Journal of Industrial Engineering
Scientific Journal on Research and Application of Industrial System
Volume 08 No 1 - Maret 2023
http://e-journal.president.ac.id/presunivojs/index.php/journalofIndustrialEngineering
ISSN 2527-4139 (*online*) – ISSN 2503-3670 (*print*)

Quality Improvement of Low Pressure Flush Column Reflux Pumps Using PDCA Method: A Case Study in an Urea Plant

Heri Kurniawan[1], Gde Windar Lesmana[2], Muhammad Asrol[3]
[1,2,3]Industrial Engineering Department, BINUS Graduate Program – Master of Industrial Engineering, Bina Nusantara University, Jakarta, 11480, Indonesia
Email: heri.kurniawan002@binus.ac.id[1)], gde.lesmana@binus.ac.id[2)], muhammad.asrol@binus.edu[3)]

ABSTRACT

This study focuses on the problems in the use and miaintenance of centrifugal pumps at PT Pupuk Kalimantan Timur (PKT) in Indonesia. This study specifically looks at the 110-J pump, which is critical to the production process as its failure can result in a shut down of the factory. The study analyzes the history card of the pump over the period of 2015 to 2021 and identifies that there have been multiple repairs due to high vibration, shaft bending, and other internal damage caused by differences in throat bushing sizes. The study calculates that the average loss due to these issues is around IDR 122,012,857 annually and the repair work takes on average about 5 working days. The study uses quality improvement tools plan, do, check, action (PDCA) identify the problems and formulate improvement efforts to increase the usage period and reduce maintenance costs. This study is important for improving the reliability of the production process and ensuring the availability of urea and NPK fertilizer, particularly in Indonesia. Result of this research is the decrease in the frequency of pump repairs from 3.7 times per year to none and accelerate pump assembly from 5 days to 3 working days.

Keywords: Centrifugal pumps, maintenance, quality improvement tools, shaft bending, vibration

ABSTRAK

Studi ini fokus pada masalah penggunaan dan pemeliharaan pompa sentrifugal di PT Pupuk Kalimantan Timur (PKT) di Indonesia. Studi ini secara khusus fokus pada pompa 110-J, yang sangat penting bagi proses produksi karena kegagalannya dapat menyebabkan pabrik berhenti beroperasi. Studi ini menganalisis riwayat data pompa selama periode 2015 hingga 2021 dan mengidentifikasi bahwa sudah terjadi beberapa perbaikan karena getaran tinggi, pembengkokan poros, dan kerusakan internal lainnya yang disebabkan oleh perbedaan ukuran bushing. Studi ini menghitung bahwa rata-rata kerugian karena masalah ini sekitar IDR 122.012.857 per tahun dan bahwa pekerjaan perbaikan memakan waktu sekitar 5 hari kerja. Studi ini menggunakan *quality improvement tools plan, do, check, action (PDCA)* untuk mengidentifikasi masalah dan memformulasikan upaya perbaikan untuk meningkatkan masa pakai dan mengurangi biaya pemeliharaan. Studi ini penting dilakukan untuk memperbaiki kehandalan proses produksi dan memastikan ketersediaan pupuk urea dan pupuk NPK, terutama di Indonesia. Hasil dari penelitian ini adalah adanya penurunan frekuensi perbaikan pompa dari 3,7 kali per tahun menjadi nihil dan mempercepat pemasangan pompa dari 5 hari menjadi 3 hari.

Kata kunci: Getaran, pembengkokan poros, pemeliharaan, pompa sentrifugal, *quality improvement tools*

1. Introduction

Quality Management has a long history, with some tracing its origins back to ancient Egypt, but it is widely recognized that modern quality management emerged with scientific management in the late 19th and early 20th centuries. Organizations such as the American Society for Quality Control (ASQC), the European Organization for Quality (EOQ), and ISO developed quality standards and models in the mid-20th century. The focus of quality management has shifted from product inspection to a more systematic approach that includes Statistical Process Control and sampling for quality inspection, particularly in mass production settings.

Juran (1989) and Crosby (1990) have made significant contributions to the principle of quality in organizations, but (Deming's, 1988) ideas have had the greatest impact on management practices. Deming's theory of 14 points of management became the basis for Japan's successful adoption of the Total Quality Management (TQM), which contributed to their economic success. Deming believed that most mistakes and inefficiencies in a business were caused by its systems, rather than individual employees.

PT Pupuk Kalimantan Timur (PKT) produces urea, NPK, and ammonia fertilizer located in Bontang, East Kalimantan. PKT is responsible for distributing fertilizer to 2/3 of Indonesia and also for export needs. One of the plants has a problem, as indicated by the history card from the period of 2015 to 2021. Pump 110-J has experienced damages including high vibration, shaft bending, and other internal pump damages caused by differences in throat bushing sizes. As a result, the pump has undergone 5 overhauls during the 6-year period. The repair of the pump during the overhaul requires significant time, materials, and manpower. The significant losses incurred due to the low lifetime and high maintenance costs have become an issue that needs to be resolved. This pump is responsible for pumping Carbon Dioxide (CO2) fluid from the LP Flash Column Overhead Reflux Drum to the CO2 Absorber and Stripper, and serves to wash the CO2 Absorber gas flow while maintaining the water balance of the aMDEA system. Based on data process flow diagrams and interviews with the process member, if this pump is not operating properly, the aMDEA concentration becomes thick, leading to excessive CO2 entering the system, tripping the methanator and causing ammonia carbamate to form in the converter area. This can cause heavy loads in the dryer area, damage the catalyst, and potentially result in plant shutdown.

