waiting Equip. Release	2.3%	2.5%	2.0%	2.3%	
Wait Tools	1.3%	1.2%	0.6%	1.0%	
Wait Material	1.7%	2.3%	2.2%	2.1%	
Wait Other	1.7%	0.9%	1.0%	1.2%	
Idle Time	1.9%	1.1%	1.2%	1.4%	
Break	11.1%	10.9%	10.6%	10.9%	18.9%

Operation factors (added value and non-added value) were the significant causes of the underutilization of the workforce productivity caused by more time consumed in travel, breaks, planning, and permits to work and report. The wrench time of the workforce productivity is 38.1%, below the medium range score of 50% according to the Maintenance Excellence Institute standard. According to the finding, a proposed roadmap was developed to diminish the losses in the maintenance business process and then to enhance the maintenance efficiency by improving the wrench time of the workforce productivity.

The observation results demonstrated the key factors that affected the workforce productivity (WT), and to decrease the waste generated through; travel, breaks, planning, permits to work, and reporting, management needs to assign the necessary resources. The percentage value of each operation factor is presented in Table 8.

In Table 8, travel, break, planning, permit to work, and reporting are the major factors that impact the workforce productivity determined by the three-month observation and the percentile distribution of the workforce productivity (WT), value-adding, non-value adding time and major factors.

According to the key operation factor values demonstrated in the percentage trends in Figure 7, there were a few positive developments in Travel, Break, and Planning throughout the research. The changes were heading in a negative direction for factor permit to work. On the other hand, the change in Permit to work is negative. This change is due to the change in workforce behavior during short-term periods of being monitored, and usually they soon return to their previous practices.

Table 8. Major Factor of VA and NVA(Percentage)

Item	July	August	September	Mean %
Travel	13.1%	12.7%	12.2%	12.7%
Break	11.1%	10.9%	10.6%	10.9%
Planning	7.7%	7.4%	7.3%	7.4%
Permit to work	5.4%	5.6%	5.9%	5.7%
Reporting	4.6%	4.6%	4.7%	4.6%
Total	41.90%	41.20%	40.70%	41.30%

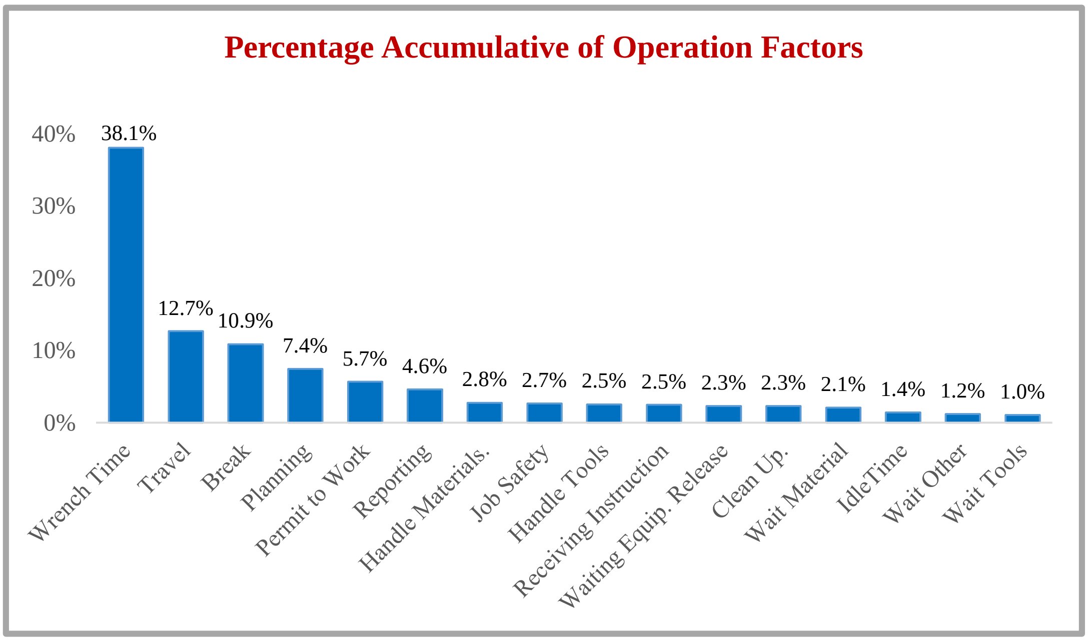

Figure 5. Percentage Accumulative of Operation Factors(Percentage)

