Using QFD and FMEA to Improve Maintenance Effectiveness in a Petroleum Refinery

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USING QFD AND FMEA TO IMPROVE MAINTENANCE EFFECTIVENESS IN A PETROLEUM REFINERY

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Abstract. A case study is reported which Improve the maintenance effectiveness by combines Quality Function Deployment (QFD) and Failure Mode and Effects Analysis (FMEA), QFD was used to identify the critical technical attributes which affect the customer satisfaction the most. FMEA was adopted to identify potential failure models and causes of critical manufacturing processes. Customer requirements (CRs) were obtained through Internal MMIP team. Analytic Hierarchy Process (AHP) selections was used to sort the importance of CRs and then compared to the technical attributes (TAs) in the House of Quality (HoQ). FMEA were used to analyse the Maintenance activity which resulted the relative solutions from High Risk Priority Number (RPN) indices failure models. By the integration of FMEA into QFD, a new maintenance management model developed and implemented, has increase by 116% Mean Time Between Maintenance and Decrease by 41% Number of Breakdown Maintenance Intervention, 47.6% Mean Time To Repair and 82% of maintenance cost or Rp.5.754.791.630,00 lower compare to the same period in the previous year maintenance cost.

1. Introduction

Global demands over high-quality products in the manufacturing sector continue to increase. However, the future of competitiveness for any manufacturing companies are become more challenging due to the equipment's aging, equipment's addition and modification, upgrading technology, or expansion production unit are mandatory to be maintain to reduce downtimes, stoppages, breakdowns, and failures to increase the reliability of a production system. the scheduling of maintenance activities may improve its productivity, efficiency, and quality, [8]Maintenance productivity aims to get the reduction of the maintenance cost by maximizing the maintenance performance. [1]

In the Petroleum refinery, where this research implemented the 2018 - 2019 maintenance activity at the selected Critical equipment Hydroskimming Plant resume, show that there is 59 times cumulative maintenance breakdown during May 2018 – June 2019 period, and then MTBM & MTTR analysis, the average duration in which at least one maintenance breakdown will be required in this system is 52 Days with the average repair duration is 21 days, and as the impact of those activity cost

Rp. 7.014.206.497. The product quality strongly related to the maintenance quality which it also has a direct contribute to the cost reduction. The measurement of asset maintenance performance and its continuous control and evaluation is becoming critical through the outsourcing, separation of asset owners and asset managers, and complex accountability for the asset management, [4]. However, the latest methodology for designing maintenance systems, i.e., no fully structured approach leading to an optimal maintenance system organizational structure with a defined hierarchy of authority and span of control; defined maintenance procedures and policies, etc and currently still there is no method or model that universally accepted. Even if there are similar product organizations, but if the technology advancement and production size is different[4]. for this reason, maintenance systems are designed using experience and judgment supported by a number of formal decision tools and techniques [4] and the developed Maintenance models are typically valid solely for a specific industry. Analysis and implementation effort through a wider scope which considers other aspects within the manufacturing system should be carried out. This means is very potential to provide a more realistic picture of the Maintenance Effectiveness Implementation prospect in the manufacturing industries. Therefore, it is urgent to produce a creative solution to increase the maintenance effectiveness to achieve the reliability improvement. This study will focus on the problems that occurring the maintenance management which are coped by the QFD and FMEA combination.

2 Literature review

Consumer requirements into an appropriate company requirements at each stage from research and product development is critical and QFD has the ability to translated it [3], QFD helps designers to reveal the voice of customers (VOC), or customer requirements, to determine which engineering elements or product specifications are the most crucial. This prioritization helps designers to know which part of the product or process is the most beneficial to focus on during design, resulting a better acceptance[9] so it can give a benefit for a new product development or current products improvement [12].

