Service Quality and Risk Analysis-Based Maintenance Policy Selection for Rail-Transport

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Abstract

In recent years, maintenance activities have become more complex along with the trends of automation in various industries. It implies maintenance being a dependent factor to service quality, one of which is urban rail transportation that already adhered to the grade of automation. In addition to its complexity, maintenance is also a major contributor in the cost-of-service delivery, reaching 15% of the total operating costs for urban rail services in Indonesia. Maintenance itself was a risk-based business process considering potential failures of technical equipment that affect equipment availability or service revenue indirectly. Previous studies recognized that the increased expectation of service quality and risk of maintenance activities are still linear to maintenance costs. Furthermore. most companies only follow OEM (Original Equipment Manufacturer) rather than develop their own strategy. Several studies have been conducted to determine maintenance strategies but have not considered the quality and risk of failure comprehensively. Therefore, this study aims to design a model of determining maintenance policies through priority arrangement of maintenance activities based on the risk of failure and its impact on service quality. Data are obtained from service quality attributes survey and stakeholder interview of urban rail company. Using House of Quality (HoQ) the importance of each maintenance activity is identified and prioritized subsequently based on potential failure and detection capabilities using FMEA (Failure Mode Effect Analysis). The result shows priority indexing on each maintenance activity. Afterwards those priority can be utilized as the main criteria for determining maintenance and inventory policy.

Keywords
Service Quality, House of Quality, FMEA and Maintenance Policy.

1. Introduction

Maintenance has been played a critical role for most of industries in terms of quality assurance and process efficiency through the availability of machine during production or service operation (Glawar et al., 2016). Equipment availability becomes the main objectives of maintenance activities so that service level or product quality can be managed. It may cause a great damage on the business continuity, included for transportation sector especially the one adopted automation in Their operation. Once the fleet of vehicles or critical subsystem is experiencing problems and cannot be operated, then transportation services cannot take place so that there is a blocked for creating revenue. Furthermore, there is an indirect impact also of potential customer satisfaction aspects on future revenue (Jiang and Murthy, 2008). Besides the positive impact, it has cost should be borne by the company which calculated almost 15-40% of operation cost (Mobley, 1990). Looking at rail-transport industry in Indonesia, maintenance activities burden 15% of the total operating and maintenance costs. It was significantly great compared to other transport operators in Asia such as Bangkok and Delhi, the proportion of maintenance costs required only 1% and 3% (Nurcahyo et al., 2020).

The challenge of maintenance strategy is how control equipment deterioration with the least total cost as well as ensuring safe and environmentally friendly operation (Golonka and Brennan, 1996). Notwithstanding the importance of maintenance strategy was, it receives inconsiderable attentions from the top management. In general, companies only follow guidance from the Original Equipment Manufacturer (OEM) (Jiang and Murthy, 2008). In the recent years, the complexity of maintenance activities also increases following the growth of automation transformation. This also applies to the rail-based transportation. Rail transportation is a growing sector and a strategic project in Indonesia. In their research, Hakim and Kartikoseno (2018) through the Kano integration model and Quality Function Deployment (QFD), found that "availability of facilities in trains and stations" is a major determinant of the quality of public services. These factors are related to automated service characteristics where the quality of service depends directly on the reliability of the facility or system or service. Maintenance strategies selection should depend on failure characteristics of equipment which become more difficult to analyze (Glawar et al., 2016). Other than that, it become more challenging if company only adopt guidance from the OEM since there is increased expectations of quality from the growing market. To achieve such objectives, company also shouldn't adopt all the advance methods of maintenance for the whole system. It would cause a great cost to overrun for Rail-transport industries which consist of several major system such as trains or called rolling stocks, power system, signaling system, telecommunication system, building infrastructure, and ticketing system. Therefore, prioritization for maintenance activities has become very important for companies with limited resources (Saleh et al., 2015).

