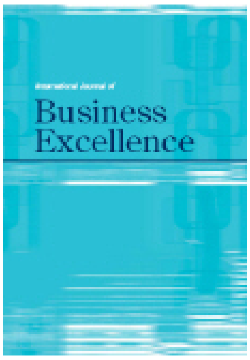

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DMAIC methodology for productivity improvement of preventive maintenance in an oil and gas company

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Abstract: Maintenance is an integral part of any organisation success and improves customer satisfaction and increase profitability. The purpose of this study is to propose a systematic approach for implementing define-measure-analyse-improve-control (DMAIC) methodology in an oil and gas company's maintenance department using case based research. A well-known DMAIC techniques is implemented using tools such as value stream mapping (VSM) and 5 Why's. Result shows the improvement of considered case company's maintenance department performance in 20% reduction in PEC coordinator process, 50% reduction in inspection, cleaning process and assembly, and 25% reduction in pressure test. This study is unique in a sense that it is implemented in an oil and gas company to improve productivity of preventive maintenance operations and provide managerial insight to decision makers and practitioners.

Keywords: productivity improvement; preventive maintenance; define-measure-analyse-improve-control; DMAIC; value stream mapping; VSM; 5 Why's; case study; oil and gas sector.

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1 Introduction

Six-sigma and its concept is not new and been for many years and proved to be an effective and efficient methodology and been widely adopted in several process for process improvement (Al-Abdallah and Lic, 2020; Devi et al., 2020). Define-measure-analyse-improve-control (DMAIC) is one of the lean six-sigma techniques that have grabbed the attention of innumerable manufacturing and tertiary firms globally for process/product improvement in constructive manner. It encompasses five step by step sub-processes namely define, measure, analyse, improve and control. Each sub process consists of its own problem solving tools and techniques that a user can exploit depending upon organisation's requirement and available resources. Performance and productivity measurement and its improvement are critical to the success of any organisation (Khan et al., 2019a, 2019b). All types of organisations need to be as productive as possible to best utilise their precious resources, to meet their customer's needs, and to stay competitive with similar organisations (Pritchard, 1995).

Maintenance can affect main points and stages in production line, since it affects the equipment's life style or the timing needed to work with each equipment. Its focus is to ensure that all equipment's used in the production are working impeccably that ultimately increase productivity and operation to the best. Additionally, systematic planning and inspection in the production line always give positive outcome to the company. Moreover, proper maintenance is considered as one of the most critical aspects that are needed to keep everything work well.

A robust association has been witnessed between maintenance and productivity. The importance of the maintenance function has increased, due to its role in keeping and improving availability, performance efficiency and product quality (Al-Najjar, 1996; Alsyouf, 2007). As business performance facets like profits, productivity and efficiency have been impacted greatly by maintenance, a suitable and effective maintenance performance measurement (MPM) is needed to monitor the maintenance activities and the planning for more successful improvement (Kutucuoglu et al., 2001).

Besides, cost reduction is also considered as the most significant factor behind maintenance process improvement. As maintenance cost is a sharply increasing part of the operational costs, it is an evident target for operational and managerial improvement (Mikler, 2015). Hence, applying effective maintenance aims to enhance company's profitability and competitiveness through continuous cost-effective improvement (Al-Najjar, 2007; Maletic et al., 2012).

DMAIC is a widely used continuous improvement technique to identify and improve specific area or process (Qureshi et. al. 2014; Rehman et al., 2018). It has been applied in many areas such as in supply chain performance measurement and improvement (Rehman et al., 2018) to improve organisation performance (Khan et al., 2019b); in scheduled maintenance operations (Chandler et al., 2020); process improvement in automotive parts manufacturing (Meena et al., 2018) in software development industry (Dweiri et al., 2015, 2012) in a telecom company to improve customer satisfaction (Shamsuzzaman et. al., 2018) in productivity improvement in a caravan manufacturing company (Khan et al., 2020) in improving the carbon footprint of food and packaging waste management in a supermarket of the Italian retail sector (Marrucci et al., 2020) in healthcare sector for improvement of registration process of a hospital (Bhat et al., 2014) in reduction of ship loading commercial time (Garza-Reyes et al., 2016), etc.

Any delay or poor management in maintenance can show negative outcome to the company. If any part or equipment is not working well due to poor maintenance, can lead to quality issues, or delay in the production. For instance, if a company does not schedule regular clean up timing for their equipment, can result in sudden small or ample breakdowns that lead to the waste of time and resources both. Considering the importance of the preventive maintenance and up time of machine, the objective of this study is as follows:

- Identify issues associated in maintenance stages, especially the one which affects the amount of maintenance tasks given in over a month (work order over month), head count utilisation and turnaround time (TAT).
- Analyse 'why' and understand 'how' each issue occurs.
- Create solutions suitable for each issue found to increase productivity of the preventive maintenance.

Considering the background of this research and importance of DMAIC tools and technique, it is evident from past studies that it has been vastly implemented in several productivity, process, and performance improvement projects. Efficiency and effectiveness of DMAIC tools and techniques such as 5 Why's and VSM is proven successful by many authors in the literature, therefore the objective and purpose of this study is to demonstrate how these tools and techniques implemented in a maintenance department of an oil and gas company. This study outcome will also help managers and decision makers and provide clear view to how they can implement these tools and technique in their organisation.

The reminder of the study is structured as follows. Section 2 will provide a brief overview of literature about DMAIC, VSM, and 5 Why's applications in different area. Section 3 will describe and implement proposed methodology followed by results discussion in Section 4. Finally, Section 5 will conclude this study and highlight some future research directions.

2 Literature review

The application of DMAIC, which is one of the methods of quality improvement used in Six Sigma concept, can increase the effectiveness while adequate reacting for the appearing problems (Smętkowska et al., 2018). As conversed above, numerous researchers and practitioners have successfully utilised DMAIC for different process improvement areas, out of them few are briefed below.

Smętkowska et al. (2018) have used DMAIC process and implemented single minute die exchange (SMED) and total productive maintenance (TPM) at one of the production machines for improvement of process's quality.

Similarly, Girmanova et al. (2017) have utilised DMAIC approach for product quality control in metallurgical operation. Quality of annealing process of steel has been improved by using multiple tools like flow chart, Pareto chart, failure mode and effect analysis (FMEA), Fish Bone diagram, etc. while sigma level of the same process has been improved by 13%. Singh and Lal (2016) have improved the welding and rolling process of a manufacturing industry by application of DMAIC methodology. Rejection rate of welding process has been reduced from 8.21% to 4.81%, process yield increased from 91.73% to 95.19% whereas sigma level has been improved from 2.89 to 3.16.

