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Measurement of Maintenance Planning and Control Effectiveness using the Lean approach

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Abstract:

Ineffective maintenance management can result in a backlog of maintenance work orders, inefficient activity prioritisations, and unnecessary outages. Making a strategic decision is challenging due to traditional procedures that only treated maintenance at a tactical level. Usually, the key performance indicator (KPI) measured for maintenance management is related to work order compliance. However, there is still less work focusing on measuring the effectiveness of Maintenance Planning and Control (MPC) processes. This paper aims to showcase a measurement of the maintenance effectiveness at offshore facilities using Lean methodology by measuring the lead time of sub-processes of MPC activities to evaluate existing practices, identify gaps and develop key recommendations. To this end, the lead time of the baseline MPC process is analysed and benchmarked with that of the improved MPC where new parameters to monitor and verify the process efficiency are included. The results show that a lead time improvement of close to 60% was achieved with the proposed methodology.

1. Introduction

In order to remain relevant, competitive and profitable in the global market, organisations must be flexible and adaptable to the ever-changing situation. Even though globalisation has increased trade and capital flow, organisations must be aware of not only changes in policies, the economy, and culture but also market demands for higher quality products at competitive prices [1,2]. Correia Pinto *et al.,* [1], further elaborated that these organisations need to regroup to diminish the waste including equipment downtime through a prudent maintenance management approach. In response to these requirements, numerous tools were developed in maintenance strategy including Reliability-Centred Maintenance (RCM) and Total Productive Maintenance (TPM) focusing on defect elimination, improving efficiency and risk management. All these tools, regardless of the methods, aimed to make the organisation more profitable and sustainable.

The standard IEC 62264-3 defines maintenance as "*the collection of activities which coordinate, direct and track the functions that maintain the equipment, tools and related assets to ensure their availability for manufacturing and ensure scheduling for reactive, periodic, preventative, or proactive maintenance*" (3). This includes all the effort to ensure production and manufacturing equipment are kept in optimum operating condition. In general, maintenance approaches can be distinguished into three categories: preventive maintenance, corrective maintenance, and improvement (3),(4). According to the standard EN 13306:2001, maintenance management is defined as "*all the activities of the management that determine the maintenance objectives or priorities, strategies, and responsibilities and implement them by means such as maintenance planning, maintenance control and supervision, and several improving methods including economical aspects in the organization*" (5). In Blanchard *et al.* (6), maintenance management is described as the process of applying the proper planning, right resource, program implementation, and control technique to a maintenance activity to guarantee that the assets are well maintained for the entire asset life.

This paper will employ the Maintenance Planning and Control (MPC) concept to represent the whole activities of maintenance management. Organisations use several key performance indicators (KPI) to measure the effectiveness of the operation and maintenance (O&M) including production loss ratio, corrective maintenance ratio, mean time to failure, mean time to repair, and Overall Equipment Effectiveness (OEE) (7). As for maintenance activities, no standardised set of maintenance KPIs exists. Nevertheless, most organisations relate the maintenance KPIs to a higher-level organisational target (8). A Computerised Maintenance Management System (CMMS) is used to store the data for maintenance KPIs (9). However, it is still limited by its implementation and restricted to proprietary software packages making it difficult to standardise (10).

According to Rødseth *et al.*, (11), the KPI for MPC should be linked to the OEE metric to improve coordination and increase the throughput time. OEE is defined as a total measurement of equipment performance in terms of availability, performance, and quality output. It is a bottom-up approach used to eliminate six large losses including equipment breakdown and identifies process improvement opportunities (12). Since OEE can integrate different aspects of manufacturing into a single performance indicator, it is widely used to measure productivity. However, the traditional OEE measurement is limited to the productivity performance of individual equipment (13). Ultimately, the high performance of the overall facility is more desired rather than outstanding individual equipment (14). Thus, the improvement of MPC will eliminate waste during maintenance activities for the overall facility rather than single equipment hence reducing the breakdown period of assets or equipment.