Several studies have been conducted to determine appropriate maintenance strategy for each equipment try to optimize the reliability with the minimum cost. Total Productive Maintenance (TPM) is set to improving the quality of the product, lower costs, and waste, and increase equipment availability using Total Quality Principles (Jiang and Murthy, 2008). Other quality management consideration was put on POMDP (Partially Observable Markov Decision Processes) strategic to make decision under several scenarios (Ivy and Nembhard, 2005). In healthcare industry, Saleh, et al. (2015) develop the three-domain framework to prioritize the implementation of preventive maintenance period. They adopt House of Quality to examine the importance of each subsystem. That strategy also modifies House of Quality tools for evaluating risk aspect in each subsystem to prioritize maintenance task. This risk evaluation methods are specific to the healthcare industry and had not considered detection capabilities and the possibility of failure to operate in dynamic engine conditions. In the other hand, RCM or Reliability Centered Maintenance (Jiang and Murthy, 2008), as one of the earliest strategies developed, carry out Failure Effect Mode Analysis (FMEA) to evaluate risk of failure for each system or equipment. Both quality and risk evaluation are important to determine maintenance policy for the whole system of rail-transport that optimize the reliability and total cost. So that the prioritization model prepared needs to be equipped with a comprehensive quality consideration and risk evaluation.

As the interest in maintenance activities develops that have a direct impact on the quality of transportation services (Hakim and Kartikoseno, 2018), the development of maintenance policies is not in line with the trend. Businesses tend to follow the guidance of OEMs more, while these activities have a major impact on costs (Murthy, et al. 2008). Maintenance policy selection with consideration of service quality attributes and potential risks are still limited. This was supported by Saleh et al., 2015, in his research which successfully consolidate a model of prioritization of maintenance activities of several systems in the health industry with the attributes of customer perspective. However, the preparation of such maintenance strategies needs to be complemented by a more comprehensive risk assessment with the risk approach in RCM (Jiang and Murthy, 2008) using FMEA techniques to look at the failure detection capabilities of a system. To meet these limitations, the study is intended to answer some of the following questions:

- How is the correlation of quality attributes for passenger service and risk analysis appropriate for maintenance activities?
- How are the various maintenance activities of rail-transport being prioritized?
- What is the appropriate maintenance policy for each category of maintenance priorities?

1.1 Objectives

This study aims to design a model of determining maintenance policies in the form of a priority arrangement of maintenance activities based on the risk of failure and its impact on service quality. Several advantage that may be gain as follows:

- Simplify maintenance-related decisions such as preparation of maintenance schedules, inhouse or outsourced decisions, and spare part inventory arrangements
- Lower the risk of cost overruns for maintenance activities

2. Literature Review

Quality Function Deployment (QFD) is one of the quality management techniques that can identify technical requirements to meet customer needs. One of the tools in QFD techniques commonly used in various industries is The House of Quality (HoQ) where the voice of customer (VoC) relates to voice of engineers (VoE) (Ficalora and Cohen, 2010). HoQ which described in Figure 1 is used in Saleh et al. (2015) research to prioritize maintenance activities on medical equipment by considering the quality importance factors activities through two phases (HoQ Phase 1 and HoQ Phase 2). The House of Quality may not require consideration of competitiveness, referring to Glawar, et al. (2016), because it focuses on the relationship between voice of customer and voice of engineers when it comes to maintenance policy design (Figure 1).