Singhtaun and Imkrajang (2016) have enhanced the weaving process of textile industry by the application of DMAIC method. The major defects were identified along with root causes and minimised with the help of multiple tools like Histograms, Pareto charts, etc. Yadav and Sukhwani (2016) successfully implemented Six Sigma through DMAIC technique in automotive parts producing industry to improve quality level by reduction of rejection rate of clutches. Multiple tools of DMAIC have been applied and rejection has been reduced from 15 to 2 out of 220 per batch that results in increase of sigma level from 2.99% to 3.86%.

Jenicke et al. (2008) have examined the challenges faced in implementation of Six Sigma in academic sector and proposed a framework consisting of DMAIC process as an execution guide. Taner et al. (2007) have applied DMAIC approach in healthcare sector to cater the problems arise in daily healthcare operations and to improve healthcare services. Tools like flowcharts, Ishikawa diagram, etc. were utilised to identify, analyse and address the problems and challenges through the system. Hence resulted in increased satisfaction of doctors and patients along with cost saving.

In an occupied and demanding environment of an organisation, it might be difficult to study the flow of goods briefly from supplier to customer without visualisation. Value stream mapping (VSM) is one of the lean practices that permit its user to identify record, measure, analyse and modify the complex process through its proper mapping via pictorial representation. VSM has been described as one of the most powerful lean tools for an organisation wanting to plan, implement and improve on its lean journey [Manos (2006), p.64].

A VSM can be drafted aided by predefined symbols, knuckling down to material and information flow along with total time including cycle time, takt time, up time, setup time and all lead times of the process selected for evaluation purpose. An absolute process of an individual product/service from start till end becomes glance-able once it is mapped through VSM. A few applications of VSM as an example are defined below. Guzel et al. (2018) have utilised VSM for reduction of lead-time of T-shirt manufacturing process in one of the textile industry of Turkey. Case study shows that production lead-time has been drastically reduced, i.e., from 14.5 to 5.2 days (64%) using VSM.

Yuvamitra et al. (2017) have proposed the utilisation of VSM for optimisation of production process of ropes starting from ordering of raw material till shipping of final product. After complete process evaluation via VSM it has been estimated that implementing VSM will reduce the process time by 68%, total waiting time by 88% along with the saving of 33% material handling time and 75%of manufacturing time of ropes.

Tortorella et al. (2016) have applied VSM in sterilisation unit of the Public Healthcare Organisation of Brazil. A significant improvement has been observed in reduction of customer complaints, i.e., by 35% and employees' overtime by 41% respectively. Delivery service level has also been improved by 23%.

Singh et al. (2015) have successfully implemented VSM in fastener industry for process improvement purpose. After elimination of identified wastes, overall lead-time of manufacturing process has been reduced by 44.84%, cycle time by 9.38%, inventory by 87.5%, operators by 11.11% and distance by 23.80%.

Venkataraman et al. (2014) have utilised VSM for waste elimination and particularly cycle time reduction of machining process of crankshafts. Results showed that manufacturing lead-time has reduced by 40% and productivity has been improved by 20 to 28.57 pieces/hour. Dighe and Kakirde (2014) have applied VSM along with other lean tools in Pumps manufacturing company for identification and elimination of non-value added activities as well as enhancement of assembly process. Result of the case study shows that process lead-time has been reduced from 54 to 36.5 days whereas inventory (in days) has been reduced from 33 to 22.4 days.

5 Why's is an elementary and effortless technique in the pool of Lean Six Sigma tools significantly deployed in principle-cause analysis pertaining to obstacles appear at any stage of a process/project. Progressing deep down following series of 'whys' will not only identify the fundamental cause but also highlights the relation between multiple causes of problem, that will further lead to the process defence from repetitive failures/faults. Many researchers have practiced 5 Why's tool in conjunction with other Lean Six Sigma tools for waste identification, prioritisation and elimination.

Talukder et al. (2013) targeted systematical waste reduction and productivity improvement in one of the garments industry via application of multiple Lean tools. VSM, Pareto analysis, cause and effect diagram, 5 Why's (for root cause analysis), layout improvement through cellular manufacturing, and Kanban have been implemented successfully with satisfactory results. Similarly, one of the visible applications of 5 Why's is observed in 'analyse' phase of DMAIC methodology along with other supplementary tools. Prashar (2013) has deployed 5 Why's tool through DMAIC for enhancing 'right first time dyeing (RFT)' percentage in dying process of fabrics. After corrective action, RFT has been improved from 94% to 98%, that in turns generated cost saving of INR 2.951 million per month.

Myszewski (2013) formulated a scheme to represent and analyse the process improvement done at operational, tactical and strategical levels in different organisations. A complete model is developed based on questioning scheme and graphical illustrations (Improvement snail diagram and prevention states transition graph) for problem solving purpose. It's then applied in one of the company producing wire cables to examine the functionality of developed model.

Murugaiah (2010) has utilised 5 Why's technique along with Pareto analysis for problem identification and correction in one of the biggest barrel manufacturing industry. In this case study scrap loss, machine downtime loss and changeover time loss reduction has been targeted. By properly applying 5 Why's technique, industry has overcome the highlighted problems and turn up with the corrective action that completely eliminated the top defects which in turns resulted in zero scrap thereafter.

Hassan and Jalaludin (2016) have successfully implemented 5 Why's technique to enhance the predictive maintenance strategy for injection moulding machine. In the same way, Benjamin et al. (2015) has found 5 Why's analysis as an effective approach in reducing/eliminating OEE's speed losses in one of the manufacturing firm resulted in appreciable yearly savings of USD 32,811.5.

2.1 Literature round up and our contribution

Literature review shows that DMAIC, VSM, and 5 Why's have been successfully applied in variety of applications over the last years. It is also evident from the literature that many researchers and practitioners improved productivity using DMAIC. However, the application of DMAIC in maintenance productivity improvement, specifically in preventive maintenance improvement is limited. However, literature is limited in the context of preventive maintenance process improvement in Middle East country's oil and gas sector. Therefore, this study will be a stepping-stone in this direction and helps practitioners and researcher to get benefit from it.

