Maintenance Performance Evaluation of an RCM Implementation: A Functional Oriented Case Study

H. Supriyanto, N. Kurniati, and M. F. R. Supriyanto
Department of Industrial and Systems Engineering, Faculty of Industrial Technology and Systems Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
Email: hariqive@ie.its.ac.id, nanikur@ie.its.ac.id, ferdian.work@gmail.com

***Abstract*— Maintenance is a core function of production, necessary for keeping production systems running and avoiding failures. In reliability centered maintenance (RCM), maintenance is implemented based on concrete evidence reduces equipment failure rates, and increase competitive advantage and customer satisfaction. The maintenance strategy starts by collecting data to evaluate the functionality, condition, performance, and health of equipment, and our aim is to analyze maintenance performance, and identify potential indicators, to ensure that the maintenance sector is competitive, and efficient. Failure mode effect and Analysis (FMEA) is used as a tool to support RCM information worksheets and determine the functions of components, and failure, the cause of failure, and its consequences. These factors are used to determine the maintenance intervals of parts in a cooling water pump. The program to achieve these goals is supported by organization.**

***Index Terms*—maintenance, failure, function, RCM, FMEA**

I. Introduction

Global growth and competition have caused tremendous change in manufacturing, and this change has influenced the concept of *maintenance*, making it more essential for business sustainability. In the past, maintenance was a supporting sector; however, it now occupies a strategic position. The main reason for *this* is that machinery and equipment must meet the plans and expectations of a company.

The maintenance of the production systems is the most crucial area of the business environment, the increased ability to identify failures has *helped* to improve quality, productivity, and profits by changing the manufacturing paradigm. Some of the factors that are considered to be priorities for winning market competition are demand, delivery, reliability, quality, and flexibility, which are increasingly dynamic. In addition to the management of maintenance, personnel, production planning and control processes are needed [1]. Competition for increasingly volatile world markets, especially in manufacturing-based industries, hence, efforts are being continuously made to improve quality, reduce costs, and encourage industry to offer various products with better services [2], [3]. Maintenance is the main challenge for a company that is committed to integrating production and installation under one roof to achieving business goals. Maintenance is the main problem, to achieve this goal; it can help decrease costs and a positively impact business performance [4], [5]. Within a competitive environment, with modern management and production systems that are efficient, economical, and profitable, maintenance can reduce failure, and enhance quality, and productivity, without interfering with organizational results [6], [7]. Here, organizational performance relates to the research, improvements in methods and procedures, that subsequently allow organizational changes and policies for innovation and continuous improvement. The models used, including total quality management, just-in-time, and supplier collaboration, support the development of this continuous improvement [8]–[10]; for the production system to work without waste, the maintenance system must effectively and efficiently operate. The maintenance of production equipment is associated with return on investment; maintenance techniques and strategies will prevent equipment failures, increasing the availability and reliability of operations to eliminate unplanned equipment downtime.

Maintenance models are grouped according to whether they are preventive, corrective, or total productive maintenance (TPM) [11]. Preventive maintenance can be time-based (operational time and calendar-based) or condition-based (periodic inspections and continuous monitoring). Corrective maintenance comprises planned and unplanned corrections.

TPM integrates all actions within an organization by changing the traditional management model through waste elimination, continuous problem finding, improvement of production processes and quality, increasing capabilities, of people, and transforming companies to achieve greater competitiveness [12]. Corrective maintenance is used for cases where process maintenance is expensive; however, it runs the risk of downtime and unexpected production reductions. One acceptable method of corrective maintenance is that based on reliability; this method is used to ensure the

Manuscript received December 23, 2020; revised February 18, 2021.

doi: 10.18178/ijmerr.10.12.702-709

confidence of production facilities [13]. This technique is known as reliability-centered maintenance (RCM). RCM is used to ensure that maintenance requirements are met, for each elemental asset, and each operation. RCM identifies the functions of a system, its physical assets, and the equipment that fails when in conducting operations. RCM also uses this information to optimize maintenance strategies. RCM mainly focuses on the functions of the system, and minimizing maintenance costs while increasing reliability and security is main goal of RCM. The concept of RCM is simple and is categorized as organized engineering. This concept has four activities, (i) identification and assignment functions, (ii) identification of the failure mode for each function that caused the malfunction, (iii) prioritization of functional risks (via failure modes), and (iv) use of preventive maintenance [6]. The RCM implementation program focuses on the functioning of the system or equipment and analyzes compliance with requirements.

II. Literature Review

A. Reliability Centered Maintenance

Much literature shows that RCM can be used to rationalize and systematize sufficient tasks and that RCM is widely adopted for maintenance plans. The aim is to guarantee the reliability, and operational safety of equipment, and installations, at low cost [14]. RCM is performed to protect the functionality of equipment by determining its. RCM is based on the principle that all maintenance tasks must be correct before they are executed [15], [16]. There are many contemporary maintenance techniques, but RCM has penetrated almost activities for maintaining the functionality of physical assets. Starting in the American aviation industry, RCM has been implemented in many modern economic sectors, to increase efficiency, productivity, environmental preservation, and industrial competitiveness. The concept of customized maintenance increasingly popular, and companies strive to always follow it [17], [18].