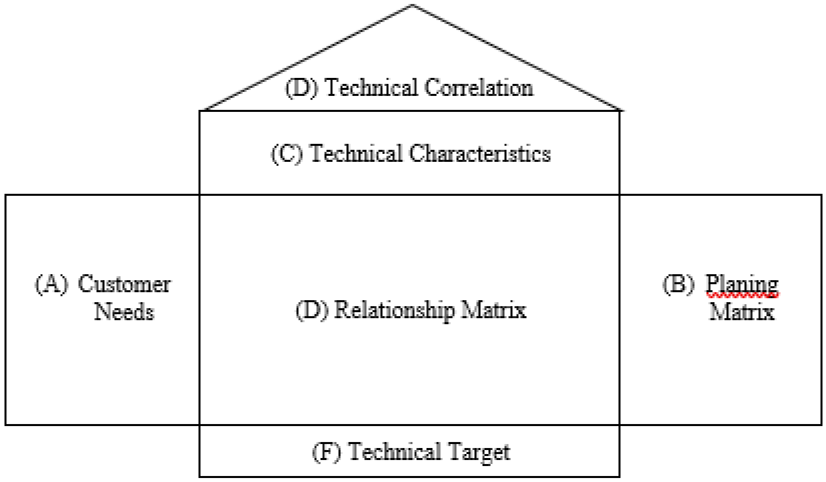

Figure 1. House of Quality Diagram

For risk evaluation, most of techniques used in maintenance management is FMEA or Failure Mode Effect Analysis. In addition to focusing on customers, maintenance strategies should also not be separated from risk analysis related to technical conditions (such as the rate of degradation) of each existing infrastructure or system or facility and the ability to detect potential failures. This will certainly lower the potential failure of the system to be maintained. Related to rail-transport operations, Szmel and Wawrzyniak (2017) uses FMEA to analyze potential failures of system running, its causes and impacts. The output resulted from FMEA is Risk Priority Number (RPN) which can be calculated through below equation:

$$Risk\ Priority\ Number_j = \sum Severity\ Rating_j \times Probability\ of\ Occurence_j \times Detectability_j$$

Carl, S. Carlson (2015) in his book indicates the criteria evaluation for severity, occurrence, and detectability described in Table 1, Table 2, and Table 3.

Table 1. Severity Criteria Evaluation

Effect	Criteria: Severity of Effect on Product (Customer Effect)	Rank
Failure to Meet Safety and/or Regulatory Requirements	Potential failure mode affects safe vehicle operation and/or involves noncompliance with government regulation without warning	10
	Potential failure mode affects safe vehicle operation and/or involves noncompliance with government regulation with warning	9
Loss or Degradation of Primary Function	Loss of primary function (vehicle inoperable, does not affect safe vehicle operation).	8
	Degradation of primary function (vehicle operable, but at reduced level of performance)	7
Loss or Degradation of Secondary Function	Loss of secondary function (vehicle operable, but comfort/convenience functions inoperable).	6
	Degradation of secondary function (vehicle operable, but comfort/convenience functions at reduced level of performance)	5
Annoyance	Appearance or audible noise, vehicle operable, item does not conform and noticed by most customers (>75%).	4
	Appearance or audible noise, vehicle operable, item does not conform and	3

Effect	Criteria: Severity of Effect on Product (Customer Effect)	Rank
	noticed by most customers (>50%).	
	Appearance or audible noise, vehicle operable, item does not conform and noticed by most customers (>25%).	2
No Effect	No discernible effects	1

Table 2. Occurrence Evaluation Criteria

Likelihood of Failure	Criteria: Occurrence of Cause (Incidents per Items/Vehicles)	Rank
Very High	≥100 per thousand ≥1 in 10	10
High	50 per thousand 1 in 20	9
	20 per thousand 1 in 50	8
	10 per thousand 1 in 100	7
Moderate	2 per thousand 1 in 500	6
	0.5 per thousand 1 in 2000	5
	0.1 per thousand 1 in 10,000	4
Low	0.01 per thousand 1 in 100,000	3
	≤0.001 per thousand 1 in 1,000,000	2
Very Low	Failure is eliminated through preventive control.	1

Table 3. Detectability Evaluation Criteria

Opportunity for Detection	Criteria: Likelihood of Detection by Process Control	Rank
No Detection Opportunity	No current process control; cannot detect or is not analyzed.	10
Not Likely to Detect at any Stage	Failure Mode and/or Error (Cause) is not easily detected (e.g., random audits).	9
Problem Detection Postprocessing	Failure Mode detection postprocessing by operator through visual/ tactile/ audible means.	8
Problem Detection at Source	Failure Mode detection in-station by operator through visual/ tactile/ audible means or postprocessing through use of attribute gauging (go/no-go, manual torque check/clicker wrench, etc.)	7
Problem Detection Postprocessing	Failure Mode detection postprocessing by operator through use of variable gauging or in-station by operator through use of attribute gauging (go/no-go, manual torque check/clicker wrench, etc.)	6
Problem Detection Postprocessing	Failure Mode or Error (Cause) detection in-station by operator through variable gauging or by automated controls in-station will detect discrepant part and notify operator (light, buzzer, etc.). Gauging performed on setup and first-piece check (for setup causes only)	5
Problem Detection Postprocessing	Failure Mode detection postprocessing by automated controls that will detect discrepant part and lock part to prevent further processing.	4
Problem Detection at Source	Failure Mode detection in-station by automated controls that will detect discrepant part and automatically lock part in station to prevent further	3