Lean philosophy enables work process improvement by reducing or eliminating waste, which brings no value and consumes additional resources in an organisation using various tools that can be applied to multiple work processes (15). In maintenance, the key contribution of improvement using Lean philosophy may come from the reduction in human errors, improvement of maintenance activities by optimising Non-Value-Added (NVA) tasks, good maintenance planning activities and correct usage of tools and parts (16,17). Various Lean tools have been established and used to achieve improvement targets. Selection of Lean tools for maintenance includes TPM, Kaizen, Poka-Yoke, Value Stream Mapping (VSM), Gemba, 5S, visual management and takt-time (18,19). VSM is a tool to visualise the overall process and help to identify waste and NVA in the work process (18). It can use lead time analysis to measure the baseline performance and identify NVA. Gemba walks refer to the "go-see" principle and go through the operation to identify issues and solve them (20). Not only it helps to surface the issues, but it can also improve the team relationship and ensure alignment among team members. Smith and Hawkins [21] highlighted the usage of Lean tools including dashboard or visual management enables organisations to achieve improvement targets.

The aim of the study is to provide the catalyst to achieve pacesetting asset performance through strategic intervention and embracing best practices for MPC. To achieve the aim, a set of objectives are defined:

1. To provide baseline analysis on the MPC process in measuring lead time/process efficiency.
2. To provide new parameters to monitor and verify MPC process efficiency.
3. To propose an improvement to the MPC process and possible improvement in the organizational structure.

The paper first explains the maintenance performance measurement and effectiveness review followed by a proposed conceptual model using LEAN methodology to evaluate maintenance effectiveness during MPC. Next, a conceptual model of effectiveness measurement for MPC including the proposed framework and tools used to evaluate each process is introduced. The author presented a case study from an offshore oil and gas production facility adopting the proposed method and indicating a positive improvement in work performance as well as elaborating on the key discussions and conclusions that have been identified throughout the MPC improvement journey.

The remainder of this paper is structured as follows. In Section 2 a conceptual model for MPC effectiveness review is presented. Section 3 presents the case study for an offshore facility. Section 4 presents the findings and discussions. Finally, in Section 5 the conclusions and suggestions for future work are presented.

2. Conceptual Model of Maintenance Planning Control (MPC) Effectiveness Assessment

This section will present the conceptual framework to measure MPC effectiveness based on the LEAN methodology. The overall process can be divided into three phases. **Phase 1** is referred to as the *Define and Measure phase*; **Phase 2** is referred to as the *Analyse and Improve phase*; and **Phase 3** is referred to as the *Control phase*. The first phase is to define the case for change including selecting the facility and assets, maintenance teams involved, and work process related. Relevant Lean tools such as VSM, process lead time, Gemba, and visual management can be utilised to measure and evaluate the baseline MPC performance. Historical data from CMMS can be extracted and used to perform the baseline measurement. For organisations without a CMMS database, new datasets can be gathered based on the work process involved. This process may involve capturing the data using the manual form and updating it to a single database *e.g.,* MS Excel. To understand the overall behaviours and potential gaps within current practices, VSM is used to review the work process with relevant stakeholders. Walk-through analysis or Gemba walk is then performed to understand the constraints and limitations of the current MPC process at the operational level. The observations from the assessment will be compiled and outlined according to the work process. Root cause analysis is then performed to identify the hidden issues within the current practices and pave the way for the development of action items or improvement. An overview of the MPC effectiveness framework is graphically illustrated in Figure 1.