Previous research has explored the application of the Plan-Do-Check-Act (PDCA) cycle in various settings. Arif, Putri, and Tjahjono (2018) applied the Kaizen method and PDCA cycle to improve the quality of sarongs and reduce production defects, resulting in improved product quality and production efficiency. Kurniawan, Sumarya, and Merjani (2017) also used PDCA to reduce defects in die attach and achieved improved production quality. Darmawan, Hasibuan, and Hardi Purba (2018) applied the 8-step PDCA process to reduce in-line defects during the pasting process in the automotive battery industry. Sangpikul (2018) applied PDCA in academic service learning to improve students learning outcomes and provide valuable services to non-profit organizations. Jangid (2019) implemented True Lean in a manufacturing company using PDCA and achieved improved production efficiency. Chen (2019) used PDCA to control the quality of waterproof and drainage construction for planting roofs. Bereskie, Rodriguez, and Sadiq (2017) presented a PDCA framework for drinking water management and governance in Canada. Silva, Medeiros, and Vieira (2017) applied PDCA to implement cleaner production and reduce the Cans Loss Index in a beverage company. Nsafon *et al.* (2020) integrated multi-criteria analysis with PDCA for sustainable energy planning in Africa. Kurniawan *et al.* (2017) reduced machine damage in electroplating production using PDCA. Cheng (2019)proposed a framework for curriculum management in educational institutions using PDCA and SECI process. These studies demonstrate the effectiveness of PDCA in improving product quality, reducing defects, and enhancing process efficiency in a range of industries and settings.

The purpose of this research is to improve the reliability of the pump, solve the problem by identifying the root cause, and implement improvements that will impact the production process as a whole. The problem-solving methods used in this research can also be applied in similar industries or for similar equipment.

2. Methods

Many scientific studies discussed quality improvement using the PDCA cycle step or other well-known cycle steps such as Define Measure Analyze Improve Control (DMAIC) in the Six Sigma method. PDCA cycle step are widely discussed in scientific research: Gilbert et al. (2020) used the PDCA cycle step approach to improve the quality of service at The Royal Orthopedic Hospital by developing virtual consulting services in line with restrictions on community activities in England during the COVID-10 pandemic. Shanafelt *et al.* (2019) used PDCA process iterations for continuous improvement in the healthcare industry. Van Kemenade & Hardjono (2019) explains that PDCA can be combined with other methods of quality management.

2.1 Guidelines for Quality Improvement

Alauddin (2019) Total Quality Management (TQM) is an approach that aims to involve every member of an organization in the effort to continuously improve the organization. It is a philosophy that empowers everyone to contribute to this process. TQM has emerged in industries over long period and many methods in TQM combined to meet customer expectations. Deming, Juran and Crosby are the big names in TQM who inspired many organizations in the world to implement continuous improvement program.
Deming Prize is well known TQM award among the industries which concern about continuous improvement program.

Cousson *et al*. (2019) explain the "Plan" The Deming cycle, also known as the PDCA cycle, consists of six steps in its methodology:

- Analysis of scientific sources to determine the desired procedure.
- Selection of relevant clinical indicators to assess the targeted procedure.
- On-site evaluation of the actual situation compared to the desired procedure.
- Calculation of the gap between the ideal and actual situations.
- Identification of possible reasons for the differences between the ideal and actual situations.
- Development of proposals for improvement to bring the actual situation closer to the ideal.

The "Plan" phase is very important because it will bring a continuous quality improvement program to the failure or success. This also applies to PDCA cycle step.

2.2 Quality Improvement Tools

According to (Gupta & Kaplan, 2020) measurement plays a crucial role in quality improvement (QI). QI efforts can incorporate structural, process, outcome, and balancing measures, and each measure should have a well-defined definition. To effectively improve, data should be analyzed over time, with a focus on understanding the variation within the data. Determining the difference between common and special cause variation is necessary to evaluate and direct improvement efforts. Raman and Basavaraj (2019) state that the most frequently used tools and techniques in quality improvement include: fishbone diagram or cause and effect diagram, pareto analysis, control charts, scatter diagram, control charts, histogram and flow chart. Botezatu *et al*. (2019) theoretical research methods can be classified into several categories, including analysis methods, synthesis methods, modeling and simulation methods, and optimization methods. One particular analysis method is the cause-effect analysis, which can be represented using an Ishikawa diagram. The Ishikawa diagram displays the relationship between the result and the factors that impact it. The use of this diagram has several benefits, such as a clearer understanding of processes and equipment, the stimulation of innovation, the enhancement of learning and idea generation, the effective management of factors that may have negative effects, and the potential establishment of technical norms. Over time, the Ishikawa diagram has been utilized and studied for solving various scientific research issues.

2.3 PDCA implementation in this study

This research project started with a field study conducted on one of the PKT production units where equipment, specifically the 110-J pump, was frequently getting damaged. The study aimed to identify the problems that occurred during the 2015-2021 period, and then to determine the most appropriate methods to solve them.

To begin the research process, data was collected on the damages to the 110-J pump equipment during the six-year period, and the cost of repairs per year was calculated. After collecting this data, the damages were classified to determine which one was the most dominant.

Next, an identification and inspection process were conducted on the damaged pump parts, and an examination of the vibration trend over the last six years was carried out. Following this, hypothesis brainstorming about the problem was conducted using an Ishikawa diagram. The results of the brainstorming were verified by conducting shaft strength simulations, inspections during overhauls, studies on the strength of shaft materials, maintenance guidelines, and expert opinions to determine the dominant cause.

An improvement plan was developed in the final stage of the planning process and targets were set. Tools used in this stage included pareto diagrams, Ishikawa diagrams, shaft strength simulations, SWOT analysis, and 5W+2H analysis.

The next stage in the research process was the Do stage, which involved implementing the improvement plan developed in the planning stage. Repairs were made to the 110-J pump, and a comparison was made between the pump's performance before and after the repairs were carried out.

In the Check stage, the results of the improvements were examined, both before and after implementation, to assess the design, vibration trend, target achievement, and benefits. This stage helped to identify whether the improvement plan was effective or not.

Finally, in the Actions stage, the results of the improvements were incorporated into a new standard to become a new Standard Operating Procedure (SOP). The new SOP helped to ensure that the problem did not recur in the future.

The research process is summarized in Figure 3, which depicts the stages of the PDCA method used to carry out this research. This research project aims to identify the problems that occurred with the 110-J pump equipment and develop an effective solution to ensure that the problem does not recur in the future. The PDCA method was used in this research to identify the root cause of the problem and develop an improvement plan to solve it.