Opportunity for Detection	Criteria: Likelihood of Detection by Process Control	Rank
	processing.	
Error Detection and/or Problem Prevention	Error (Cause) detection in-station by automated controls that will detect, error and prevent discrepant part from being made.1 in 1,000,000	2
Detection Not Applicable; Error Prevention	Error (Cause) detection in-station by automated controls that will detect, error and prevent discrepant part from being made.	1

3. Method

This study is focusing on determining prioritize maintenance activities for several system of rail-transport industry. Those level of priorities become the basis to select appropriate maintenance policy. Data was collected through customer survey and stakeholder interview from one of rail-transport company in Jakarta, Indonesia which adopted grade of automation level 2 in terms of their railway system. Integrated model of House of Quality two phases with Failure Mode Effect Analysis carried out in this study simultaneously as described in Figure 2. House of Quality is derived and modified from Saleh et al. (2015) which the competitiveness matrix was taken out in terms of focusing on calculation of technical importance.

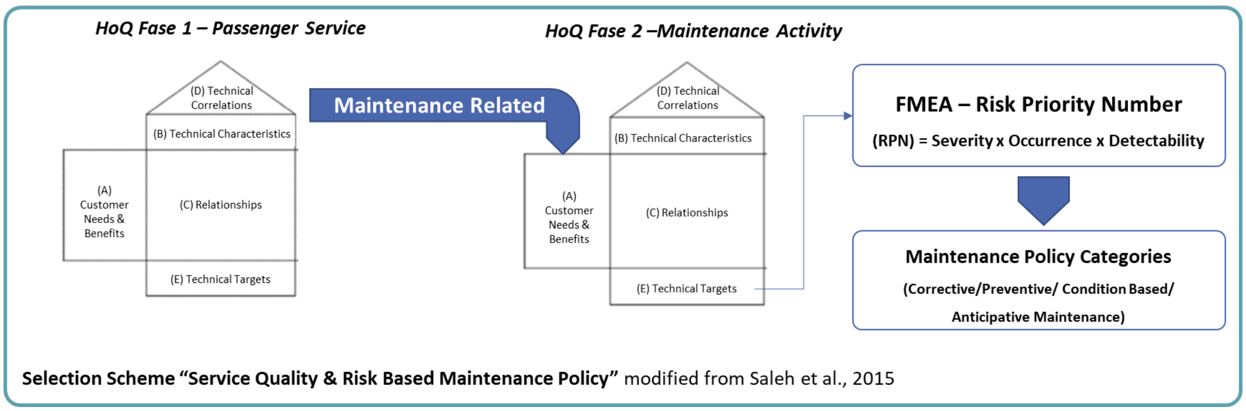

Figure 2. Service Quality and Risk Based Mainteanance Policy Selection Scheme

Risk analysis is carried out by FMEA method, which considers 3 factors as follows "Severity of effect", "Probability of Occurrence", and "Detectability" (Carlson, Carl S., 2012). In his research on quality-focused maintenance management, Glawar, G., et al, 2016, linked the technical targets of the quality matrix or House of Quality with the magnitude of the impact on the quality of related technical responses. Therefore, in this study, the use of severity of effect values refers to the technical target results of HoQ Phase 2 with a scale adjustment of 1-10 according to Carlson's guidance (Carl S., 2012).

4. Data Collection

This study was conducted through 4 stage calculation, as follows:
Stage 1: Developing House of Quality Phase 1
Stage 2: Developing House of Quality Phase 2
Stage 3: Risk Analysis
Stage 4: Classification of Maintenance Priorities

4.1 House of Quality (HoQ) Phase 1

The quality attributes to describe HoQ phase 1 part "customer needs" were obtained through a previous study, literature review of quality attributes for Urban Train Services (Ibrahim, A., et al., 2019). 36 attributes listed in Table 4 are the customer needs with grouping according to the dimensions of customer service quality, namely

Reliability, Empathy, Tangible, Responsiveness, Assurance (Parasuraman, et al., 1998) in this study. Importance rating for each attribute being calculated from survey of 150 passengers and described in Figure 3.