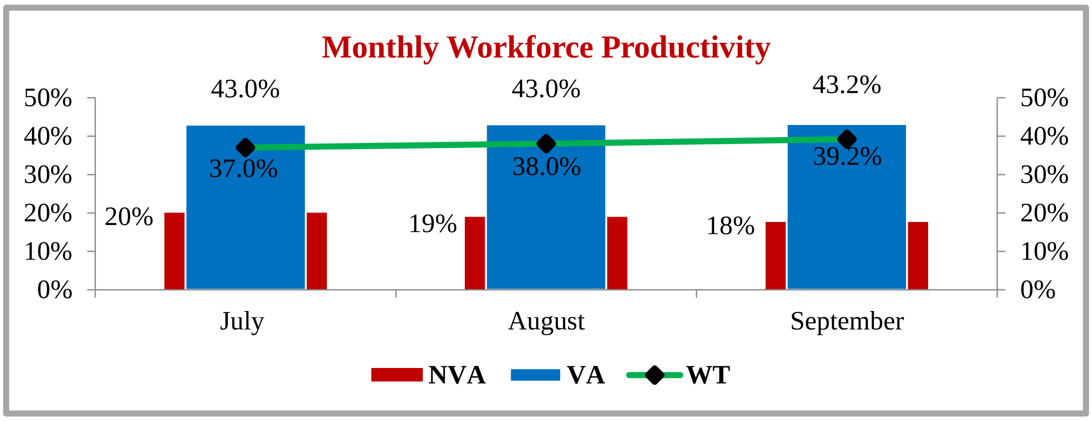

Figure 6. Monthly Percentile Distribution of WT, VA, and NVA(Percentage)

Reporting factor has approximately changed by 0.10% during the three-month observation. These changes are out of control since the observation was focused only on the maintenance workforce team, and the Permit to Work (PTW) team is from another department. Table 9 shows the main reasons behind the excessive time-consuming operation factor.

These require close follow-up by the management with the help of the monitoring tools to manage and sustain the Workforce Productivity (WT), as demonstrated in Figure 8.

The dashboard, presented in Figure 10, consists of an accumulative observation table, operation factors monthly trends, percentage accumulative of operations factors, VA and NVA, monthly workforce productivity, and overall workforce productivity.