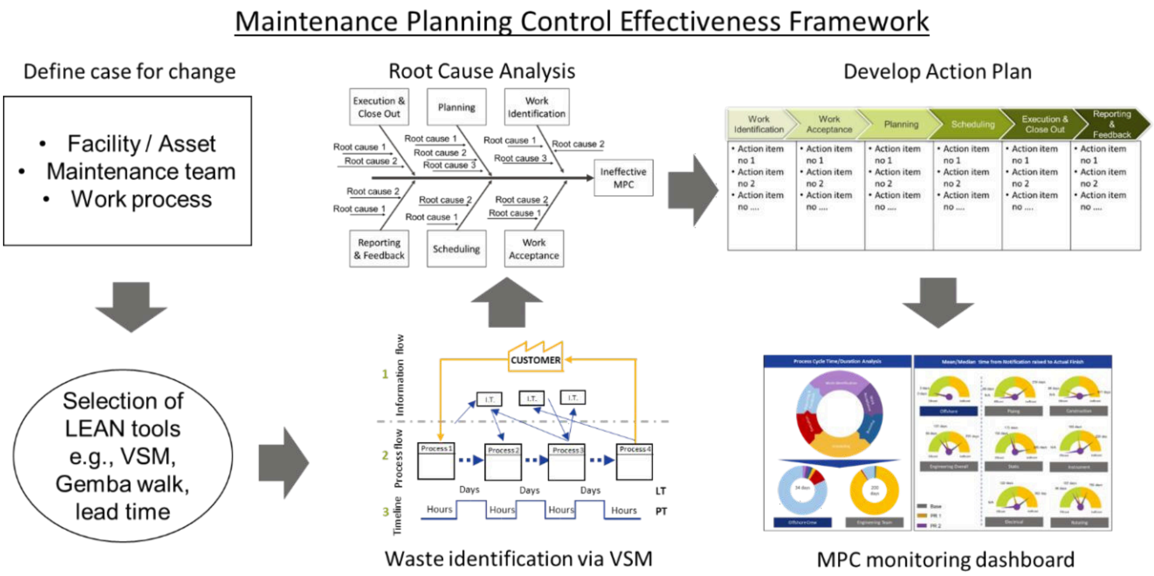

Figure 1. Maintenance Planning Control Effectiveness Framework

2.1 Define and Measure Phase

Phase 1 involves identifying the pain points utilising facts and figures which have been verified and agreed upon by the asset owner. The first step in this phase involves understanding the site-specific Organisation Chart and Work Process (both written and practised). The next step is the collection of Maintenance Management data from CMMS covering a span of several years. Examples of data include dates of Notification raised, Work Order type, Technical Completion (TECO) date, etc. These data are then filtered and verified together with the asset owner representative. Once the data has been verified, lead time analysis is conducted to surface pain points. Lead time within several stages of the Work Process is calculated using Statistical Analysis Software and compared against their target wherever available. Details Work Process stages are indicated in Figure 2. A Gemba Walk is then conducted to observe actual practice and conditions at the site in executing the Maintenance Work Process. This is to validate the data from earlier statistical analysis. It is here that the pain points are deliberated and prioritised into Key Focus Areas for further analysis in Phase 2.

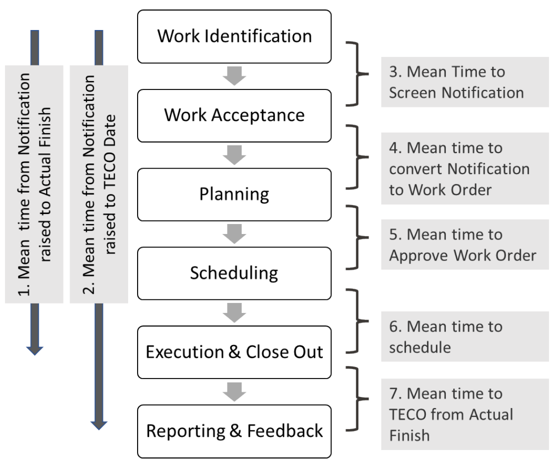

Figure 2. Maintenance Planning Control work process

2.2 Analyse and Improve Phase

To understand the root causes of ineffectiveness within MPC processes, Phase 2 aims to analyse the gaps identified from Phase 1 using relevant Root Cause analysis tools to surface out the hidden issues and undesired practices. Each work process is deliberated and discussed among the maintenance and operation personnel with facilitation by a competent person. Figure 3 illustrates the Ishikawa method (the fishbone diagram) that can be used to identify the root causes of ineffective MPC.