Table 4.. Quality Attributes for Rail-Transport Service

Quality Dimension (code)	**Code**	**Service Quality Attributes**
Responsiveness (RS)	RS1	Personnel are help quickly
	RS2	Media to get help, information, and complaints are well provided
	RS3	Staff have knowledge in providing information clearly
	RS4	Information on train timetable delays is available accurately
Assurance (A)	A1	Personal security and safety inside the train is assured
	A2	Personal security and safety on station is assured
Tangible (T)	T1	Station is easy and close to reach from the place of activity
	T2	Parking is available and easy to find
	T3	Information displays (directions, prohibition stickers and recommendations) on trains are clearly available
	T4	Train audio information is delivered with clear sound intensity
	T5	Information displays (directions, prohibition stickers and recommendations) on stations are clearly available
	T6	Station audio information is delivered with clear sound intensity
	T7	Elevator and escalators are available properly
	T8	Station officers are groomed well and clean
	T9	Facilities at stations are clean
	T10	Toilets are clean and in good condition
	T11	Number chair and handgrip inside train are sufficient
	T12	Train in good condition and clean
	T13	Low noise level at station and inside train
	T14	Convenience train and station temperature
Empathy (E)	E1	Station officers are friendly
	E2	Security officers are friendly
	E3	Facilities for priority passengers are well provided
	E4	Bikers' facilities are well provided
	E5	Travel route information and advanced modes of transportation are easy to find
	E6	Ease of ticket purchase process and top up through various channels (TVM, QR Code, counter)
	E7	Prayer rooms are well provided
	E8	Nursery rooms are well provided
	E9	Convenience during the trip inside the train (no shock when the train departs, moves, and stops)
Reliability (Rl)	Rl1	Quick waiting time on station
	Rl2	Operational hours are sufficient
	Rl3	Passing the gate process is easy
	Rl4	Punctuality of train schedule
	Rl5	Rapid travel time
	Rl6	Officers are able to handle disruption properly
	Rl7	Officers are able to handle emergency situation properly

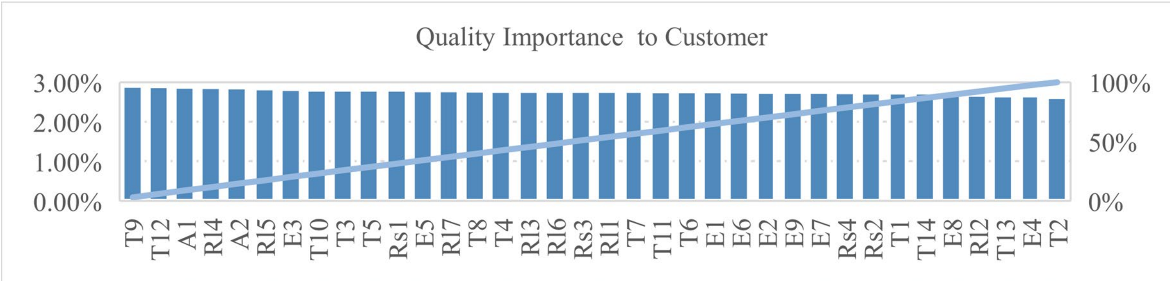

Figure 3. Service Quality Importance to Passengers

Table 5. Technical Characteristics Phase 1

Code	Technical Characteristics
T01	*Availability Mechanical Electrical (lamp, AC, exhaust and water)*
T02	*Availability of Bike Facilities*
T03	*Availability of Customer Relationship Management Channel*
T04	*Availability of Elevator*
T05	*Availability of Escalator*
T06	*Availability of Information Sign*
T07	*Availability of Parking Facilities*
T08	*Availability of Power System*
T09	*Availability of Safety equipment*
T10	*Availability of Signaling System*
T11	*Availability of Telecommunication System*
T12	*Availability of Ticketing System*
T13	*Availability of Train Announcement System*
T14	*Availability of Trains*
T15	*Availablity of Priority Chair*

Code	Technical Characteristics
T16	Sound intensity < 95dB
T17	Temperature in range 22-27C
T18	*Congestion Rate*
T19	Number of integrated buildings
T20	Number of integrations with other modes
T21	*Number of accident and incident*
T22	*Staff performance (Skills and Attitude)*
T23	*Punctuality of Train Schedule*
T24	Actual operational hours
T25	Compliance to building standard regulation
T26	*Response Time CRM Agent*
T27	*Vendor Performance (cleaning)*
T28	*Vendor Performance (Security)*