2.2 Significance of the study

This study is unique in a sense that it has been implemented in an oil and gas company to improve productivity of preventive maintenance department as compared to manufacturing/service industry. In any manufacturing or service sector, usually experience and knowledge of decision makers and managers mainly affects the performance of the improvement tool. However, in this study, we consider maintenance department in which operation and process are different and customised. In addition to that, in any manufacturing/service industry, lesson learned are usually categorised based on their specialty group, however in this study the domain of lesson learned move from specialty group to personals who are involved in performing maintenance operation. Lastly, as any improvement initiative will be successful if all employees are involved in improvement process. In addition, productivity improvements in supporting department such as maintenance are limited in the literature. This study shows the involvement of all employees responsible for maintenance process shows the uniqueness of the implementation and application of DMAIC tools and techniques.

3 Company overview and proposed methodology

In order to achieve the objectives, set in Section 1 and to provide understanding to the researchers, academicians and practitioners, our research methodology adopted a case study approach. Case study approach will help the audience to better understand the

DMAIC implementation in an oil and gas sector for preventative maintenance's productivity improvement. Managerial implications and lesson learned from this study will also be discussed to give generalise outcome. The reason behind using case study approach is that this approach provides flexibility in design and application, helps in investigating complex processes, and can be used to generalised theoretical proposition (Sunder and Antony, 2015; Yin, 2014). In addition, generality of outcome based on single case company outcome is limited, however, learning from single case company experience can add sum of the knowledge in existing literature that can later be used by future researchers and academicians (Antony et al., 2012). Therefore, our research methodology is based on a single case company, which is in one of the Middle East countries. In addition to that, based on literature review our methodology used widely applied process improvement technique, DMAIC. For a discussion of the DMAIC cycle, readers can refer (Gijo et al., 2011; Jirasukprasert et al., 2014; Pyzdek and Keller, 2010) for details of each steps.

3.1 Case company background

The company where the study was conducted is one of the largest oilfield service company founded in 1920s. Considered case company has around 100,000 people representing around 140 nationalities working in more than 85 countries around the world. They supply an industry's most comprehensive range of products and services, from exploration through production and integrated pore-to-pipeline solutions for hydrocarbon recovery that optimise reservoir performance. Specific product and services of considered case company are Seismic, drilling services, characterisation for better understanding of reservoir, well completions by preparing the bottom hole to run production tubbing, subsea production, well intervention, and processing and separation are some of them. The considered case company is following several standards to fulfil customer requirements such as QHSE: stands for quality, health, safety, and environment.

Proposed methodological steps based on DMAIC are illustrated in Figure 1.

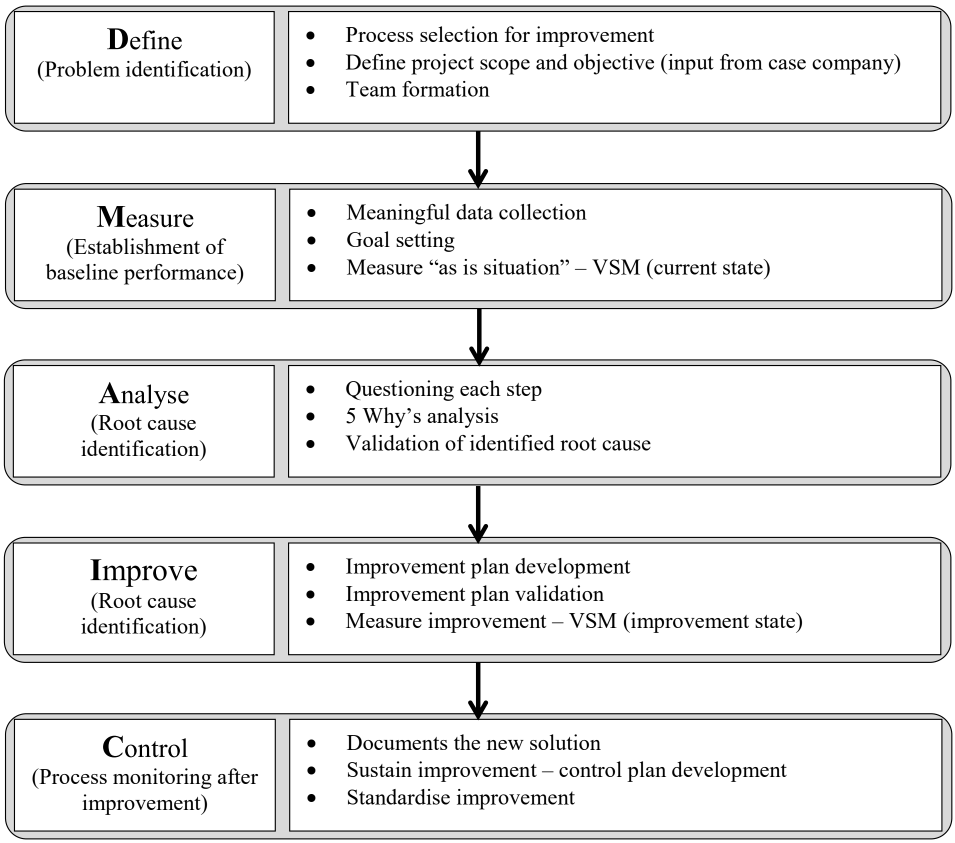
3.2 Define phase

The main objective of define phase in DMAIC methodology is to establish project team, selection of process for Improvement, and to define project scope and objective (Ghosh and Maiti, 2014).

3.2.1 Process selection for improvement

There are 52 active pressure control equipment (PCE) as assets in the fleet of considered case company. During the discussion and preliminary data collection, we came to know that not all of them are working at required performance level. After discussion with the concerned people in the department, we identified that the main issue behind this is not following the standard processes and thus performance that is needed by the organisation is not achieved. Therefore, we recognised that this PCE in the fleet needs comprehensive analysis and improvement. At current, the case company is handling around 15 work orders/month (WO/month) for every four headcounts (HC). In addition, their TAT is approximately 7.32 hours illustrating that the WO/HC in any month is 3.76. This initial data indicates that case company is performing well behind the target and needs improvement. Therefore, we have decided to select this as an opportunity of improvement.