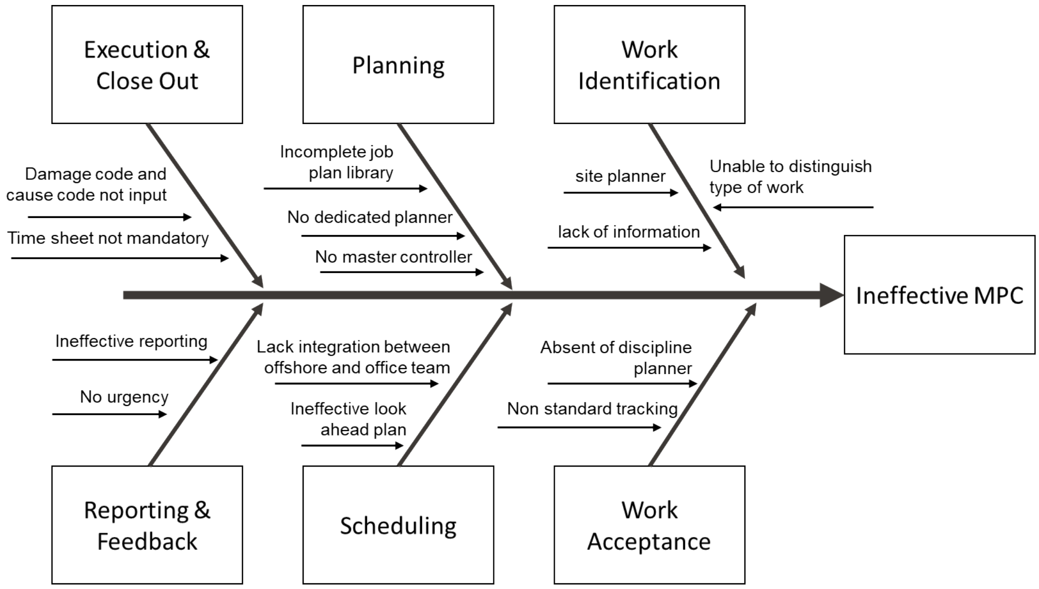

Figure 3. Ishikawa (fishbone) diagram for root cause analysis

The next step is to develop an action plan for improvement based on the identified root causes. The action plans are discussed amongst the same members including the management team to strategically develop corrective action plans. A good mixture of maintenance and operation personnel is important during the development of the Action Plan to ensure viable and sustainable solutions. An example of the template utilised to develop Action Plans is shown in Figure 4.

Work Identification	Work Acceptance	Planning	Scheduling	Execution & Close Out	Reporting & Feedback
1. How to standardize notification priority? • Training on MPC • Improve communication on prioritization • Priority for establish inspection program refer to inspection findings • Other findings based on discussion with SME 2. Amend MPC guideline from work completion to "attempt to failure"	1. Work order listing (PM+CM) template • Standardize template • Communicate / train 2. Identify dedicated planner to verify list of screened notification applicable to related section	1. Job library / Planning norm • Develop from work pack • Basic start / Basic finish / Materials / Resource 2. Dedicated section planner to ensure correct basic start/finish / materials / resource 3. Master compiler extract list of priority job from SAP to ME/OE for syndication	1. Job agreed / lock between operation with maintenance (window) at integrated planning meeting 2. Schedule 30 days (LAP)	1. Time sheet not mandatory in SAP 2. Damage code and cause code to be input by engineer prior to job completion 3. Reliability to perform analysis for damage code and cause code	1. Explore a new dashboard to monitor MPC performance 2. Establish a clear communication plan for all parties