HoQ Phase 1 is built by connecting the technical response (obtained through stakeholder interview) listed in Table 5 and importance to customer and indicates the strength of relationship following Ficalora and Cohen, 2010. Technical Target is calculated using the following equation (Saleh et al., 2015) and the results describe in Figure 4.

$$Technical\ Target\ (TT)_j = \sum VoC\ Rating_i \times relationship_{ij}$$

Service Characteristics / Customer Needs		T01	T02	T03	T04	T05	T06	T07	T08	T09	T10	T11	T12	T13	T14	T15	T16	T17	T18	T19	T20	T21	T22	T23	T24	T25	T26	T27	T28
RS1	4.38																												9
RS2	4.26			3																							9		
RS3	4.32																						9						
RS4	4.27										3	9																	
A1	4.49									1												9							3
A2	4.47									1												9							3
T1	4.26																			3	9								
T2	4.09							9																					
T3	4.38						9																						
T4	4.33								1					9															
T5	4.38						9																						
T6	4.31								1			9																	
T7	4.32				9	9			3																				
T8	4.34																						9						
T9	4.52																									3		9	
T10	4.38	9							3																	9		9	
T11	4.32																		9					3	9				
T12	4.51																											9	
T13	4.15																9												
T14	4.26																	9											
E1	4.31																						9						
E2	4.29																						9						3
E3	4.40	3			3							1				3										3			
E4	4.14		9																										
E5	4.35						9																						
E6	4.30								3			3	9																
E7	4.29	9							1																	9		3	
E8	4.19	9							1																	9		3	
E9	4.29																							3					
RI1	4.32								3		3				9									9					
RI2	4.17								1		1				3										9				
RI3	4.33								3			3	9																
RI4	4.48								3		3				9									9					
RI5	4.43								3		9													3					
RI6	4.33																						9						
RI7	4.35																						9						
Technical Importance Rating		128.92	37.29	12.79	52.11	38.90	118.00	36.81	112.95	8.95	83.23	107.51	77.62	38.95	91.70	13.21	37.33	38.38	38.86	12.79	38.38	80.57	233.43	118.30	76.38	142.49	38.38	146.19	79.11
Relative Weight		6.32%	1.83%	0.63%	2.56%	1.91%	5.79%	1.80%	5.54%	0.44%	4.08%	5.27%	3.81%	1.91%	4.50%	0.65%	1.83%	1.88%	1.91%	0.63%	1.88%	3.95%	11.45%	5.80%	3.74%	6.99%	1.88%	7.17%	3.88%
Technical Ranking		4	23	26	15	17	6	24	7	28	10	8	13	16	9	25	22	19	18	26	19	11	1	5	14	3	19	2	12

Figure 4. House of Quality Phase 1

4.2 House of Quality Phase 2

Hous of Quality (HoQ) Phase 2 is focusing on the relationship of maintenance activities with technical characteristics from HoQ Phase 1 (Saleh et al., 2015). At this stage, confirmation was carried out to experts in the Operation and Maintenance Team to filter the technical characteristics which in scope of maintenance activities. Using the same method as phase 1, HoQ phase 2 obtained as described in **Fi**gure 5 and description for maintenance activities P01-P21 are listed in

Technical Characteristics / Service Characteristics		P01	P02	P03	P04	P05	P06	P07	P08	P09	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21
T01	128.92				3	1								9								
T04	52.11				3		9															
T05	38.90				3			9														
T08	112.95				9						3				9							
T09	8.95			3		3				9	3											
T10	83.23				3				3			3						9				
T11	107.51				3				9							3			3			
T12	77.62	9			3				3													
T13	38.95																3					
T14	91.70														3		9				1	
T16	37.33																9					
T17	38.38																9					
T23	118.30												1		9		9	9				3
T24	76.38					1			1	1	1	1	9	1	9		3	9		3		1
T25	142.49		9				3	3												3		
Technical Importance Rating		698.57	1282.43	26.86	2481.48	232.16	896.48	777.62	1526.56	156.95	442.10	326.08	805.73	1236.67	3043.81	322.54	2917.43	2501.24	322.54	656.62	91.70	431.29
Relative Weight		3.30%	6.06%	0.13%	11.72%	1.10%	4.23%	3.67%	7.21%	0.74%	2.09%	1.54%	3.80%	5.84%	14.37%	1.52%	13.78%	11.81%	1.52%	3.10%	0.43%	2.04%
Technical Ranking		11	6	21	4	18	8	10	5	19	13	15	9	7	1	16	2	3	16	12	20	14