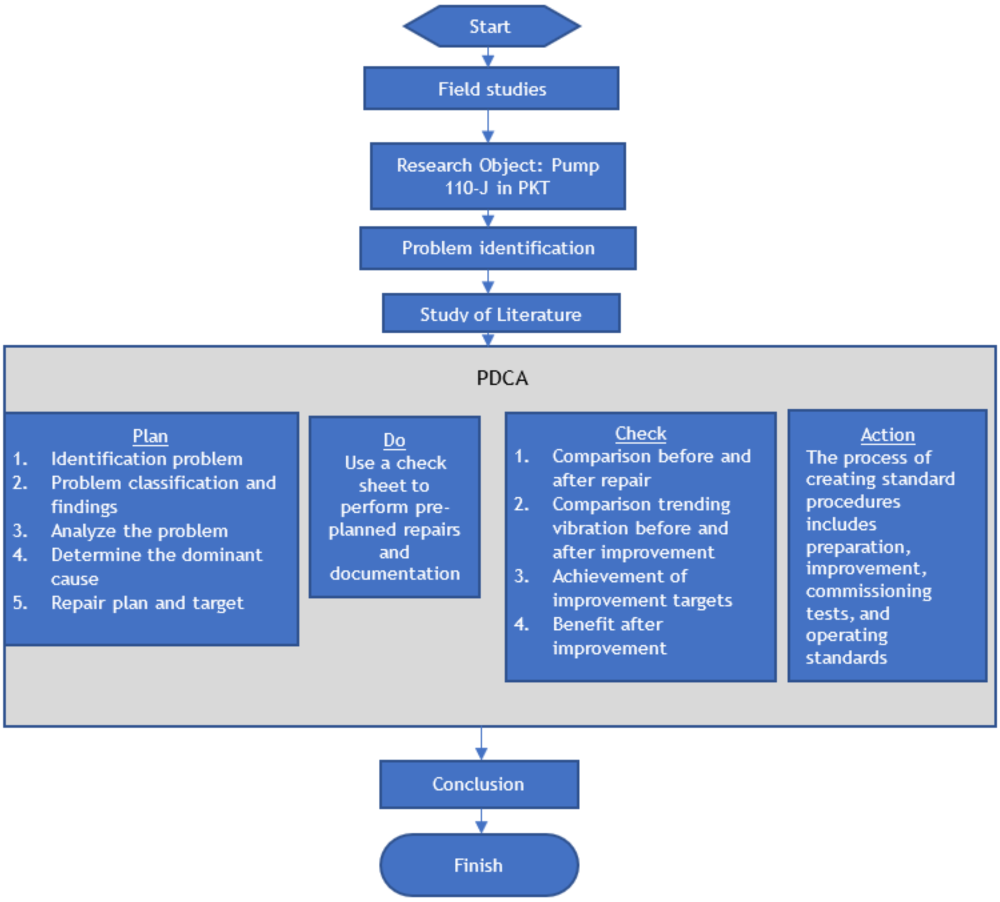


Figure 3. Research flow chart

3. Result and Discussion

The selected case study to be analyzed here is a problem with the low-pressure flush column reflux pump in the process area of a fertilizer plant. In this case study, we will use the PDCA framework to identify, improve, and solve the problem.

3.1 Plan

The Plan step in the PDCA method aims to plan the details and determine good process standards. Therefore, to gain attention and set standards, a good process must determine the theme, research targets, analyze initial conditions, analyze the causes of damage, and develop damage management plans.

3.1.1 Identification problem

Based on the history card from 2015 to 2021 (Table 1), there were issue on Pump 110-J among others: high vibration, shaft bending, and internal pump differences in the size of the throat bushing. As a result, the pump has been overhauled on average 5 times in 6 years period. A high cost of maintenance and low life time of the pump become an issue that needs to be resolved. Therefore, it is necessary to find the root cause of the pump damage and seek a solution for the problem. The cost of repairs is presented in Table 1. on a yearly basis.

Table 1. Frequency and cost of repairing Pump 110-J

No.	Year	No of Job (times)	Cost (IDR)
1	2015	1	135.530.000
2	2016	3	145.000.000
3	2017	6	12.500.000
4	2018	4	145.000.000
5	2019	4	135.530.000
6	2020	4	135.530.000
7	2021	4	145.000.000
Average		**3.7**	**122.012.857**

Table 1 shows the annual amount of repair work and cost, assuming an average of 3.7 repairs per year and a total repair cost of IDR 122,012,857. Based on the description, "Improving the reliability of centrifugal pump 110-J Plant-5" become more relevant to learn for many reasons, among others:

- The 110-J pump is a pump that functions to pumping condensate process fluid from the LP flash column overhead reflux drum to the CO2 Absorber and to the stripper, for washing the CO2 Absorber gas flow, and to maintain the water balance of the aMDEA system.
- To avoid disruption of the production process and the operator's mental state in operating the ammonia plant.
- To avoid the possibility of pump shutdown and overhaul due to undetected pump damage.
- To avoid the potential loss of company production because the pump cannot operate due to sudden shutdown.
- Reduce the cost of purchasing new pump spare parts and reduce the long repair time of the pump by IDR 122,012,857 per year.

3.1.2 Problem classification and findings

In general, 110-J pump problems are summarized based on the most frequent problems presented in a pareto diagram (as shown in Figure 3) to find the most cumulative frequent problems.

Table 2. The cumulative classification of problems.

NO.	Classification problem	FREQ (X)	F. CUM (%)
1	High vibration, Overhaul pump & impeller rubbing	19	73
2	Soft foot on motor	2	81
3	Strainer	2	88
4	Oil empty	1	92
5	Others	2	100

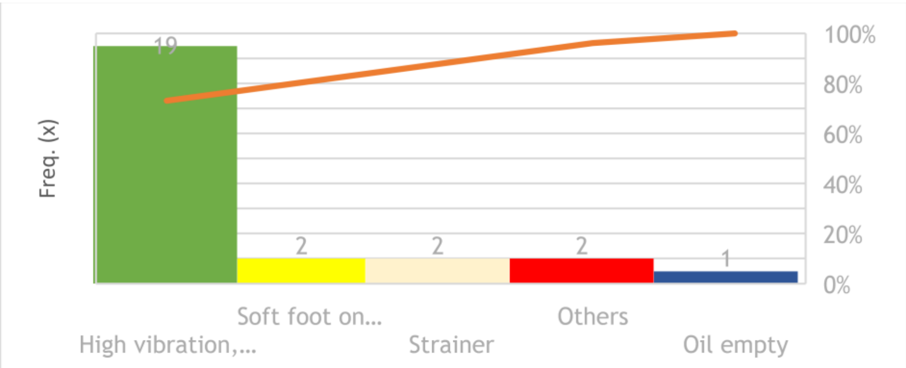


Figure 3. Problem cumulative

Table 2 shows the classification of problems, including high vibration, pump overhaul, impeller rubbing, soft foot on the motor, strainer, and oil empty. These account for a cumulative 73% of the problems, with high vibration, pump overhaul, and impeller rubbing being the primary contributors.