Figure 1 Proposed methodology



3.2.2 Define project scope and objective

According to Furterer (2009) and Pyzdek and Keller (2014), defining scope of project is essential for its implementation successfully. The case company has an organised structure to manage each department. Since the case company is facing some problems in the maintenance department, it has been decided to implement DMAIC in the maintenance department only. In addition, for companies like considered case company, maintenance department is the fundamental department to achieve overall goals of the company. Therefore, the scope of this project is limited to the maintenance department only.

The targeted goals and objectives have been decided after discussion with the line manager of the case company. The goal of WO/month set to 52 WO/month from 15 WO/month followed by the TAT, set to 4.5 hours from 7.32 hours. Lastly, in order to improve the overall productivity, the WO/HC goal set to 13 from 3.6. The objective of this project's implementation is to achieve the set goals described above, approved by the management of the case company.

3.2.3 Team formation

Team forming is the first step of DMAIC define phase. Team member should have adequate knowledge and experience related to the process (Furterer, 2009). Team for this project is based on personals who are directly involved in process and responsible for maintenance. Thus, team includes three supervisors, one assistant manager, one manager, and one of the authors. The manager is responsible for full process of maintenance. The participant author is the leader of the project implementation.

3.3 Measure phase

The main purpose of this phase in DMAIC cycle is to measure the actual performance of the process and compare it with the actual output (Basu, 2009; Garza-Reyes et al., 2014; De Mast and Lokkerbol, 2012; Pyzdek and Keller, 2014). In this project, we measured and recorded the equipment that are used in maintenance and found out the timings in order to show the location of main points that should be underlined and reviewed. The first method that is used to measure the equipment timings is recording of STEM2 which is done on monthly basis. The meaning of STEM is 'standard equipment maintenance' which basically tells the standard timing for equipment maintenance according to the technician and employees working in the organisations, logs recording by stop watch, and records used by the RTIE system. RITE is a system in case company where the operators can open work-orders when they start maintenance and close the same after completion, record time logs of each stage and mention the status of maintenance for example down for parts, waiting for maintenance, etc. Table 1 shows the current.

Table 1 STEM 2 working hours

	Body wash	*Disassemble equipment*	*Clean equipment*	*Redress equipment*	*Pressure test*	*3rd part inspection*	*Painting/ welding*	*Total process time*
Single BOP	0.333	0.625	0.5	0.667	0.75	0	0.33	3.205
Combi BOP	0.333	1.067	1	0.875	1.5	0	0.5	5.275
Quad BOP	0.333	1.5	1.5	1.3333	1.45	0	0.75	6.8663
Side door stripper	0.333	0.6333	0.7	0.41667	0.5	0	0.5	3.08297
Tandem stripper	0.333	0.7	0.7	0.41667	0.5	0	0.55	3.19967

The STEM 2 log also indicated the barriers that are faced within the process. It seems like each step in the equipment maintenance shares the same barrier times, such as waiting in the wash bay, or waiting the pressure test bay. Table 2 shows the average barrier timing.

Table 2 average barrier timing

Unclassified task (barrier time)	*Waiting on washday*	*Waiting on forklift/crane*	*Setup time*	*Waiting on special tool*
1.5	0.75	2.25	0.5	0
Waiting on 3rd party inspection/certification	*Waiting on pressure test bay*	*Waiting on store*	*Total*	
0	1	0	6	

Finally, the average recording time for individual BOP in each month as STEM2 and annually as STEM 3 is recorded and shown in Table 3.

Table 3 Average times recorded

	STEM2	*STEM3*
	Total process time	*Total process time*
Combi BOP	7.50	11.05
Single BOP	6.00	8.05
Quad BOP	10.50	16.55
Stripper	3.13	5.35
Annular BOP	6.50	8.05

Next step in the measure phase is to measure each step of maintenance by presenting it in VSM to gain a better, clear picture of how each step happens, and how much time does it take to happen. According to Pyzdek and Keller (2014), VSM is a powerful tool to find out the value-added and non-value-added activities in the process. In this project, the steps consists of maintenance are classified as value-added and non-value-added. Figure 2 shows the VSM for the maintenance process. VSM will help in identifying the main problems of the maintenance process. There are seven steps involved in maintenance which are body wash, disassemble equipment, clean equipment, redress equipment, pressure test, painting, and green tag.

In order to identify the time consuming stage, the VSM should be understood especially the process part and the maintenance part in each stage. It starts as the following:

- The complete process starts from body wash stage and takes 45 minutes waiting at wash bay to get a body wash whereas body wash process itself takes 20 minutes.
- Before reaching to disassembly stage, it takes ten minutes for setting up an equipment on the stand. An average waiting of 35 minutes is done including the use of forklift. The process of disassembly takes 62 minutes.
- Cleaning takes 60 minutes for the process with no waiting time.
- Assembly takes 52 minutes for the process with no waiting time.
- Before reaching to pressure testing stage, it takes ten minutes for setting up an equipment on the stand and 15 minutes for securing equipment properly on the stand (pressure stand). An average waiting of 35 minutes is done including the use of forklift. Furthermore, 60 minutes are consumed on average basis to stand in the

queue for using the pressure test bay. The process of the pressure test takes 90 minutes.

- Before reaching to painting stage, it takes ten minutes for setting up an equipment on the stand and 15 minutes to remove the equipment from the pressure stand. An average waiting of 35 minutes is done including the use of forklift. The process of Painting takes 30 minutes.

Finally, ten minutes waiting is done including the use of overhead crane before reaching to last Green tagging stage. It takes only five minutes is green tagging of an equipment. In VSM, an information flow of Maintenance process is illustrated on the top side. This VSM is done on 'combi BOP' as it is the most frequent equipment that comes to the workshop so; it has the most accurate data between the other time logs of equipment.

3.4 Analyse phase

In order to identify, organise, and find out the root cause of the problem, this is the key phase in DMAIC methodology (Sin et al., 2015). Several tools and techniques can be used in this phase such as process mapping, brainstorming, cause-and-effect diagrams, 5 Why's, hypothesis testing, etc. (Jirasukprasert et al., 2014; Pyzdek and Keller, 2014). However, the selection of tools and techniques in this phase is normally depends on the nature of project and problem in hand (Pyzdek and Keller, 2014). In this project, 5 Why's technique has been used to identify, organise, and find out the root cause of the problem.