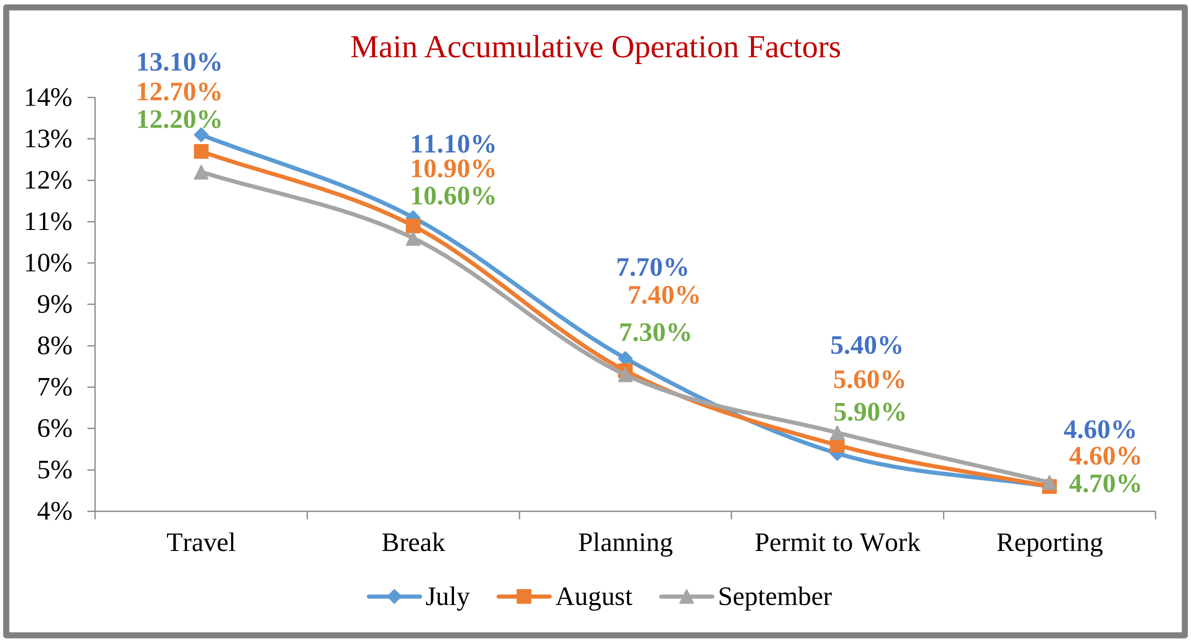

Figure 7. The trend of Main Accumulative Operation Factors (Percentage)

Table 9. Reasons for Excessive Time

Travel	Break	Planning	Permit to Work	Reporting
Wide area facilities and shortage of transportation **Long trips from workshop to control room to field and back to the workshop** **Minimum two trips per day in the same observation took three to four trips per day.** **Using bicycle or tricycle for commuting from workshop to field and vice versa**	The workforce team does not follow the company rule by spending more than one hour during the lunch break. The unofficial teatime break between 9:00am to 10:30 am consumed by the workforce team is unconventional.	Involved in tasks contrary to the job description. Scheduling role was assigned to the senior technicians. Unavailability of the scheduler team within the planning section. Unavailability of the integrated planning of maintenance activities. A shortcoming in communication between different departments. Planning consumes time for data collection and interpretation.	PTW issuance takes more time due to the unavailability of the day supervisor, field operator, and unready machines for intervention or crowded with the maintenance team during the peak time of the PTW issuance process. PTW team is from the production department and was not considered in this study. The same shortcoming in the PTW process occurred every day	An updated work order in SAP with a complete technical finding. Inter the time writing (working hour) related to each workforce member and technically complete the work order. Update the contractor register with the total number of contractors involved in the daily activities