Based on the ISO 10816-2 standard, the vibration for a 52 kW pump in the "good" category is a maximum of 2.3 mm/s rms. Figure 4 shows high variation of the vibration and the value is higher than standard. The graph displays vibrations reaching up to 8 mm/s, indicating unsafe operating conditions that pose a danger to both the equipment and individuals in proximity.

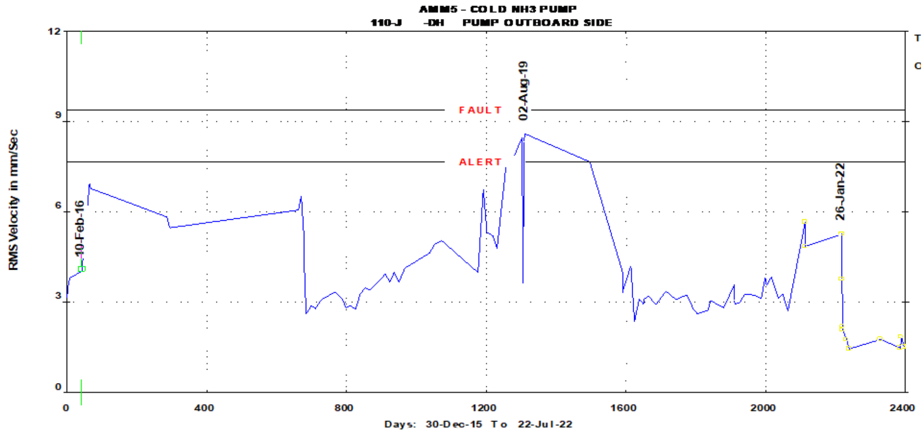


Figure 4. Vibration trend Pump 110-J

Figure 5 is a sectional drawing of the 110-J pump, with a size variation on the throat bushing indicated by a circle. It often confuses and requires extra care during disassembly and assembly. It is certainly not without reason because the rotor is quite long, so the design is made to reduce friction and bending.

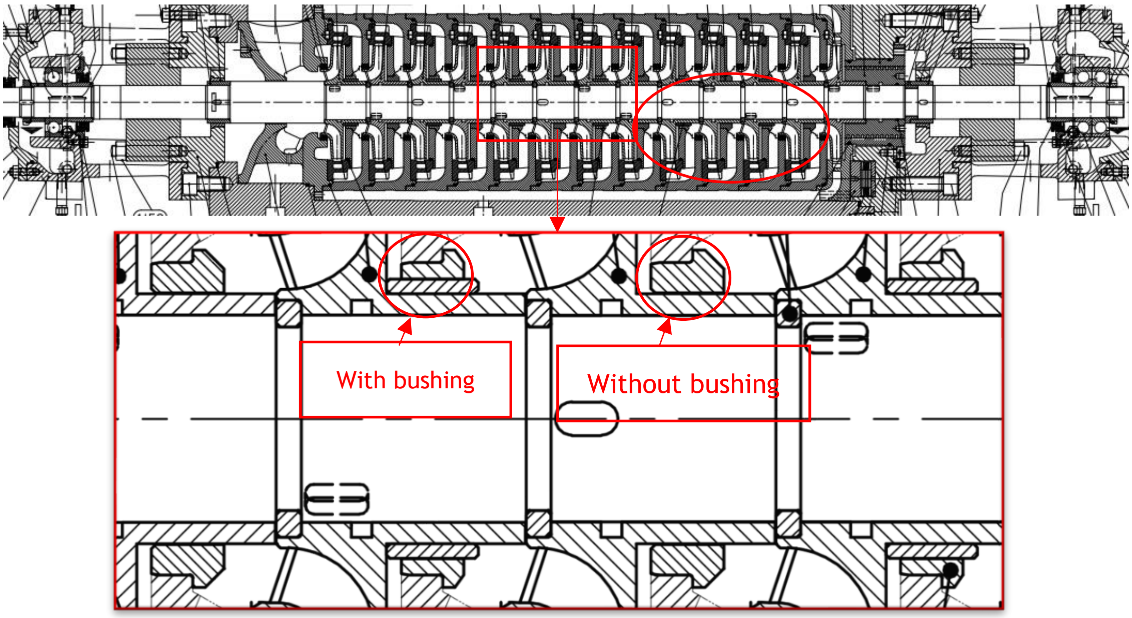


Figure 5. Variations in bushings

Figure 6. Pump shaft was bending and the wearing ring and impeller were rubbing

Due to high variation of the vibration and the value is higher than standard, during the overhaul, it was found that the pump shaft was bending and the wearing ring and impeller were rubbing.

Based on the identification of the most dominant frequency problem, it is characterized by high vibration on the pump and the difficulty of overhauling due to the many variations in the size of the throat bushing, the target are to extend the life time and make maintenance easier for centrifugal Pump 110-J.

3.1.3 Analyze the problem

The Ishikawa diagram is a graphical representation that shows the relationship between the outcome and the factors that can affect it. The Ishikawa diagram is created through a process of field inspection and interviews with the mechanical and operation team to reveal all possible hypotheses that could be the root cause of the problem.