In order to investigate issues faced at each stage, we have performed 5 Why's technique for each stage of the process. It is initiated by questioning at each stage about both, i.e., process and maintenance. Some of the stages did not have vibrant issues as they were working under timings assigned by the company. However, application of 5 Why's indicated that some of the stages were facing valid issues that required improvement. In addition, some other stages show aspects that are related to improvement rather than problems. Only those stages are selected for 5 Why's that strongly needed improvement particularly that really consist of a root cause for their negativity or a chance of improvement. We have performed 5 Why's analysis at disassembly, cleaning and degreasing (part 1 and part 2), assembly, pressure test barrier time and barrier time between stages. Figure 3 shows the 5 Why's analysis of disassembly process.

Based on the analysis we have identified the unavailability of specialised tools as the root cause of delay in disassembly.

Figure 4 shows the 5 Why's analysis of cleaning and degreasing (part 1 and part 2).

Based on the analysis, we have identified unavailability of proper solvents as the root cause of delay in cleaning and degreasing. In addition, PCE enters the wash bay while it is closed and cannot be washed thoroughly from inner side.

Similarly, Figure 5 and Figure 6 show the 5 Why's of assembly process and pressure test barrier time. Lack of planning and coordination is identified as the root cause of delay at assembly stage. Whereas, usage of PT Bay by more than one segment is identified as the root cause of delay at pressure test barrier.

Figure 2 Current VSM (see online version for colours)

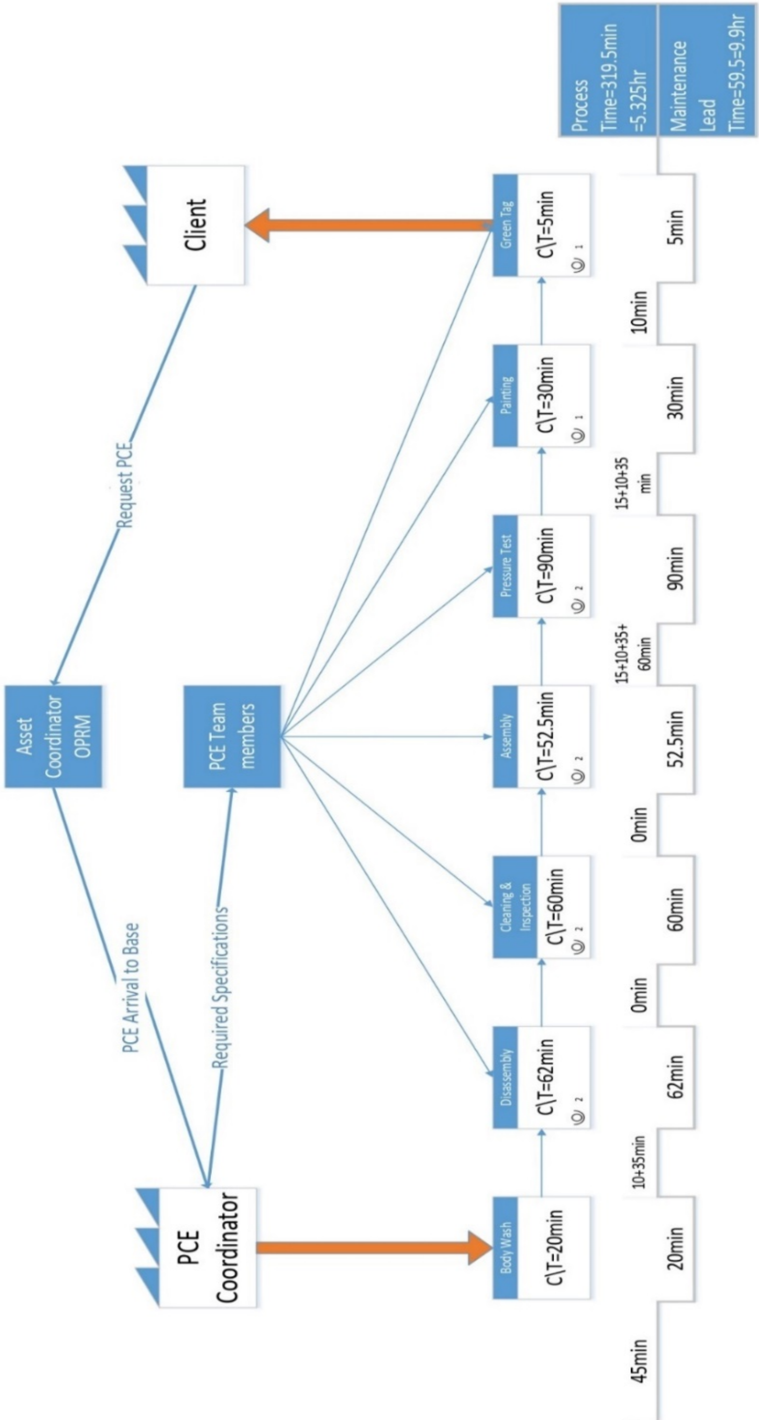


Figure 3 5 Why's of disassembly process

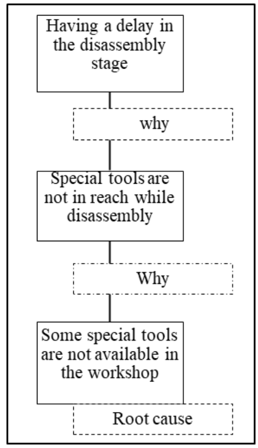


Figure 4 5 Why's of cleaning and degreasing

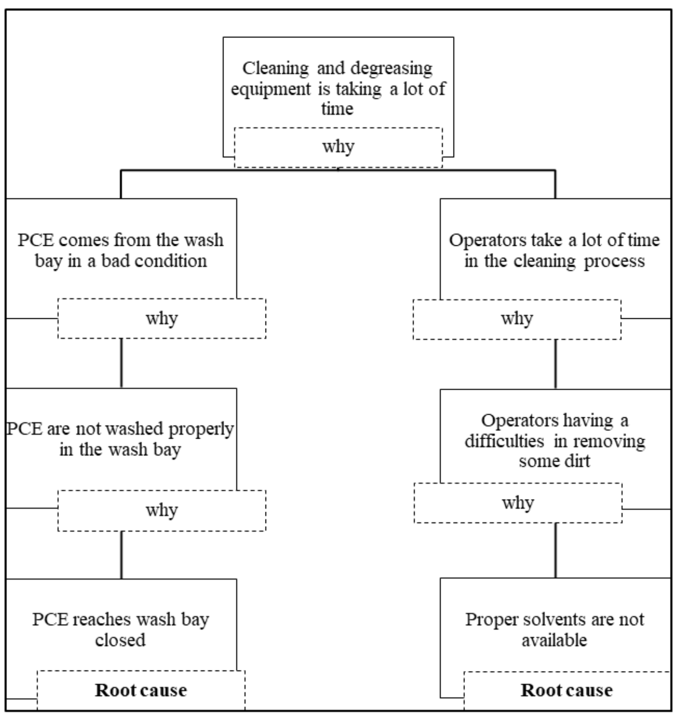


Figure 7 shows the 5 Why's analysis of cleaning barrier time between stages. The root cause identified in this process is that the crane is needed to set PCE at different stages of the process consuming extensive time at each stage. Furthermore, coordination problem is also noticed among teams and forklift operator.