To identify potential failures of a product or service and then to determine the frequency and impact of the failure by using disciplined approach with FMEA. FMEA is an important method for preventive quality and reliability assurance. It involves investigation and assessment of all causes and effects of all possible failure modes of a product, from the earliest development phase [11]. for present study the equipment failure mode during normal operation and regular maintenance activity was analyse using FMEA. There are three indices that help to define the priority of failures: occurrence (O), severity (S) and detection difficulty (D). Occurrence is the frequency of the failure. Severity is the seriousness of the failure. Detection difficulty is the hardness to detect the failure before it reaches the customer. Risk Priority Number (RPN) is used to evaluate the risk level of a product's failure mode, and is determined by multiplication of the three failure mode indices:

$$RPN = O \times S \times D \quad (1)$$

QFD and FMEA are from different perspectives but tackling the same issue of customer satisfaction. [10] Tanik (2010) presented an integrated application of FMEA-QFD on a food package industry. FMEA analysis was helped the sales team for channeling these efforts in a better direction. The author also indicated that with the help of FMEA customer satisfaction is guaranteed by eliminating potential errors through the order handling process. Ginn (1996) introduced two schools of thought from Ford Motor Company with regards to the effective deployment of QFD and FMEA together. The first approach is applying QFD Phase 1 or Phase 2 followed by a full FMEA process. The second approach is arguably the ideal long-term solution, applying four-phase QFD with full support of an FMEA process. Based on the two thoughts, Ginn et al. (1998) proposed a new model to push FMEA upstream and QFD downstream along the product development circle.

[5] programming model with a fuzzy linear to consider quality elements and parts/components risk analysis during the stage of new product development were developed by Chen and Ko (2009) [2] Almannai (2008) developed a joint QFD and FMEA model to choose the best alternative. Both QFD and FMEA were used to support the manufacturing decision-making process. This model combines two quality tools in a systematic way and forms a good decision tool because QFD has the ability to identify the most fit alternatives and FMEA has the ability to identify the associated risks with that alternative in design and implementation phases.for present study, QFD-FMEA a combined methodology was conducted to increase the maintenance effectiveness, first of all by introduce the critical of technical attributes using QFD while FMEA was used to reveal the critical failure modes during maintenance activity which has high level of RPN indices. Finally as the result of the analysis from QFD-FMEA combination, the Solutions and suggestions were delivered to improve current peformance. The study plan and steps as shown in Figure 1.

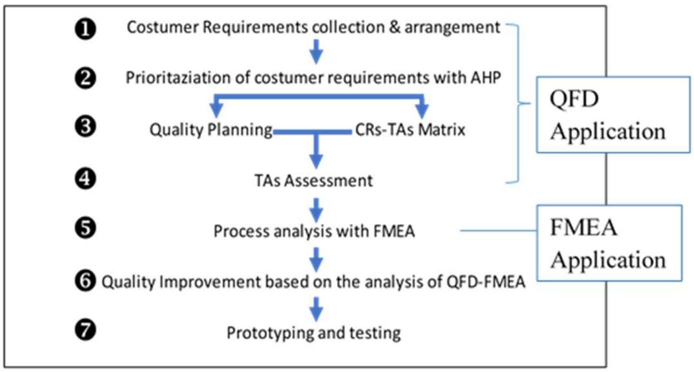


Figure 1 Study Plan

3 Methodologies

3.1 The application of QFD

3.1.1 Customer requirements (CRs) Collections

CRs were collected through Workshop Internal Maintenance Group Division (MMIP Team) as shown in Table 1.

Table 1. Customer requirements arrangement for the effective maintenance management