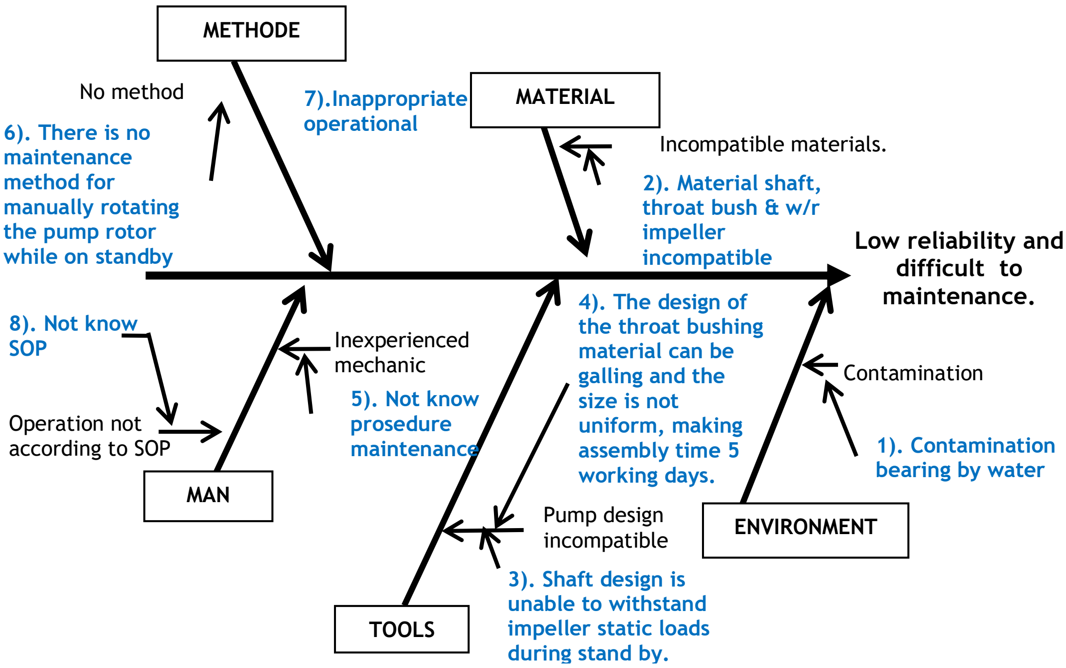


Figure 7. Ishikawa diagram problem statements.

Based on the fishbone diagram, there are eight hypotheses that need to be verified, namely: contamination borne by water, material of the shaft, throat bush, and wearing ring; impeller incompatibility; shaft design unable to withstand impeller static loads during standby; throat bushing material design can cause galling and non-uniform size; assembly time takes 5 working days; unknown maintenance procedure; lack of maintenance method for manually rotating the pump rotor while on standby; inappropriate operation; and unknown standard operating procedure (SOP).

3.1.4 Determine the dominant cause

1. Verification of dominant cause

Based on mapping the connection between a result and the factors shown in Figure 7, the next step is verifying dominant causes (Table 3) by a team focus group discussion. The brainstorming session will consist of inspectors, operators, and mechanics who are experts in their respective fields. The results are drawn based on the verification in the field, simulation results, and inspection of material specifications, including mechanical properties and chemical composition. When determining the dominant cause, several factors are taken into account, including results from field inspections during overhauls, simulations of shaft strength, checks of oil quality, review of technical drawings, and studies of procedure and instruction manuals from manufacturers.

Table 3. Verification of dominant causes.

No.	Reason	Indicators/standard	Verification	Results
1	Contamination bearing by water	< 0.02 ppm	The result of pump verification shows that the design is for outdoor use and the sealing system inspection is good and water content check 0.015 ppm	Not Dominant
2	Material shaft, throat bush and wearing ring impeller incompatible	Hardness minimum 55 HRC	The material for the throat bushing during overhaul was not hardened because there was no facility available at PKT	Dominant
3	Shaft design is unable to withstand impeller static loads during stand by	Study document manufacture and simulation	The material for the shaft is ASTM A276 UNS S31803, based on the data sheet, the tensile strength is 650 MPa, and the yield strength is 450 MPa. According to the Solidworks simulation results, it undergoes bending of 0.23 mm (fig. 8)	Dominant
4	The design of the throat bushing material can be galling and the size is not uniform, making assembly time 5 working days	Study document manufacture	The dimensions of the throat bushing design are not uniform according to the design drawing (fig. 5)	Dominant
5	Don't know prosedure maintenance	Instruction manual	The maintenance procedure has been followed	Not Dominant
6	There is no maintenance method for manually rotating the pump rotor while on standby	Instruction manual	There is no procedure for manually turning the pump rotor during standby so that the pump rotor becomes bent	Dominant
7	Inappropriate operational	Liquid type condensate viscosity 0.653 cP, operating pressure max. 42 kg/cm^2 , suction pressure 1.1 kg/cm^2	The operation is already in accordance	Not Dominant
8	Don't know standard operation procedure (SOP)	Instruction manual	The operator already knows and understands the SOP with the check list during operation	Not Dominant

2. The simulation of the static shaft load and the initial throat bushing design

Based on the verification and simulation methods using Solidwork CAD (as shown in figure 8) and brainstorming member includes mechanical, process, and inspection, all of which are experts in their respective fields who provide their opinions this study found that the main causes of short lifespan and difficult maintenance are: the material of the shaft, throat bush & wearing ring impeller is not appropriate, the shaft design is unable to withstand the static load of the impeller during standby, the design of the throat bushing material is prone to galling and the size is not uniform, and there is no maintenance method for regularly turning the pump rotor during standby. This simulation is assumed to use AISI 316 material, which has the closest mechanical properties because of the limitations of the library for ASTM A276 UNS S31803 material.

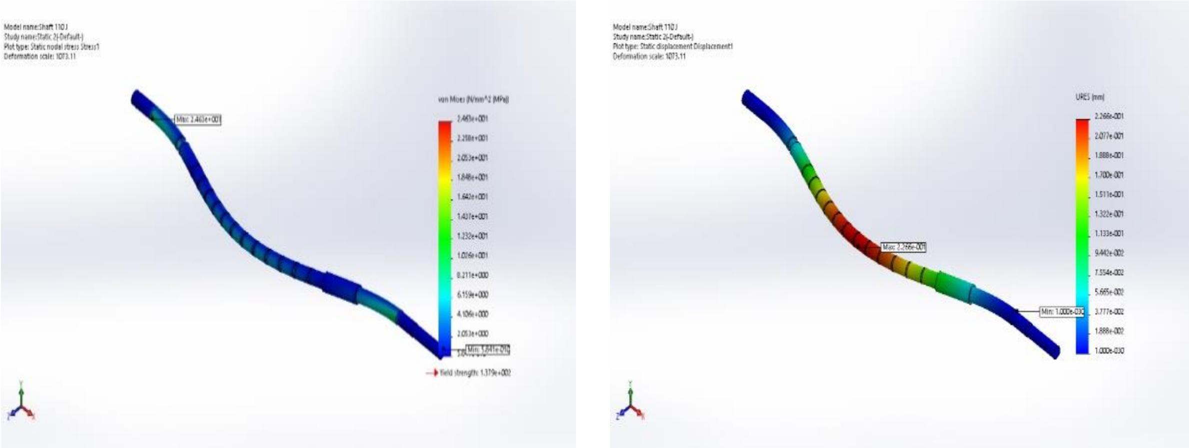


Figure 8. The simulation results show the highest static stress to be 24.63 MPA (left) and the static load simulation on the rotor with the impeller load and shaft show that the rotor experiences bending of 0.23 mm (right).