Accumulative Observation					
Operation Factors	% Jul	% Aug	% Sep	% Avg	Prod
Wrench Time	37.0%	38.0%	39.2%	38.1%	38.1%
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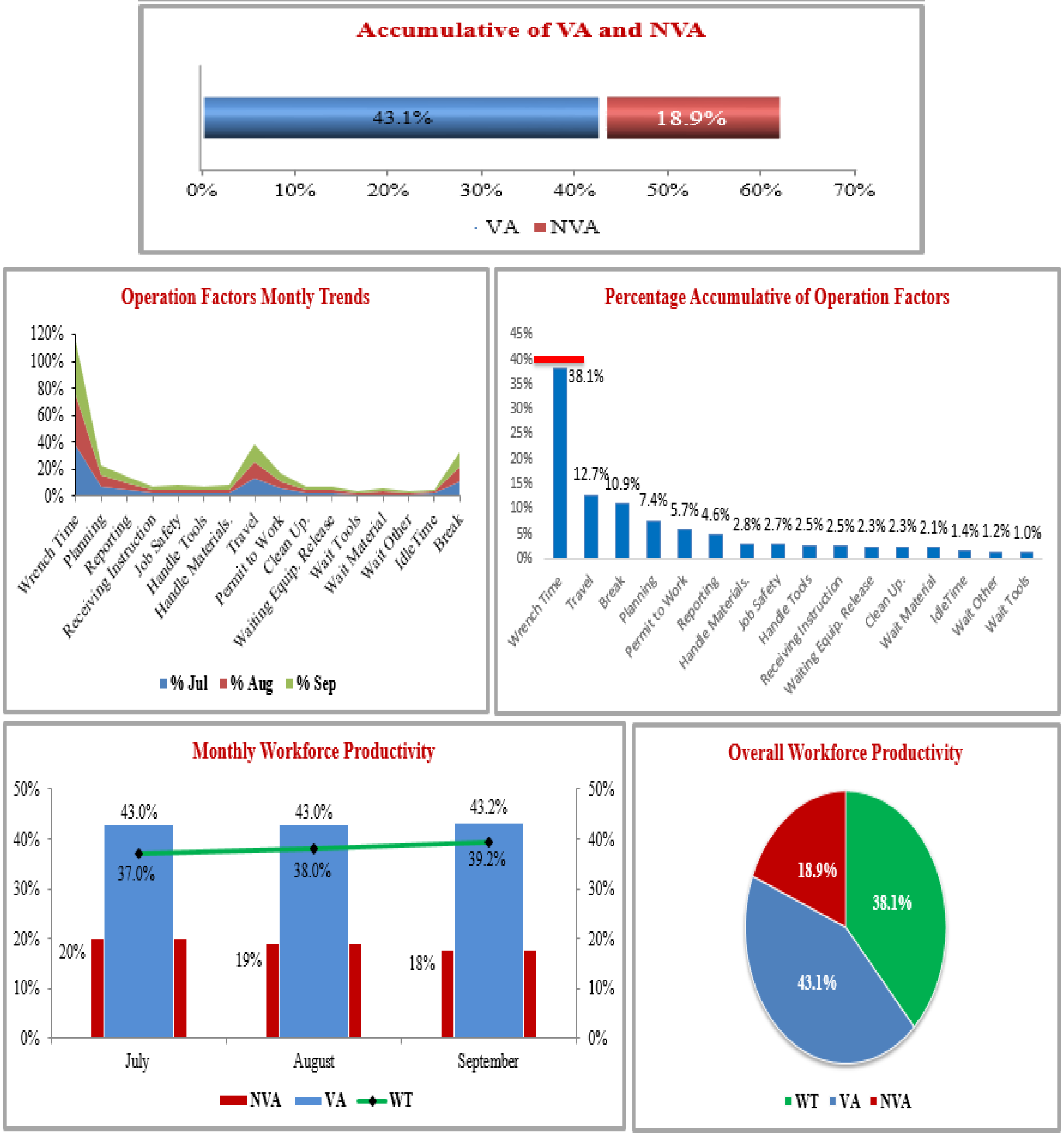

Figure 8. Workforce Productivity (WT) Monitoring Dashboard(Percentage)

5. Comparison study

The following chart describes the changes and effects of the workforce productivity and utilization and how they influence the maintenance performance and KPI. Maintenance KPI has many measuring indicators that measure the maintenance department's performance, and budget is one of these indicators. Operating the maintenance department within the approved planned budget means that the department utilizes the available resources without developing any losses in the maintenance process activities. Figure 9 presents a comparison conducted for Workforce Productivity Utilization.

6. Conclusion and Future Work

In this study, the factors that directly impact maintenance efficiency were identified. The percentile of the WT, VA, NVA, and the main operation factors that impact workforce productivity were investigated as it relates to the improvement program to sustain and enhance the current maintenance efficiency situation. The productivity losses were minimised to increase maintenance efficiency and workforce utilization.

The Day In the Life Of (DILO) approach was used to determine the factors' percentages. This was achieved through observation of the complete maintenance activities process from start to finishing of the working day. The random Sampling technique and Pilot Test were also used in this study to acquire a proper sample size and to test the reliability of the data collection method, respectively.

Based on the final result from 38.1% to 64.9% of the observation survey, it has been concluded that maintenance efficiency depends on workforce productivity; improved productivity was interconnected with cost-effectiveness, leading to improved maintenance performance.

In future work, developing standard operation factors for different industries is required since the industrial environment varies from one industry to another. It is also recommended that standardizing the operation factors would create standard percentile ranges of the productivity that can be used as a reference to measure the workforce productivity of any organization.