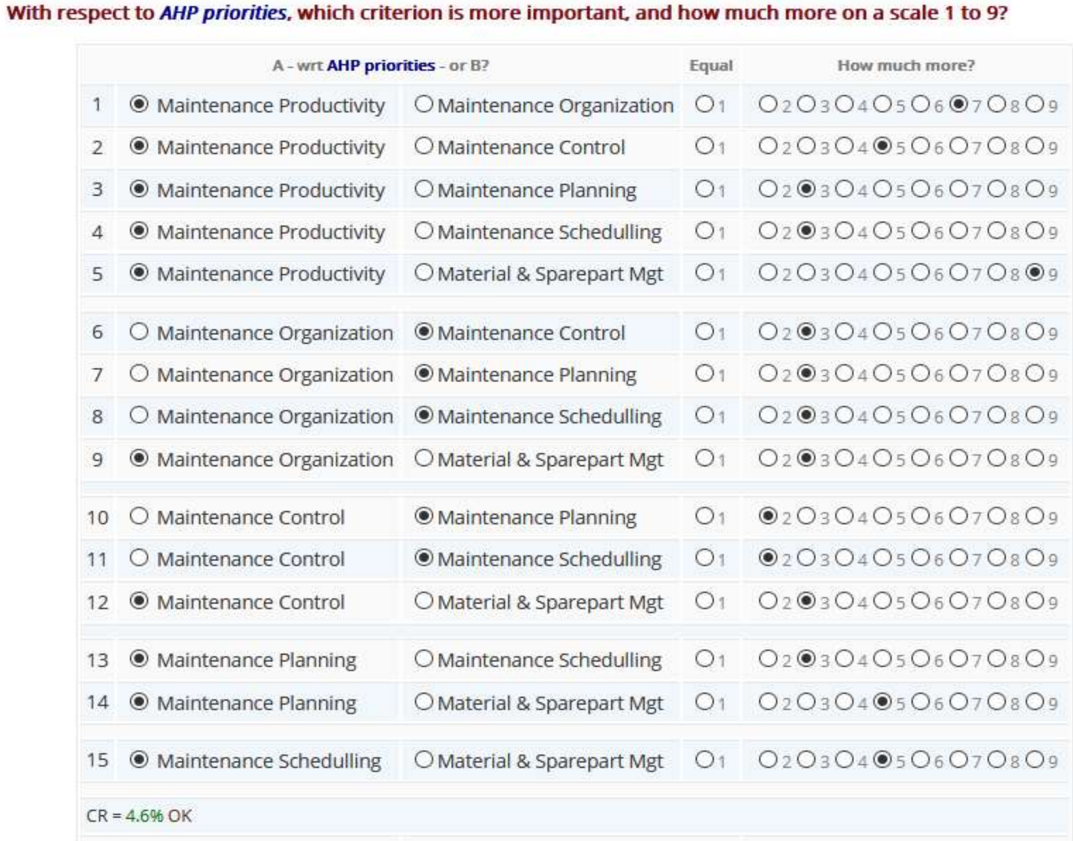
1 st Level	*2 nd Level*	*3 rd Level*
Effective Maintenance	High Maintenance Productivity	Zero Accident, High skilled people
	Good Maintenance Organization	Proven maintenance practice
	Easy Maintenance Control	Comply to procedure, Well documented
	Accurate Maintenance Planning	Comply to scope of work, Value added
	Accurate Maintenance Scheduling	Comply to work duration
	High Availability of Material & Sparepart	Minimum rework

3.1.2 Prioritization of customer requirements

AHP matrix was generalized based on the questionnaire data in Table 2. Importance rating for each customer requirement was calculated and listed in the last column of the AHP matrix. Satty (1977) proposed a consistency index

$$CI = \frac{(\lambda_{max} - n)}{(n-1)}$$

, the CRs for maintenance effectiveness was adopted to prioritize AHP with a 9-scale. Three main operations consisted under AHP: construction of hierarchy, analysis from priority and verifications consistency [6]. as shown in Table 1, This hierarchy, can be obtained through applying Affinity Diagram. Then AHP-based questionnaire for the selected different CRs was designed to collect customers' preferences. for more information on AHP-based questionnaire please refer to Kahraman et al. (2003) [7].


With respect to *AHP priorities*, which criterion is more important, and how much more on a scale 1 to 9?

	A - wrt **AHP priorities** - or B?		Equal	How much more?
1	◉ Maintenance Productivity	○ Maintenance Organization	○ 1	◉ 7
2	◉ Maintenance Productivity	○ Maintenance Control	○ 1	◉ 5
3	◉ Maintenance Productivity	○ Maintenance Planning	○ 1	◉ 3
4	◉ Maintenance Productivity	○ Maintenance Schedulling	○ 1	◉ 3
5	◉ Maintenance Productivity	○ Material & Sparepart Mgt	○ 1	◉ 9
6	○ Maintenance Organization	◉ Maintenance Control	○ 1	◉ 3
7	○ Maintenance Organization	◉ Maintenance Planning	○ 1	◉ 3
8	○ Maintenance Organization	◉ Maintenance Schedulling	○ 1	◉ 3
9	◉ Maintenance Organization	○ Material & Sparepart Mgt	○ 1	◉ 3
10	○ Maintenance Control	◉ Maintenance Planning	○ 1	◉ 2
11	○ Maintenance Control	◉ Maintenance Schedulling	○ 1	◉ 2
12	◉ Maintenance Control	○ Material & Sparepart Mgt	○ 1	◉ 3
13	◉ Maintenance Planning	○ Maintenance Schedulling	○ 1	◉ 3
14	◉ Maintenance Planning	○ Material & Sparepart Mgt	○ 1	◉ 5
15	◉ Maintenance Schedulling	○ Material & Sparepart Mgt	○ 1	◉ 5