Figure 5. House of Quality Phase 2

Table 6. Technical Characteristics Phase 2

Code	Technical Characteristics
P01	Maintenance of Ticketing System
P02	Maintenance of Architecture dan Interior
P03	Maintenance of CCTV System
P04	Maintenance of DB Panel 380/220V
P05	Maintenance of Diesel Generator (DEG)
P06	Maintenance of Elevator
P07	Maintenance of Escalator
P08	Maintenance of Fiber Optic Networks
P09	Maintenance of Fire Protection System
P10	Maintenance of Grounding dan Arrester
P11	Maintenance of Impedance Bond
P12	Maintenance of rail track

Code	Technical Characteristics
P13	Maintenance of M/E (Chiller, AHU, Water, Lighting, ECS) System
P14	Maintenance of Panel 20 kV dan Overhead Catenary System
P15	Maintenance of Passenger Display Unit
P16	Maintenance of Rolling Stock
P17	Maintenance of Signaling System
P18	Maintenance of Speaker System
P19	Maintenance of Tunnel, Viaduct and Building Structure
P20	Maintenance of Vibration Measuring Equipment
P21	Maintenance of PSD System

4.3 Risk Analysis of Railway Subsystem

Risk analysis is carried out for each subsystem that need maintenance activities using FMEA method considering "Severity of Effect" from class of the technical rating of HoQ Phase 2, "Probability of Occurrence" and "Detectability" (Carlson, Carl S., 2012). Occurrence and detectability are obtained from stakeholder's interview. RPN result of FMEA for all subsystems are described in Table 7.

Table 7. Risk Priority Numbers

Mainteanance Activities	Technical Importance Rating	Severity	Probability of Occurrence	Ability of Detecting Failure	RPN
P01	698.57	3	6	3	54
P02	1282.43	7	4	5	140
P03	26.86	2	3	3	18
P04	2481.48	10	2	1	20
P05	232.16	3	2	6	36
P06	896.48	5	6	3	90
P07	777.62	5	5	3	75
P08	1526.56	8	3	4	96
P09	156.95	2	3	2	12
P10	442.10	3	2	2	12
P11	326.08	3	2	3	18
P12	805.73	5	3	7	105
P13	1236.67	6	5	3	90
P14	3043.81	10	4	3	120
P15	322.54	3	5	3	45
P16	2917.43	10	5	3	150
P17	2501.24	10	4	3	120
P18	322.54	3	5	5	75
P19	656.62	4	1	7	28
P20	91.70	2	1	6	12
P21	431.29	3	7	3	63

4.4 Classification of Priority Maintenance Group

Refer to classification conducted by Saleh, et al., 2015, Figure 6 are the criteria each group maintenance criticality and the result of classification describes in Table 8.

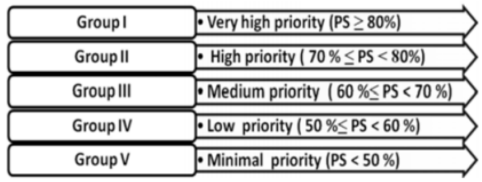

Figure 6. Criticality Group of Maintenance Activities (Saleh, et al, 2015)

Table 8. Critical Group of Maintenance Activities

Criticality Group	Code	Maintenance Activities
Very High Priority	P16	Maintenance of Rolling Stock
	P02	Maintenance of Architecture dan Interior
	P14	Maintenance of Panel 20 kV and Overhead Catenary System
	P17	Maintenance of Signaling System
	P12	Maintenance of rail track
High Priority	P08	Maintenance of Fiber Optic Networks
	P06	Maintenance of Elevator
	P13	Maintenance of M/E (Chiller, AHU, Water, Lighting, ECS System)
Medium Priority	P07	Maintenance of Escalator
Low Priority	P18	Maintenance of Speaker System
Minimal Priority	P01	Maintenance of Ticketing System
	P03	Maintenance of CCTV System
	P04	Maintenance of DB Panel 380/220V
	P05	Maintenance of Diesel Engine Generator (DEG)
	P09	Maintenance of Fire Protection System
	P10	Maintenance of Grounding dan Arrester
	P11	Maintenance of Impedance Bond
	P15	Maintenance of Passenger Display Unit
	P19	Maintenance of Tunnel, Viaduct and Building Structure
	P20	Maintenance of Vibration Measuring Equipment
	P21	Maintenance of PSD System

5. Results and Discussion

Through the survey of customer perspective on service quality attributes, it was obviously explained that customer is very sensitive to cleanliness both stations and trains. From the technical perspective it was related directly to third party performance for cleaning activities. Other than that cleanliness inside train or at stations also a result from the good condition of infrastructure (station building and train). So that, it was in line with the result of criticality group "very high priority".