3.1.5 Improvement plan and target

1. **Improvement plan**

In planning a quality improvement project, the process starts with a pattern of thought and continues into a strategic plan. The strategic plan is then translated into a improvement plan and target. SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis is used to determine the appropriate strategy for improving the company's performance by considering internal and external conditions. Based on the SWOT analysis (Table 4), extending the lifespan and improving maintenance ease of Centrifugal Pump 110-J Factory-5 would be a beneficial strategy for the company.

Table 4. Matrix SWOT analysis

INTERNAL / **EXSTERNAL**	STRENGHT (S) 1. Skilled man power. 2. Reliable equipment	WEAKNESS (W) 1. High vibration 2. Difficult to maintenance
OPPORTUNITY (O) Reducing the potential for production loss	STRATEGY (S-O) 1. Task distribution and monitoring 2. Self-modification	STRATEGY (W-O) 1. Create a schedule method for turning the pump on standby 2. Uniform throat bushing size
THREAT (T) Pump failure due to high vibration	STRATEGY (S-T) 1. Use skilled man power and existing facilities 2. Improved reliability	STRATEGY (W-T) 1. Proper planning 2. Repair in short time

Strengths of the system include skilled manpower and reliable equipment. However, there are weaknesses such as high vibration and difficult maintenance. Opportunities for repair include reducing potential production loss. One strategy to take advantage of this opportunity could be task distribution and monitoring, or self-modification. In order to address the threat of pump failure due to high vibration, strategies could include using skilled manpower and existing facilities, as well as improving reliability. Other strategies to address the weakness of high vibration could be to create a schedule for turning the pump on standby or using a uniform throat bushing size. To address the threat of pump failure, it may also be important to have proper planning and the ability to repair the equipment quickly.

Table 5. Improvements planning using 5W+2H

WHY	HOW	WHAT	WHERE/ WHEN/WHO	HOW MUCH(IDR)
1. The shaft design is unable to withstand the static load of the impeller during standby. 2. The design of the throat bushing material can gall and its size is not uniform. 3. There is no maintenance method for rotating pump rotor periodically during standby.	1. Develop a maintenance method for the pump during standby to prevent shaft bending. 2. Standardize the size and replace all materials with Polyetheretherketone (PEEK). 3. Develop a maintenance method for the pump during standby to prevent bending.	1. To prevent the rotor from bending. 2. To prevent the throat bushing from galling and to have a uniform size. 3. To prevent the rotor from bending.	Amonia Plant - 5 September 2021 PIC: Observer HK	15.370.000

In order to carry out improvements, it is necessary to develop a improvements plan using the 5W (why, how, what, where, when, and who) and 2H (how and how much) concepts. There are three main problems that are the dominant causes to be resolved: shaft design is unable to withstand the static load of the impeller during standby, the design of the throat bushing material can gall and its size is not uniform, and there is no maintenance method for rotating the pump rotor periodically during standby. To resolve these problems, it is necessary to standardize the size, replace all materials with PEEK, and develop a maintenance method for the pump during standby to prevent bending. The cost required for this repair is IDR 15,370,000.

2. Target

Based on the description above, the following targets are:

1. Reduce pump repairs from 3.7 times/year to zero.
2. Accelerate pump assembly from 5 days to 3 working days.

3. Analysis of improvements target

As shown in table 6, the target of is: (1) There was no rotor bending, and (2) Assembly process become easier and faster from 5 days to 3 days.

Table 6. Analysis of repair target

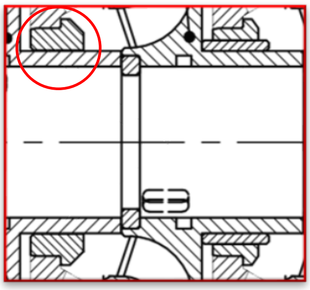
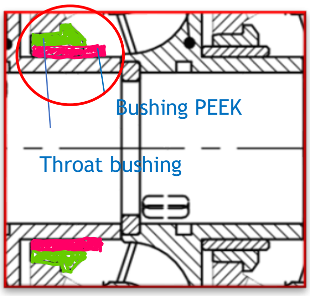
Improvements Solution	Successful Analysis	TARGET	Successfully Target (%)
Improved a pump maintenance method during standby to prevent bending.	The method is quite simple by making a schedule to turn the pump rotor on standby.	There was no rotor bending, which resulted in damage to the pump as much as 3.7 times on average to zero.	100
Standardizing the size and replacing all materials with PEEK.	The price of PEEK raw material is relatively cheap and can be self-fabricated.	Assembly easier and faster from 5 days to 3 days.	100

The solution included two improvements: Improved pump maintenance method during standby to prevent bending, and standardized the pump size and replaced all materials with PEEK. According to the successful analysis, the pump maintenance method was made simpler by implementing a regular schedule to turn the pump rotor during standby, and using PEEK material, which is relatively cheap and can be self-fabricated, made assembly easier and faster. As a result of these improvements, the target was achieved, which included: Zero rotor bending and a 100% reduction in pump damage caused by rotor bending, compared to an average of 3.7 times before the improvement. A 100% improvement in assembly time, reducing it from 5 days to 3 days, by standardizing pump size and using PEEK material.

3.2 Do

This step is following the repair planning that has been set as shown in Table 5. Table 7 shows two repair steps: (1) Inspection, repair and replacement of throat bushing material to PEEK material and uniform size and (2) Modification throat bushing.