Figure 4. Action Plan

2.3 Control Phase

To ensure sustainability, continuous monitoring of the action plans is necessary. One of possible ways of achieving this is to monitor the 'Measure of Success' for each Action Plan developed during Phase 2. Apart from that, re-evaluating the lead time for each Work Process identified in Phase 1 also can be one of the success criteria for identifying correct pain points and Action Plans. This independent periodic performance review may be conducted on a quarterly basis or whenever deemed suitable. The biggest challenge in this phase is to get every personnel involves and contribute to the process. Some organisations may require change management and cultural transformation agenda to elevate the initial result to the desired target hence reducing the 'value leakage' in terms of productivity and efficiency. Figure 5 illustrates the desired transformational target of MPC improvement.

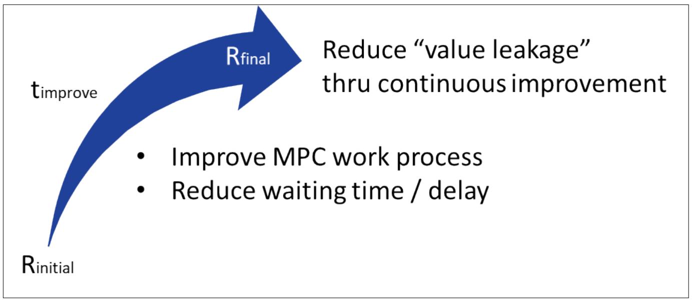

Figure 5. MPC transformation concept

3. Case Study

An offshore oil and gas production facility has been selected as a case study to showcase the implementation of the proposed maintenance effectiveness model. The facility is located within Malaysia water approximately 80 miles from onshore and is operated by a local oil and gas operator. It is a manned facility with two weeks rotational crew. The facility is supported by two teams; the main team is the offshore crew and supported by the engineering team located at the onshore office. All immediate responses will be provided by the offshore crew and major engineering repair and analysis will be supported by the engineering team. The facility has been in operation for more than 30 years and currently facing operational and integrity challenges due to contaminant threats such as *Mercury*, H_2S, sand issue, and high CO_2 contents. The operation and maintenance team needs to respond to the everchanging scenario to remain profitable. One of the gaps identified at the facility is maintenance effectiveness specifically for planning and scheduling work processes.

This study was conducted for a duration of three months excluding the revalidation of results after the implementation. The datasets were acquired from CMMS records. Reactive maintenance notifications and maintenance work orders from January 2017 until September 2020 are evaluated. The analysis is divided into three sets of data segregated by different timeframes. The first data set is from January 2017 until December 2018 and the second data set is from January 2019 until September 2019. The last data set is from September 2019 until September 2020. The first and second dataset was differentiated due to changes in organizational structure while the third dataset is the revalidation period post-implementation. Table 1 describes the datasets used in the analysis.

Table 1. Dataset for MPC effectiveness measurement

Data Set No	Timeframe	No of Notifications	No of Work Order
1	Jan 17-Dec 18	1807	4020
2	Jan 19-Sep 19	757	1503
3	Sep 19-Sep 20	832	1825

VSM is performed to identify all the work processes involved during the MPC from work identification or notification raised whenever any failure occurred until the work order has been closed or maintenance work has been completed. Figure 6 illustrates the simplified VSM for offshore oil and gas production facilities that have been analysed in this study. For each of the work processes, the lead time analysis will be calculated to get the baseline behaviours for each of the engineering teams as well as the offshore crew. The lead time will indicate the average time taken by each maintenance team to perform the planning and scheduling activities prior to the maintenance execution and closure.