Refer to the result of HoQ Phase 1 and 2, power system or called "Panel 20KV and Overhead Contact System" has been determined as the highest priority. It can be accepted since power system has been the backbone for automated rail industry. It also confirmed by the company that power system has been the biggest cost in railway industry. It has been invested with advanced technology to monitor the performance and become a great disruptor to service operation and customer satisfaction.

Ranking of the priority from HoQ Phase 2 and RPN is slightly different especially in the top rank of subsystem. It may be caused by the ability of detection failure from the train or rollingstock due to the lack of in station (before processing) notification. Moreover, for architectural parts which has played major role to perform station cleanliness, there has no system to detect the failure. Only rely on the supervision from the station officers which regularly going around to observe station condition.

Based on the priority, the most advanced maintenance policy should be adopted by the "very hight priority" because it already considered risk and the cost damage may be caused if the system failed to operate. As mentioned in research from Glawar et al., 2016, maintenance policy generally classified into 4 terms, Corrective Maintenance (CM), Preventive Maintenance (PM), Condition Based Maintenance (CBM), and Anticipated Maintenance (AM). The first three also being metioned by (Velmurugan and Dhingra, 2015) to develop their conceptual framework of maintenance selection. Result from the Analytical Hierarchy Process and Goal Programing of the maintenance policy options, Arunraj and Maiti, 2010, explain that CBM was appropriate the most to system with highest critical risk consideration. Preventive Maintenance, Corrective Maintenance, and Shutdown Maintenance are considered for the lower priority risk respectively (Arunraj and Maiti, 2010). Therefore, for each subsystem, maintenance policy recommended as describe in Table 9. Company may reallocate the maintenance budget over the whole system by investing or rearrange the number of personnel from one system to another. This classification also need to be followed by the spart parts inventory policy for each subsystem.

Table 9. Maintenance Policy Recommendation

Policy	Maintenance Activities
Condition Based Maintenance	Maintenance of Rolling Stock
	Maintenance of Architecture dan Interior
	Maintenance of Panel 20 kV and Overhead Catenary System
	Maintenance of Signaling System
	Maintenance of rail track
Preventive Maintenance/ Time Based Maintenance	Maintenance of Fiber Optic Networks
	Maintenance of Elevator
	Maintenance of M/E (Chiller, AHU, Water, Lighting, ECS System)
Shutdown Maintenance	Maintenance of Escalator
Corrective	Maintenance of Speaker System

Policy	Maintenance Activities
Maintenance	Maintenance of Ticketing System
	Maintenance of CCTV System
	Maintenance of DB Panel 380/220V
	Maintenance of Diesel Engine Generator (DEG)
	Maintenance of Fire Protection System
	Maintenance of Grounding dan Arrester
	Maintenance of Impedance Bond
	Maintenance of Passenger Display Unit
	Maintenance of Struktur Beton dan Baja
	Maintenance of Vibration Measuring Equipment
	Maintenance of PSD System

6. Conclusions and Future Research

Throughout this study, maintenance policy has been selected by consideration to service quality and failure risk of the system. By using two phases of QFD and FMEA principle comprehensively, maintenance policies can be derived as priority basis so that company may not be burdensome of the maintenance cost. Using this scheme also can be increased the accuracy of "severity" when analyzing risk using FMEA. Priorities also made by considering the technical capability in terms of detecting the failure. When the system as is has already been adopted advanced monitoring or inspection equipment so that the number of detectability rating can be decreased as well as the risk priority number. However, this framework already consume time to calculate and gather the responses of technical rating. It will be great if there is automated model which can be used regularly and also to monitor the 'probability of occurrence' which may be changed over the time being.

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