CR = 4.6% OK

Figure 2.AHP Questionaire

the dimension of the matrix are n and λ max and the maximal eigenvalue, respectively. when the consistent ratio is less than 0.1 the matrix is consistent [1]. Consistent ratio is the ratio of CI and RI, and which CI and RI are the consistency index and the random index, respectively.

3.1.3 Quality Planning Assessment

This team consisting of members from maintenance senior supervisors, maintenance area section heads, maintenance execution manager and human resource manager was established. Current and targeted level from companies related the maintenance effectiveness also decided to compared and analysed. Each customer requirement and the target level was set by the team, as value in Table 3. Target level / Current level resulted the Improvement ratio. Absolute importance value was taken from Importance rating x Improvement ratio. the percentage of the absolute importance value in the sum of total absolute importance values is Relative importance. the voice of customer give tought from the relative importance value.

Table 2. AHP matrix

CR's	Maint. Productivity	Maint. Organization	Maint. Control	Maint. Planning	Maint. Scheduling	Material Mgmt.	Importance Rating
Maintenance Productivity	1,0	7,0	5,0	3,0	3,0	9,0	0,4

Maintenance Organization	0,1	1,0	0,3	0,3	0,3	3,0	0,1
Maintenance Control	0,2	3,0	1,0	0,5	0,5	5,0	0,1
Maintenance Planning	0,3	3,0	2,0	1,0	3,0	5,0	0,2
Maintenance Scheduling	0,3	3,0	2,0	0,3	1,0	5,0	0,1
Mat'l & Sparepart Mgmt.	0,1	0,3	0,2	0,3	0,2	1,0	0,0

Table 3. Quality planning table

CR's	Importance rating	Current level	Target level	Improvement ratio	Absolute Importance	Relative Importance
Maintenance Productivity	0,4	4,0	5,0	1,3	0,5	0,4
Maintenance Organization	0,1	4,0	4,0	1,0	0,1	0,0
Maintenance Control	0,1	3,0	4,0	1,3	0,2	0,1
Maintenance Planning	0,2	3,0	5,0	1,7	0,3	0,3
Maintenance Scheduling	0,1	3,0	5,0	1,7	0,2	0,2
Material & Sparepart Management	0,0	4,0	4,0	1,0	0,0	0,0

3.1.4 Relationship Matrix CRs-TAs

Refer to the collected CRs and The internal target, 9 Zero Accident, High skilled people, Proven maintenance practice, Comply to procedure, Well documented, Comply to scope of work, Value added, Comply to work duration and Minimum rework. for CRs and TAs the Relationship matrix set up numerical values are 1, 3 and 5 as data shown in Table 4. to show the relationships strength (weak, moderate or strong), respectively. And no relationship indicate by the Blank cells.

Table 4. CRs-TAs two way dimensional table

CR's	Zero Accident	High skilled people	Proven maintenance	Comply to procedure	Well documented	Comply to scope of work	Value added	Comply to work duration	Minimum rework	Importance rating CRs
Maintenance Productivity	1,0	5,0				1,0		1,0	5,0	0,4
Maintenance Organization		3,0	5,0		1,0				1,0	0,1
Maintenance Control	3,0	5,0	1,0	3,0	3,0	3,0	3,0	1,0	5,0	0,1
Maintenance Planning	3,0	3,0	1,0	5,0	1,0	5,0	1,0	3,0	3,0	0,2
Maintenance Scheduling	5,0	3,0	1,0	3,0	1,0	5,0	1,0	5,0		0,1
Material & Sparepart Management			1,0	1,0	5,0		1,0	3,0	3,0	0,0