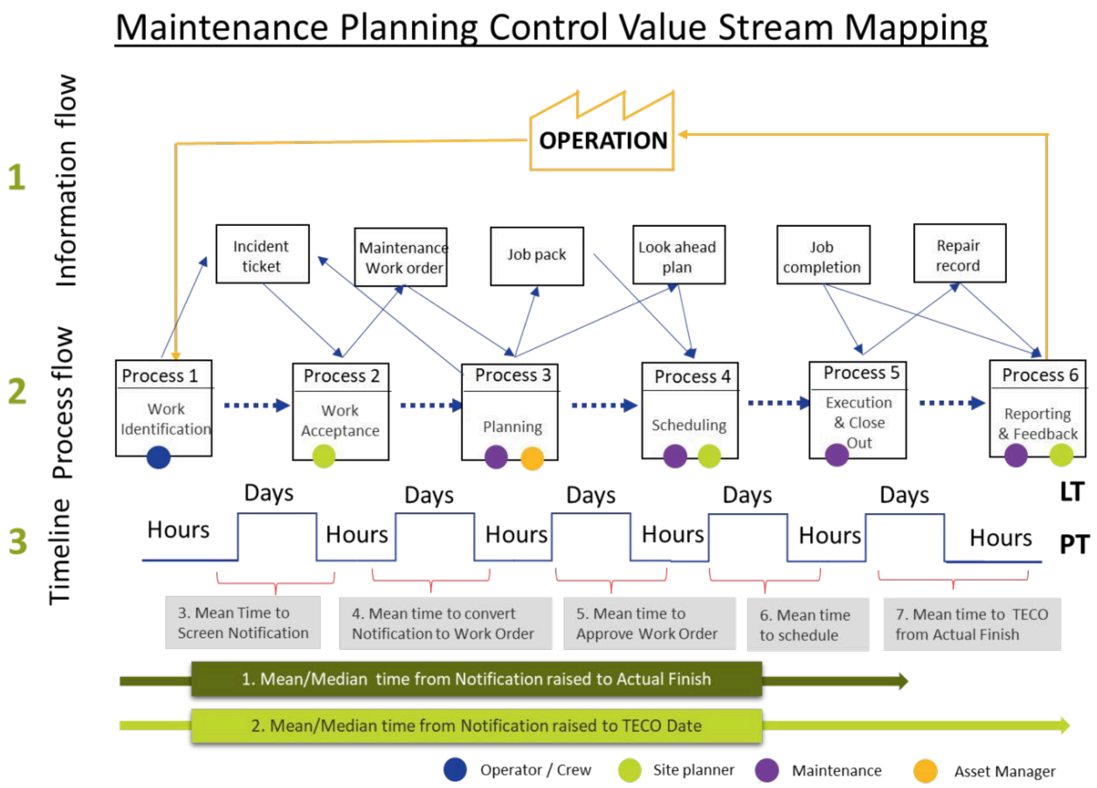

Figure 6. Simplified value stream mapping and lead time analysis

Gemba walk is then performed by interviewing the personnel involved in the MPC process including the operator, site planner, discipline engineer, maintenance coordinator and maintenance manager. Current practices are then captured and mapped against the VSM to further analyse through a root cause analysis approach. Table 2 outlines the result of the average lead time for the offshore team for Dataset No 1. It can be noticed that the average time for the Piping team to complete reactive jobs is between 259 days and 305 days until reporting or technical completion (TECO). The average time to screen a work order took about 57 days due to a lack of information during the work identification resulting in difficulties to assign the work to a relevant maintenance team. The lead time analysis is performed for all sub-discipline teams that supported the facility maintenance. The root cause analysis is then conducted to analyse the hidden issues or the root causes for each MPC work process. Figure 3 earlier illustrates the Ishikawa diagram (fishbone diagram) used to identify the root cause for ineffective MPCs. Action plans are then developed for each of the gaps identified within the individual MPC work process. The improvements are then monitored for at least six months to one year to ensure they can be sustained.