Table 7. Repair check sheet data

No.	Repair Step	Activity	
1	Inspection, repair and replacement of throat bushing material to PEEK material and uniform size		
2	Modification throat bushing	 Before	 After

3.3 Check

3.3.1 Comparison before and after repair.

The following is the result of a comparison of repair in the form of modifications to the pump design in the throat bushing area with uniform sizes.

Table 8. Before and after repair

No	Before	After
1	 The impeller in the throat bushing area is worn and without PEEK.	 Throat bushing with PEEK material and uniform size.
2	 Impeller in the throat bushing area and wearing ring wear.	 Impeller in the throat bushing area and wearing ring with uniform size.

3.3.2 Vibration trending before and after repair

Vibration trending has decreased significantly after repairs. The RMS Velocity after repair below the ISO 10816-2 standard, maximum of 2.3 mm/s rms. This repair has succeeded in overcoming the high-vibration problems and can reduce the risk of damage with low-vibration parameters.

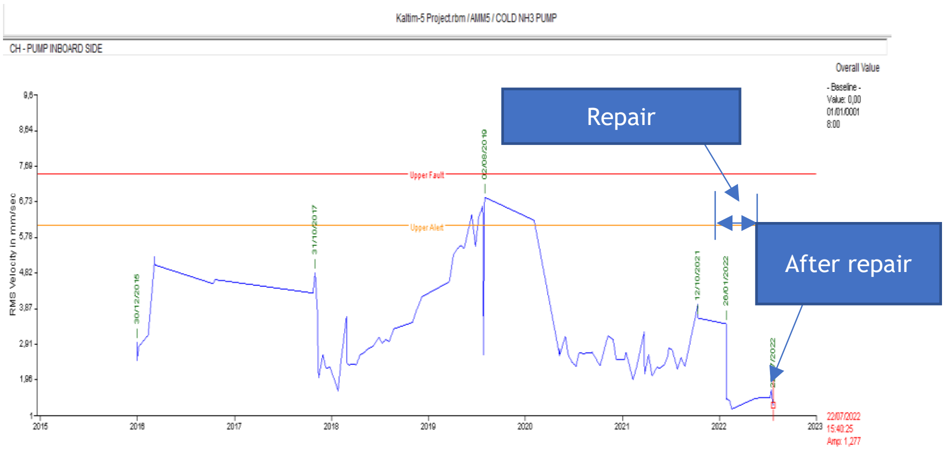


Figure 9. Vibration trend Pump 110-J after repair.

3.3.3 Achievement of improvements targets.

Achievement of targets in this improvements are:

1. The target of reducing repairs to zero 3.7 times per year has been achieved.
2. The target of speeding up pump assembly from 5 days to 3 working days has been achieved.

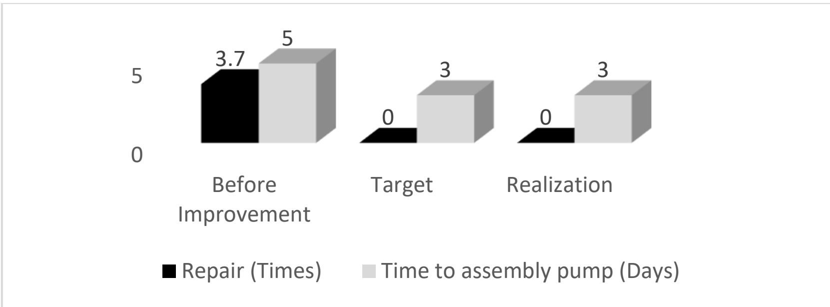


Figure 10. Improvements target

3.3.4 Benefit after improvements

The benefit after repair is cost reduction, as shown in table 9, Cost before improvements/year (A) IDR 122,012,857.00 and Cost after improvements (B) IDR15,370,000.00.

Table 9. Benefit after improvement

Component	Sum. (IDR)
Cost before repair/year (A)	122,012,857.00
Cost after improvements (B)	15,370,000.00
Benefit after improvements (A-B)	**106,642,857.00**

3.4 Action

The last step of the PDCA method is the action step where it is necessary to set new standards for modifications and improvements made so that they can become a reference for similar equipment and also standard results where these improvements have been successful and get added value.

3.4.1 Standard Prosedure

No.	Modification Standard	Operating Standard
1.	Preparation: Preparation of throat bushing materials and spare parts for overhaul Pump	Rotate the pump rotor manually once every 1 month during stand-by conditions every 90 degrees.
2.	Imrovement: 1. Measure the OD throat bushing for size uniformity. 2. Repair and change the throat bushing material to PEEK material and uniform size. 3. Assembly impeller and check mechanical runout. 4. Balancing rotor assembly. 5. Pump assembly. 6. Mark the position of the coupling turning angle 0-90-180-270.	
3.	Commisioning test: 1. Running test pump checks, performance and vibration. 2. Pump switches.	

3.4.2 Results standard

1. There has been no damage or overhaul of pump for 1 year.
2. Rotor is not bending.
3. It can be applied to similar pumps which have long rotor and many impellers.

4. Conclusion

The research on the implementation of PDCA on low-pressure flush column reflux pumps is a study on the repeated pump failure caused by a complex pump design. There are many variations in the size of the throat bushing dimensions, which makes repair time longer. The long pump shaft is prone to bending, so a repair was made by modifying the size variations to one standard size and developing a maintenance method for the pump to prevent bending during standby. The success of this problem-solving depends on the experts involved with the assistance of the PDCA method, so that problem-solving can be structured.

5. Acknowledgement

The authors would like to thank team members in PKT that involved quality improvement project. The authors would like to Binus University for research assistance and study material.