Figure 5 5 Why's of assembly

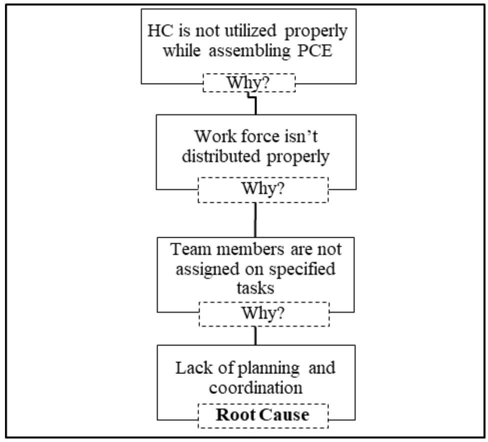
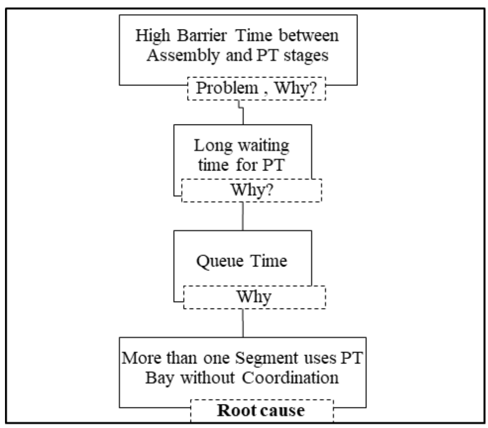


Figure 6 5 Why's of pressure test barrier time



3.5 Improvement phase

The core objective of improve phase in DMAIC implementation is to propose and build a solution that improves the current process performance (Basu 2009; De Mast and Lokkerbol, 2012; Pyzdek and Keller, 2014). In this project the improvement plan and solution to the identified problems in analyse phases are proposed based on brainstorming session and in consultation with project team members.

Below discussion will demonstrate the solutions and deliberate that how each solution is accurate and can show progressive effect on the process. The order of the solutions is same as the root causes found during analyse phase using 5 Why's.

- Disassembly process

  The problem in the stage was unavailability of specialised equipment, therefore as a solution, a Genius Tools 600750 Dr. Air Impact Wrench is proposed that can reduce a specific task in disassembly from 24 minutes by hand to 7.2 minutes. Figure 8 shows the air impact wrench.

Figure 7 5 Why's of cleaning barrier time between stages

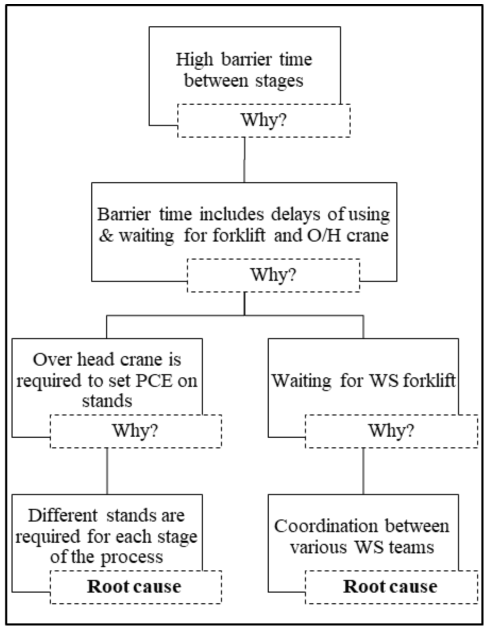


Figure 8 Genius tools 600750 Dr. Air Impact Wrench (see online version for colours)

- Cleaning and degreasing stage

  The best solution found is to utilise Enviro-Clean solvent which is far better than the traditional cleaner (diesel) that is normally used in the process. Enviro-Clean solvent shows great benefits, particularly it makes cleaning easier and it is less harmful than the diesel in terms of health. Benefits of Enviro-Clean solvent to health, safety and environment according to MSDS are shown in Table 4.

- Crane usage and cleaning process both have different issues but can have same solutions and both can be united as a single process using ICAD stands. Each process is completed by using dedicated stand and stand changing is required at every stage. Whereas, ICAD can perform three jobs instead of one, i.e., washing, maintenance and pressure tests'. Potential benefits are mentioned below:

a ICAD stand: two setups per equipment instead of three as the regular.
b 33.3% decrease in setup times.
c Less exposure to lifting hazards, increased safety.
d Less setup time between stages.
e Less delays for pressure test stands and better cleaning of inner hole.

Table 4 Benefits of Enviro-Clean

Type of risk	*Diesel*	*Enviro-Clean*
Fire	Flammable and combustible	Non-flammable non-combustible
Inhalation	Harmful if inhaled	Has not been classified as harmful by inhalation
Ingestion	May be fetal if swallowed	Has not been classified as harmful by ingestion
Skin contact	Skin irritation	May cause dryness of the skin.
Eye contact	Eye irritation	Eye irritation
Environment	Harm environment on disposal	Eco-friendly

- Pressure test queuing

  A simple sheet should be arranged that follows the request of respective personnel and register their needs for the tests in order to eliminate queuing lines while test can be performed on random basis for all segments. Foremost, it must be controlled and planned by the PCE coordinator in order to be used by the operators.

- Poor coordination among departments

  It can be improve by developing a culture of daily or weekly meetings depending upon seriousness of the issue faced by the team a day earlier in order to avoid or reduce the conflicts during work. In addition, education about new type of tasks, safety trainings should be provided.

  Introduction of updated and enhanced process flow plan to ensure flawless process without any issues or barriers. According to the new solutions, an updated flow plan has been created and shown in Figure 9.

  Summary of solutions developed for each root cause analysed through 5 Why's is shown in Table 5.