Table 2. Lead time analysis results for the piping team

Data Set	Maintenance Team	Analysis	Level 1 Parameter	Lead time result	Lead time target
1	Piping	1	Mean time from Notification raised to Actual Finish	259	Nil
		2	Mean time from Notification raised to TECO Date	305	60 Days
		3	Mean Time to Screen Notification	57	14 Days
		4	Mean time to convert Notification to Work Order	6	14 Days
		5	Mean time to Approve Work Order	24	Nil
		6	Mean time to schedule	10	Nil
		7	Mean time to TECO from Actual Finish	20	14 Days

4. Discussion

MPC effectiveness is usually associated with work order compliance in terms of the performance of planned tasks against actual tasks whereby the overall duration of a maintenance task and maintenance response are being overseen. This study showcases another perspective on measuring MPC effectiveness via monitoring the sub-process lead time as a performance indicator. As shown in Table 3, the offshore team recorded a consistent performance of an average time of two days with a slight increase to three days in 2020 to complete the maintenance task from the work identification. This indicates a fast maintenance response on offshore oil and gas production facilities to ensure high equipment availability. As for the engineering team, complex engineering issues or failures requiring a longer downtime duration need to be resolved. Without a clear line of sight, the progress might take a longer detour to be completed as seen in the period of 2017 – 2018. A correct understanding of each work process enables the team to develop a suitable action plan for improvements.

Fundamental aspects such as roles and responsibilities are being re-evaluated based on the constraints identified. Either new roles are required, or certain responsibilities can be merged into a smaller area that is subjected to the outcome of root cause analysis. The development of reference planning tasks or planning norms helps to reduce human error during the planning and scheduling process. On top of that, consistent planning meetings must be performed to ensure all maintenance tasks are well distributed, and resources can be fully utilised and optimised. As the MPC performance is being measured, the overall maintenance response has improved by more than 40% in the year 2019 and further improved to 60% in the year 2020. This has been supported by clear communication through a performance dashboard, as shown in Figure 7, to enable the relevant maintenance team to be kept informed regarding the MPC performance. There are several key findings that can be identified from this study, namely:

1. Visualisation of work process mapping and Gemba enables the team to identify waste and NVA even for a matured work process like MPC.
2. Digitalisation of all the maintenance work processes enables the analysis to be performed efficiently and paves the way for improvement.
3. Identification of root causes is crucial to develop an effective action plan rather than addressing just the immediate causes.
4. Clear roles and responsibilities are required to ensure the MPC work process can be executed timely and effectively.
5. Effective communication plans such as visual management or dashboard enable operation and maintenance personnel to keep updated with the MPC performance.
6. Commitment from all levels is desired for the management of change during the MPC work process transformation journey.

It has become evident to the authors that a good digitalisation strategy in an organisation will impact the performance specifically in MPC as presented in this paper. Even with minimal modification of existing CMMS functionalities like categorisation or prioritisation during the work identification help to convey clear information thus reducing the processing time taken. However, small changes cannot be achieved without an understanding of the overall process. This aspect is very relevant in the Industry 4.0 era and integration with the mindset of Lean or continuous improvement elevates the result further to the next level.

Table 3. MPC effectiveness results.