References

1. Agrawal, N. M. (2019). Modeling Deming's quality principles to improve performance using interpretive structural modeling and MICMAC analysis. *International Journal of Quality & Reliability Management*, 36(7), 1159–1180. https://doi.org/10.1108/IJQRM-07-2018-0204

2. Alauddin, N. (2019). Overview of Deming Criteria for Total Quality Management Conceptual Framework Design in Education Services. *Journal of Engineering and Science Research*, *3*(5), 12–20. https://doi.org/10.26666/rmp.jesr.2019.5.3

3. Arif, M. S., Putri, C. F., & Tjahjono, N. (2018). Peningkatan Grade Kain Sarung Dengan Mengurangi Cacat Menggunakan Metode Kaizen dan Siklus PDCA pada PT. X. *Widya Teknika*, *26*(2). https://doi.org/10.31328/jwt.v26i2.796

4. Bereskie, T., Rodriguez, M. J., & Sadiq, R. (2017). Drinking Water Management and Governance in Canada: An Innovative Plan-Do-Check-Act (PDCA) Framework for a Safe Drinking Water Supply. *Environmental Management*, *60*(2), 243–262. https://doi.org/10.1007/s00267-017-0873-9

5. Botezatu, C., Condrea, I., Oroian, B., Hriţuc, A., Eţcu, M., & Slătineanu, L. (2019). Use of the Ishikawa diagram in the investigation of some industrial processes. *IOP Conference Series: Materials Science and Engineering*, *682*(1), 012012. https://doi.org/10.1088/1757-899X/682/1/012012

6. Chen, S., Liu, M., & Sun, T. (2019). Quality Control of Waterproof and Drainage Construction for

Planting Roof of Underground Garage Based on PDCA – Take A Project in Q City for Example. *E3S Web of Conferences*, *79*, 02007. https://doi.org/10.1051/e3sconf/20197902007

7. Cheng, E. C. K. (2019). *Rotating PDCA Cycles Through SECI Processes for Curriculum Management* (pp. 45–56). https://doi.org/10.1007/978-981-13-2472-7_4
8. Cousson, P.-Y., Decerle, N., Munoz-Sanchez, M.-L., Roux, D., Doméjean, S., Nicolas, E., & Hennequin, M. (2019). The “Plan” phase of a Deming cycle: Measurement of quality and outcome of root canal treatments in a university hospital. *European Journal of Dental Education*, *23*(1), e1–e11. https://doi.org/10.1111/eje.12393
9. Crosby, P. B. (1989). *Lets Talk Quality*.
10. Darmawan, H., Hasibuan, S., & Hardi Purba, H. (2018). Application of Kaizen Concept with 8 Steps PDCA to Reduce in Line Defect at Pasting Process: A Case Study in Automotive Battery. *International Journal of Advances in Scientific Research and Engineering*, *4*(8), 97–107. https://doi.org/10.31695/IJASRE.2018.32800
11. Deming, W. E. (1988). *Out of the Crisis: Quality, Productivity and Competitive Position*. Cambridge University Press.
12. Gilbert, A. W., Billany, J. C. T., Adam, R., Martin, L., Tobin, R., Bagdai, S., Galvin, N., Farr, I., Allain, A., Davies, L., & Bateson, J. (2020). Rapid implementation of virtual clinics due to COVID-19: report and early evaluation of a quality improvement initiative. *BMJ Open Quality*, *9*(2), e000985. https://doi.org/10.1136/bmjoq-2020-000985
13. Gupta, M., & Kaplan, H. C. (2020). Measurement for quality improvement: using data to drive change. *Journal of Perinatology*, *40*(6), 962–971. https://doi.org/10.1038/s41372-019-0572-x
14. Jangid, A. (2019). *Implementation And Analysis Of True Lean In A Startup Company By Using PDCA Model, A Case Study In A Manufacturing Venture*.
15. Juran, J. M. (1989). *Juran on Leadership for Quality: An Executive Handbook*. Free Press.
16. Kurniawan, C., & Azwir, H. H. (2019). Penerapan Metode PDCA untuk Menurunkan Tingkat Kerusakan Mesin pada Proses Produksi Penyalutan. *JIE Scientific Journal on Research and Application of Industrial System*, *3*(2), 105. https://doi.org/10.33021/jie.v3i2.526gupta
17. Kurniawan, H., Sumarya, E., & Merjani, A. (2017). Peningkatan Kualitas Produksi Untuk Mengurangi Unit Cacat Insufficient Epoxy Dengan Metode PDCA Di Area Die Attach (Studi Kasus Di PT. Unisem). *Jurnal Program Studi Teknik Industri*, *5*(1), 44–50.
18. Nsafon, B. E. K., Butu, H. M., Owolabi, A. B., Roh, J. W., Suh, D., & Huh, J.-S. (2020). Integrating multi-criteria analysis with PDCA cycle for sustainable energy planning in Africa: Application to hybrid mini-grid system in Cameroon. *Sustainable Energy Technologies and Assessments*, *37*, 100628. https://doi.org/10.1016/j.seta.2020.100628
19. Raman, M. R. S., & Basavaraj, P. (Dr. . Y. (2019). Quality Improvement of Capacitors through Fishbone and Pareto Techniques. *International Journal of Recent Technology and Engineering (IJRTE)*, *8*(2), 2248–2252. https://doi.org/10.35940/ijrte.B2444.078219
20. Realyvásquez-Vargas, A., Arredondo-Soto, K., Carrillo-Gutiérrez, T., & Ravelo, G. (2018). Applying the Plan-Do-Check-Act (PDCA) Cycle to Reduce the Defects in the Manufacturing Industry. A Case Study. *Applied Sciences*, *8*(11), 2181. https://doi.org/10.3390/app8112181
21. Sangpikul, A. (2017). Implementing academic service learning and the PDCA cycle in a marketing course: Contributions to three beneficiaries. *Journal of Hospitality, Leisure, Sport & Tourism Education*, *21*, 83–87. https://doi.org/10.1016/j.jhlste.2017.08.007
22. Shanafelt, T., Trockel, M., Ripp, J., Murphy, M. Lou, Sandborg, C., & Bohman, B. (2019). Building a Program on Well-Being. *Academic Medicine*, *94*(2), 156–161. https://doi.org/10.1097/ACM.0000000000002415
23. Silva, A. S., Medeiros, C. F., & Vieira, R. K. (2017). Cleaner Production and PDCA cycle: Practical application for reducing the Cans Loss Index in a beverage company. *Journal of Cleaner Production*, *150*, 324–338. https://doi.org/10.1016/j.jclepro.2017.03.033
24. van Kemenade, E., & Hardjono, T. W. (2019). Twenty-first century Total Quality Management: the Emergence Paradigm. *The TQM Journal*, *31*(2), 150–166. https://doi.org/10.1108/TQM-04-2018-0045