Table 5 Summary of proposed improvement

Root cause	*Solution*
Some special tools are not available in the workshop	Air impact gun.
Lack of structure in the morning meeting	Establish morning meeting structure.
Proper solvents are not available	Enviro-Clean solvent and degreaser.
PCE reaches wash bay closed	ICAD stands and updated and enhanced process flow plan.
Pressure test bay queue time	Pressure test reservation sheet
Different stands are required for each stage of the process	ICAD stands

Figure 9 Updated flow chart (see online version for colours)

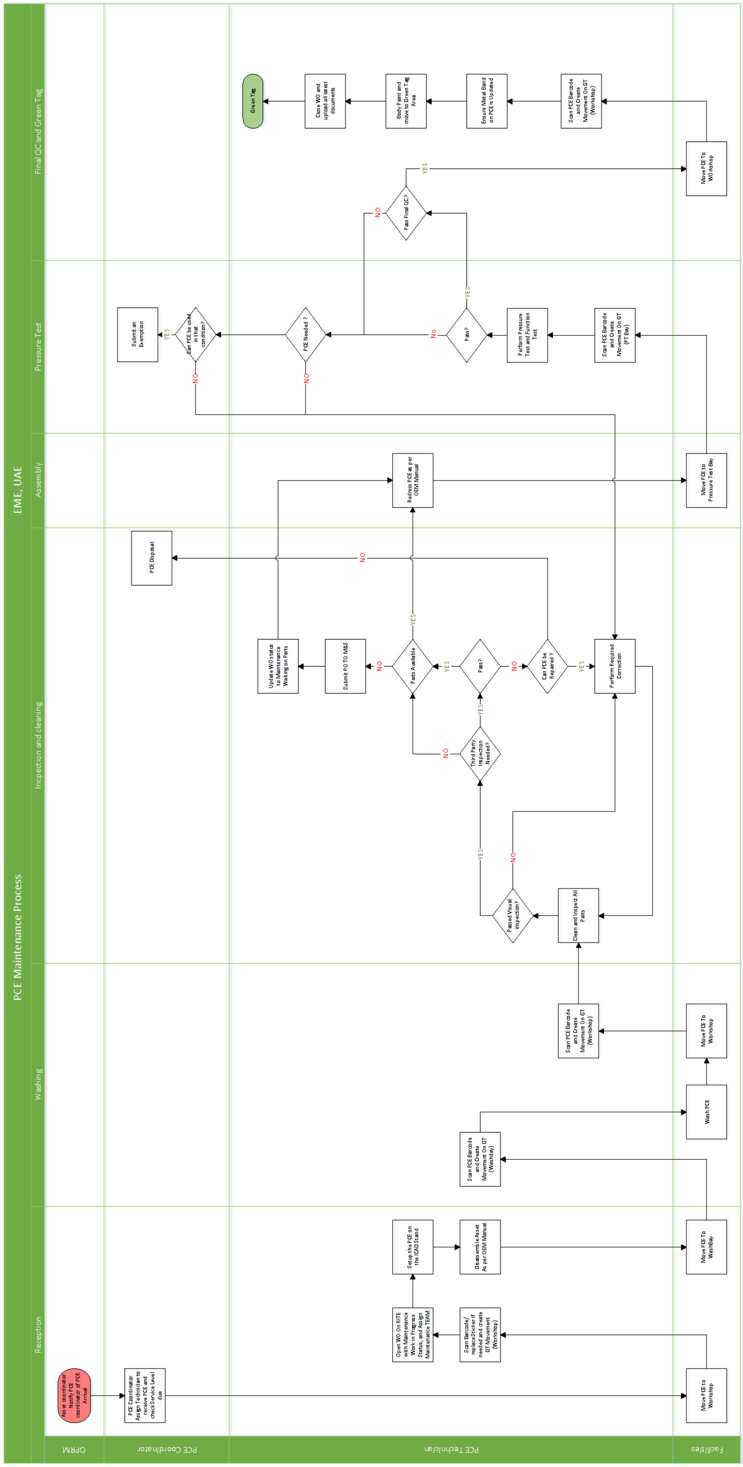
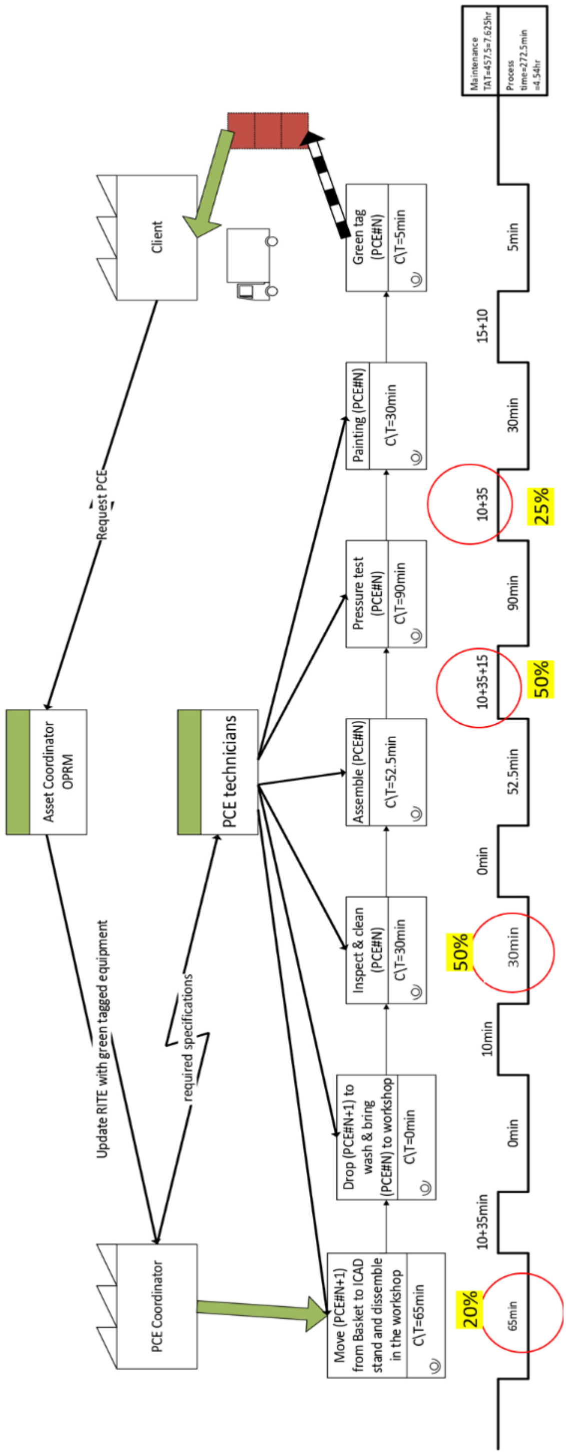


Figure 10 VSM after improvement (see online version for colours)



After development of solutions, an improved VSM (Figure 10) has been created that shows stages and process timing whenever a maintenance procedure starts. Improvements are highlighted with the new solutions for example considers third stage in which cleaning and degreasing has been discussed. In the previous VSM it took 60 minutes to finish the process while new VSM states that it is dropped to the half, i.e., 30 minutes for the process.