3.1.5 Quality designing

Technical attributes calculated to obtain the importance rating by the following equation:

$$T_j = \sum_{i=1}^{n} RW_i \, R_{ij} \; (1 \le i \le n, 1 \le j \le m)$$

n for CRs and m for technical attributes, ith row of customer requirement, the jth column of technical attribute where i, j, Tj, RWi, Rij, importance rating for the jth column of technical attribute, relative weight for the ith row of customer requirement.

relationship strength of the ith row of customer requirement and the jth. column of technical attribute [11]. Refer to the technical decision of Current operation level, target level and importance rating for every technical attribute, the target level of the matched technical attribute was determined. And then , critical technical attributes is the technical attribute with a high ranked, technical attributes which in range of category Need improvement their background would have colored in grey.

Table 5. Quality designing

Technical Attributes	Zero Accident	High skilled people	Proven maint. practice	Comply to procedure	Well documented	Comply to scope of work	Value added	Comply to work duration	Minimum rework
Importance Rating	2,1	4,0	0,8	1,9	0,9	2,6	0,7	2,0	3,5
Current Company's Level	5,0	5,0	2,0	5,0	3,0	5,0	4,0	4,0	3,0
Target Level	7,0	6,0	4,0	6,0	6,0	6,0	5,0	6,0	6,0
Need Improvement	IMPV	IMPV	MNT	IMPV	MNT	IMPV	MNT	IMPV	IMPV

3.1.6 House of Quality

the House of quality for the maintenance management as shown in Table 6. Based on the first phase of QFD analysis, key technical attributes, such as Zero Accident, High Skill People, Comply to Procedure, scope of Work, Work Duration and Minimum Rework were selected to be focused issue. Which has major impacts to the customer satisfaction of Maintenance Management.

Table 6. House of Quality

	Zero Accident	High skilled people	Proven maint. practice	Comply to procedure	Well documentd	Comply to scope of work	Value added	Comply to work duration	Minimum rework	Importance rating	Current level	Target level	Improvement ratio	Absolute Importance	Relative Importance
Maint. Productivity	7,0	6,0	4,0	6,0	6,0	6,0	5,0	6,0	6,0	0,4	4,0	5,0	1,3	0,5	0,4
Maint. Organization		3,0	5,0		1,0				1,0	0,1	4,0	4,0	1,0	0,1	0,0
Maint.Control	3,0	5,0	1,0	3,0	3,0	3,0	3,0	1,0	5,0	0,1	3,0	4,0	1,3	0,2	0,1
Maint. Planning	3,0	3,0	1,0	5,0	1,0	5,0	1,0	3,0	3,0	0,2	3,0	5,0	1,7	0,3	0,3
Maint. Scheduling	5,0	3,0	1,0	3,0	1,0	5,0	1,0	5,0		0,1	3,0	5,0	1,7	0,2	0,2
Mat'l & Sparepart Mgmt.			1,0	1,0	5,0		1,0	3,0	3,0	0,0	4,0	4,0	1,0	0,0	0,0
Importance Rating	2,1	4,0	0,8	1,9	0,9	2,6	0,7	2,0	3,5						
Current Company's Level	5,0	5,0	2,0	5,0	3,0	5,0	4,0	4,0	3,0						

Target Level	7,0	6,0	4,0	6,0	6,0	6,0	5,0	6,0	6,0
Need Improvement	IMV	IMV	MNT	IMV	MNT	IMV	MNT	IMV	IMV

3.2 FMEA Application

After result in QFD was obtained as the issue that need improvement, and then the main failure mode from the Maintenance Activity in Maintenance Management were predict by calculated the possibility of the incident and accident using FMEA. Maintenance management include Plant Reliability, Equipment Strategy, Redundant / Spare Equipment readiness, Energy consumption, Planned – Unplanned Maintenance Order and Rework Maintenance, etc. Then investigated the failure causes, severity, frequency of occurrence and assessed the difficulty of detection. with relatively high RPN indices several Failure modes were marked in grey, as shown in Table 7. In this case items with RPN index above 100 are taken as the focused item. As the result, in term to eliminate the possible failure modes or at least decrease its frequency of occurrence, recommendation for improvement action are suggested. Such as, the cause of Unplanned Maintenance Order is High is Lack of Preventive Maintenance Compliance and Lack of Operator Awareness. Suggestion were provided, such as standardized PM task list and improve the task list & the schedule accuracy so it will guide the technician activity and the operator schedule.