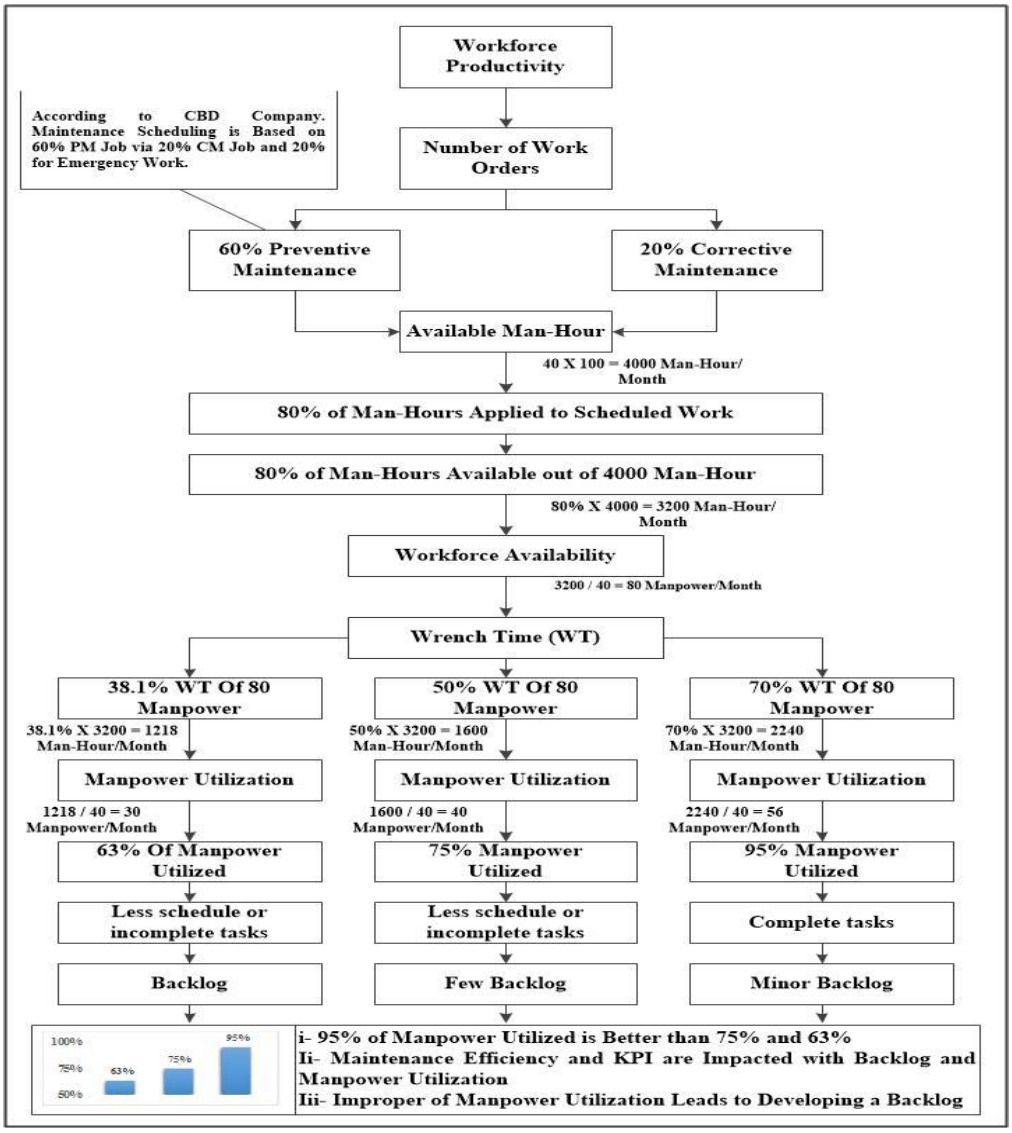

Figure 9. Workforce Productivity Utilization Comparison(Percentage)

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