<table>
<tr><th colspan="2">Work Centre</th><th>Analysis</th><th>2017-2018</th><th>2019</th><th>2020</th></tr>
<tr><td colspan="2">Offshore</td><td rowspan="8">Average time from Notification raised to Actual Finish (days)</td><td>2</td><td>2</td><td>3</td></tr>
<tr><td rowspan="7">Engineering Team</td><td>Overall</td><td>235</td><td>122</td><td>98</td></tr>
<tr><td>Static</td><td>285</td><td>175</td><td>156</td></tr>
<tr><td>Rotating</td><td>195</td><td>122</td><td>96</td></tr>
<tr><td>Construction</td><td>417</td><td>88</td><td rowspan="4">The majority of work is still ongoing during the validation</td></tr>
<tr><td>Piping</td><td>259</td><td>88</td></tr>
<tr><td>Electrical</td><td>262</td><td>122</td></tr>
<tr><td>Instrument</td><td>226</td><td>160</td></tr>
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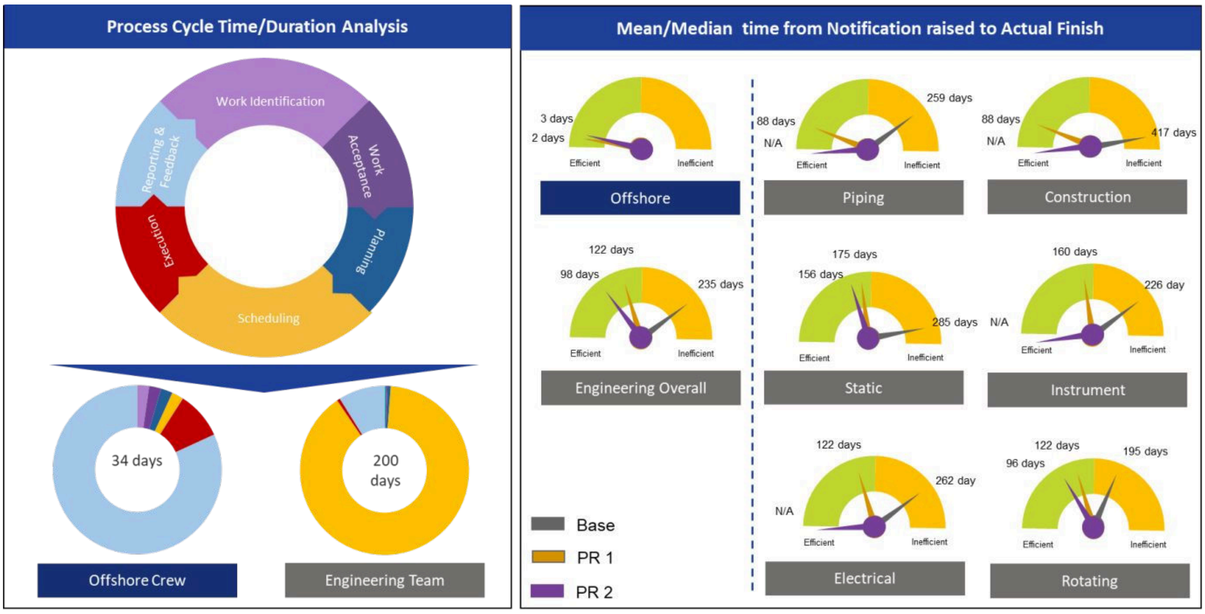

Figure 7. MPC monitoring dashboard for sustain phase

5. Conclusions

The outcome of this study indicates that the overall lead time for Maintenance Planning and Control (MPC) has improved by more than 40% during the control period and further improved by 20% by the end of the assessment period with a total process cycle time improvement of close to 60% from the initial measurement. Three prong strategy has been implemented in addressing the gaps identified namely, (i) capability, (ii) system weakness, and (iii) communication. Fundamental aspects such as training, document standardisation, digitalisation, data management, and correct resource assignments have led to the effectiveness of MPC execution.

By implementing the proposed methodology, the company can control its overall maintenance response from notification raised, followed by planning and execution, until the work completion and reporting. The asset manager will be able to distinguish between different teams and act in accordance with the performance to ensure maintenance work can be completed within the allowable time limit. This is crucial to avoid secondary and tertiary damage to the asset due to a lack of or slow maintenance response. The study was able to demonstrate the usage of LEAN methodologies including value stream mapping (VSM), lead time analysis, and Gemba-walk to improve the MPC process.

The study enables the company to strategically identify the working teams' gaps and to focus the effort on underachievers rather than on generic improvements. The lead time result has been presented as the performance indicator for MPC and potentially serves as the leading KPI towards overall performance. As the performance of MPC can be improved and controlled, this will reduce maintenance time, thus improving the availability of equipment and assets and eventually improving the OEE. This will allow the company to operate in an efficient way and reduce operating costs in the long run.

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