Table 7. the maintenance activity Failure mode and effect analysis

No	Ops.Failure	Failure Mode	Sev	Failure cause	O	D	RPN Index
1	Production capacity	Lack of Plant Reliability	7	Inappropriate Processess	3	4	84
				Lack of Maintenance Quality	4	3	84
				Uncomplete Maintenance Service (Material / Spare part is not ready)	4	2	56
2	Maintenance Strategy	Insufficient Equipment Strategy	7	Lack of Capability	5	4	140
				Unclear Role & Responsibility	5	5	175
3	Critical Equipment	Lack of Redundant / Spare Eqp Readiness	7	Lack of Maintenance Quality	6	5	210
				Uncomplete Maintenance Service (Material / Spare part is not ready)	3	4	84
4	Energy Consumption	Highly use and or release Energy	5	Inappropriate Processess	4	4	80
				Inadequate design	5	3	75
5	Maintenance Activity	Unplanned Maintenance Order is High	6	Lack of PM Compliance	8	6	288
				Lack of Operator Awareness	6	5	180
		Rework Maintenance	5	Low Quality of Material	5	3	75
				Lack of Workmanship Internal/External	6	5	150

4. Discussion

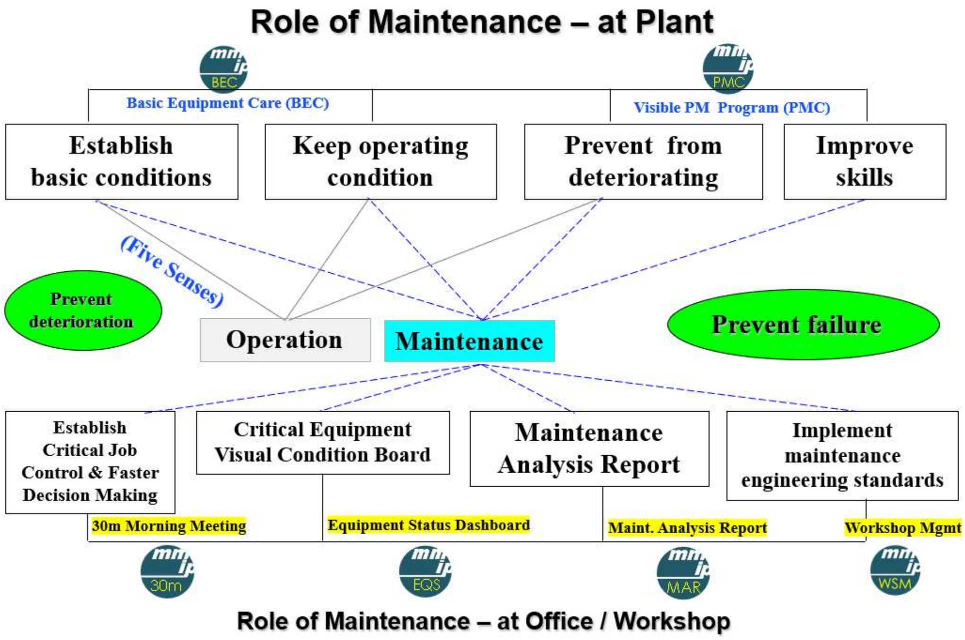
By using QFD - FMEA analysis, the solution for improvement offered from technical attributes for maintenance activity. respectively

4.1 Solutions for technical attribute improvement

as listed in Table 6. Several technical attribute were identified for improvement, such as Zero accident, high skill people, comply to procedure, comply to scope of work, comply to work duration and minimum rework. Solutions were given accordingly as shown in Figure.2. The role of new maintenance management activity design as shown in Figure 2. Therefore, The maintenance role clearer and more manageable.

To optimize the targets “Zero accident, High skill people & Minimum rework” the activity is Work progression sharing, knowledge sharing, learning from events, success story, and the task list which specifically design for each selected equipment is also expected as guide for junior technicians and minimize human error (30m Meeting, Visual PM Program). And for “Comply to Procedure, Comply to Scope of Work & Comply to Work Duration” the activity is Basic equipment care by Plant Patrol, using critical equipment sharing dashboard, maintenance performance measurement and implementing engineering standard (Basic Equipment Care, Equipment Status Dashboard, Maint.Analysis Report, Workshop Mgmt.