After calculating all KPIs with new solutions, it is possible to develop future KPIs and compare them with the current ones and required KPIs of the organisation.

In KPI's section, one of the main problems identified is the existing work-orders that are far behind than the required level. After using new solutions, work-order has been improved and converted in more effective form as compare to previous one, shown in Table 6.

Table 6 Current vs. goal vs. future KPIs

KPI(per 4HC)	*Current state*	*Goal*	*Future state*	*Percentage of compression*
WO/month	15.02 WO/month	52 WO/month		246%
TAT	7.32 hr	4.5 hr		–38.5%
WO/HC	3.76	13		246%
WO/month	15.02 WO/month		63.99 WO/month	326%
TAT	7.32 hr		3.65 hr	–50.1%
WO/HC	3.76		15.99	326%
WO/month		52 WO/month	63.99 WO/month	18.7%
TAT		4.5 hr	3.65 hr	23%
WO/HC		13	15.99	18.7%

3.6 Control phase

The main objective of control phase in DMAIC methodology is to make sure that the improvements achieved in improvement phase are sustainable (Basu, 2009; Jirasukprasert et al., 2014). It is considered as one of the essential phase in DMIAC methodology (Basu, 2009; Pyzdek and Keller, 2014). In this project, objectives of improvement phase have been achieved by the following actions.

- RITE.com is system where the operators can open work-orders when they start maintenance, close work-orders after completion, record time logs of each stage and mention the status of maintenance as (for example) down for parts, waiting for maintenance. GT system can be added to the RITE.com system to show the location of each asset inside the base by following a simple procedure, i.e., scanning of barcode on the equipment to update the movement of each stage to the desired location.
- To utilise RITE.com system, along with GT system. Using both systems together can deliver great benefits while performing maintenance related tasks, such as:
  - a Show if the equipment reached the base or not.
  - b Indicates location of equipment inside the base.

- c Asset utilisation per equipment type.
- d Clearly shows maintenance status as such ‘down for parts, waiting for certification’

- The next control plan method is forecasting of productivity in the future. The PCE time calculator is introduced, which is a tool used by the PCE coordinator to forecast the lead-time of a certain number of equipment. The user can input the number of workers assigned, type of equipment, service level due or certification due, and also the barrier time if it is found due for example, an audit. The calculator then calculates the process time needed to finish the process with and without the barrier time based on historical data collected previously and to be collected and updated in the future. This historical data includes time logs of each stage of the maintenance for each service level. This calculator will remove conflict between the operation planning and the PCE coordinator by providing information about completion time of each PCE depending upon the inputs of present situation.

4 Conclusions and recommendation

This study highlights the importance of improvement in maintenance department. Furthermore, shows the overall progress and positive impact of the same in considered case company. The experience of this improvement study has been recorded and stored in the system for future reference. Furthermore, the manager of the maintenance department of case company has welcomed the project implementation and suggestions for improvement and provided positive feedback to the team.

This study shows the successful implementation of DMAIC methodology in considered case company’s maintenance department. This will enable practitioners and decision makers to use the same approach in applying DMAIC in similar situations. It is one of the few studies on DMAIC that has been implemented in maintenance department of oil and gas sector. In addition, actual data has been used in analysing and improving the processes of maintenance department.

As a conclusion, maintenance is essential aspect to be contemplated when it comes to revenue and safety. It should be planned and organised well to enlarge revenue in any type of manufacturing or service organisation. The problem identified in the case company related to maintenance was inefficient execution of some of the maintenance tasks. Therefore, identifying issues related to such kind of maintenance tasks was needed.

The issues that revealed in this study are located in seven stages of maintenance process starting from wash bay until green tagging equipment. Each stage contained different type of issues requiring different solutions such as using new devices or improving certain plans in some departments. Moreover, some of the mentioned issues can have the same solution for two problems such as using ICAD for cleaning in wash bay, and reducing barrier timing between stages. The main benefits from ICAD are the multifunctional ability to complete non-identical tasks without changing or moving equipment.

Utmost, only having various and multiple solutions will not be always the right answer. In order to keep up with the solutions, a method/system that focuses on equipment history or maintenance is needed as a control plan such as RITE.com that can pursue with the equipment status.

4.1 Recommendations to case company

Based on the achieved results after successful implementation of DMIAC methodology, following recommendations have been proposed to the case company:

- To track the KPI's by RITE, analyse results and to record them for measurement of future performance. It will also prove to be fruitful for organisation.
- Apply analysing tools after having more accurate database to identify remaining bottlenecks so that issues can be easily addressed and underlined. Tools and techniques used in analysis will always reveal mistakes/issues and indicates hidden improvement points to the organisations.
- Assign KPI's to the PCE workshop and make them visible as not only employees have KPIs or monthly outcomes but also, devices can be good clue when it comes to KPIs in order to understand if there exist any hidden factors that requires improvement and type of improvement they require to perform better.
- Update database for the PCE calculator to perform more accurate calculations, since each PCE has its own timing for execution of task therefore, creating a method that calculates the time correctly will ensure the true identification of issues and leads to time saving.

This study has few limitations mentioned below which can be addressed in future:

- Although this study implemented DMAIC methodology in a case company's maintenance department, structured stakeholder's management is not performed due to time limitation. However, structured stakeholder's management can be performed in future.
- Findings cannot be generalised based on single case company. However, similar kind of study can be implemented in other oil and gas companies' in future following little adaption based on scenario.
- The DMAIC methodology was implemented in only one section of the maintenance department. In future, similar methodology can be implemented in other department of the case company.

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