Figure 3. Improvement of maintenance activity



Based on the discussion above, the maintenance management improvement program as proposed are summarized in Table 8.

Table 8. Improved results of technical attributes

Critical Problems	Proposed Solution	Effects
• Maintenance Productivity	Activate a standard Plant Patrol	Increase Maintenance Productivity, Early Detection of unplanned repair
• Maintenance Control	Top down Cascade Communication, Standarize Visual Information board, Standarize technical routine meeting and monthly Report	Build togetherness, faster decision making, encourage frontline and raise up the technician & the operator awareness
• Maintenance Planning & Scheduling	Develop an Accurate Maintenance Activity Schedule at the Critical Equipments with a clear and fit maintenance tasklists	Improve maintenance effectiveness, develop a better working culture, increase Prevention rather than detection of any maintenance problem, a standard guidelines will make easier for junior technician to execute the maintenance activity

4.2 Solutions for maintenance effectiveness improvement

Based on the Maintenance effectiveness analysis, as shown in Table 8. several items with high RPN indices were identified through FMEA application. Recommendation are given as shown in Table 9. The qualification ratio of maintenance effectiveness was Increas and equipment reliability improve accordingly.

Table 9. Improvement strategy of maintenance management

Critical Problems	Proposed Solutions
inappropriate Maintenance Strategy	Introduce a new maintenance management under maintenance execution
Unclear Role & Responsibility	implement a new maintenance management model, with a detail and clear target and scope of work
Lack of PM Compliance	Standarize PM tasklist Schedule and Evaluate the realization
Lack of Maintenance Quality in terms of critical equipments	Improve the Accuracy PM
Lack of frontline awareness & workmanship	Encourage Frontline, build togetherness by Top Down Cascade communication

This case study was carried out in 2018 until 2020, in May 2018 to June 2019 February were compared with those in July 2019 to August 2020 in Table 10.

Table 10 Comparison chart of maintenance peformance

No	*Parameters*	*May 2018 – June 2019*	*July 2019-August 2020*		*Value*	*Desc.*
1	Total Maintenance Intervention (Events)	59 times	35 times	↓	41.0%	The total maintenance intervention is reduced significantly
2	Mean Time Between Maintenance (MTBM)	24 days	52 days	↑	116%	MTBM increased drastically
3	Mean Time To Repair (MTTR)	21 days	11 days	↓	47.6%	MTTR decreased significantly
4	Maintenance Cost	Rp.7.014.206.497	Rp.1.259.414.867	↓	82%	Maintenance Cost decreased significantly

Several key items were exposed as the result of QFD-FMEA Analysis, such as Unplanned Maintenance order is High and Lack of PM Compliance, which highly impacted to customer complaints including maintainability as well as the maintenance quality. Activate a standard Plant Patrol and Develop an Accurate Maintenance Activity Schedule at the Critical Equipment with a clear and fit maintenance task lists are proposed as the Improvement strategies. To ensured the study can capture a wider range of the customer satisfaction by using QFD and FMEA to explore problems from several point of views.

5. Conclusions

The QFD-FMEA combination, used as the methodology to answer the lack of maintenance management and to improve the maintenance effectiveness. QFD identify technical attributes, such as Zero Accident, High Skill People, Comply to Procedure, scope of Work, Work Duration and Minimum Rework were appears as critical issue which has highly impact to the costumer satisfaction. At the same time, FMEA analyze possible failure modes from the maintenance activity from the technical point of view. Recommended action were delivered accordingly. Significant result of maintenance effectiveness improvements achieved by using this method. the new maintenance management model has successfully developed and implemented, has increase by 116% Mean Time Between Maintenance and Decrease by 41% Number of Breakdown Maintenance Intervention, 47.6% Mean Time To Repair and 82% of maintenance cost or

Rp.5.754.791.630,00 lower compare to the previous year maintenance cost. but this method is required a big effort at the beginning, such as organized an event that can gather all senior supervisors and maintenance area section head to collect all common symptoms under their area and then set the CR's. This hybrid QFD-FMEA worked effectively for improving the maintenance effectiveness.

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