RCM II is a refinement of the RCM strategy to determine activities for guaranteeing physical assets of a company and the operations a company. These criteria, as well as the availability, security, and cost effectiveness of delaying or preventing failure modes, are the main characteristics for assigning maintenance tasks; this can guarantee the operational performance of a plant while more accurately evaluating the functions of productive equipment in all system components [19], [20]. Failure mode effect and analysis (FMEA) is the most efficient tool for recognizing cost effective solutions, and preventing failures. FMEA is a deductive technique, consisting of identifying the failure mode of each component and the consequences for the whole system; it starts by surveying the functionality of each component, and the effect of the failure [21]. Maintenance makes continuous improvements in equipment to reduce operating costs, reduce product defects, and increase productivity; therefore, the cost-effectiveness of each corrective action can be checked by always evaluating costs before and after repairs. Many companies have implemented maintenance to increase profitability and process performance [7], [19].

B. Maintenance Performance Measurement

Performance is the level of achievement of a goal. It is defined as a measurement with realistic baselines and targets for facilitating the decision-making process for subsequent actions to create value along the business process. Maintenance performance is measured in terms of mean time to failure (MTTF) and mean time to repair (MTTR), as well as production level indices; productivity indicators for maintenance can measure the use of resources, such as materials, labor, tools, and equipment [22], [23]. Currently, maintenance is measured based on maintenance performance, which is linked to financial audits, and physical assets; this means that all data from financial and nonfinancial transactions are related to maintenance performance [24], [25]. Various aspects are considered in such performance measurement, such as process performance, equipment performance, maintenance functions, maintenance work-management cycles, and cost performance, [12], [26]. Maintenance performance in the company is often not evaluated or analyzed; even the use of maintenance performance indicators is very limited. Therefore, maintenance management is essential for reducing the number of equipment failures, maximizing availability, reducing the time between repairs, improving equipment reliability, and increasing worker safety. Through maintenance management to operate equipment, investment in equipment will generate profits. Weaknesses in maintenance performance are maintenance measurement objectives that are not related to business strategy. Thus maintenance performance measurement will solely focus on operational performance, ignoring the impact of maintenance policies of the organization and the influence of other departmental functions [5].

III. Methodology

Empirical data support is required for the evaluation and analysis of maintenance [9], [27], [28]. It does not use a specific methodology for maintenance activities. The steps below will discuss the systems and structures used to evaluate and check for any production machine failures and record them in the spreadsheet. Decision diagrams are used to integrate all processes into one strategic framework for decision making. If RCM is used the following, questions must be answered:

- How is analysis compiled to maintain the functioning of the system?
- How are failure modes identified?

Failure modes must be ranked in order of importance, and the most effective maintenance tasks must be chosen. Measuring maintenance performance, is especially for industry, and attention must be taken, especially for unnecessary measurements, to be followed are as follows:

a. The literature review and field study phase;
b. The data collection phase, which consists of evaluating the causes of failure in facilities/machinery

and the impact and consequences of such failures upon the facility, machinery, production flow, workers, and MTTF;

c. The design phase, which consists of the formulation of a functional block diagram (FBD), design of FMEA using the RCM II information worksheet, and design and determination of maintenance using the RCM II decision worksheet;
d. The analysis phase, which consists of analyzing the FBD and FMEA-RCM II information worksheet and conducting maintenance using the RCM II decision worksheet;
e. The adaptability phase.

IV. RESULT

The main equipment was a cooling water pump; this pump was provided with a water tank of capacity 110 m^3. To decrease corrosion on all parts of the pump, a specific fluid was added to the water tank. Failure to operate the pump can cause the mixing process to be imperfect and affecting the quality of the final product. To obtain machines, facilities, and production equipment with high availability and good production quality, planning and scheduled maintenance are needed to avoid machine breakdown.

Scheduling is conditionally done based on the subjective judgment of a technician to prevent component failure. If a pump is found to be broken, maintenance will apply corrective action to the pump. Frequent fires at the pump motor due to improper maintenance. Some components of the cooling water pump that require maintenance include bearings, oil seals, and shafts. For such damage, the percentage of loss to engine components can reach 50%, which will disrupt the production process. Consequently, an appropriate maintenance method is needed to minimize engine failure. One method for determining maintenance policy is RCM II. This is a qualitative method used to determine the right type of maintenance activity to maintain the ability of physical assets to properly function.

The objective of RCM II is to increase the performance of equipment or physical assets through effective and efficient maintenance programs [29], [30]. The function of the pump is to move and drain liquid from a low to a high surface. Pumps can be divided into two different groups: dynamic action pumps and positive displacement pumps [31], [32].

When the tank is filled with cooling water, the pump is made ready to operate by opening the cooling water inlet valve. Certain other substances are then injected to maintain water quality following the addition of anticorrosion chemicals to the water tank. The first step in implementing RCM II is creating a FBD. Fig. 1 shows the interrelations among components in the cooling water pump.

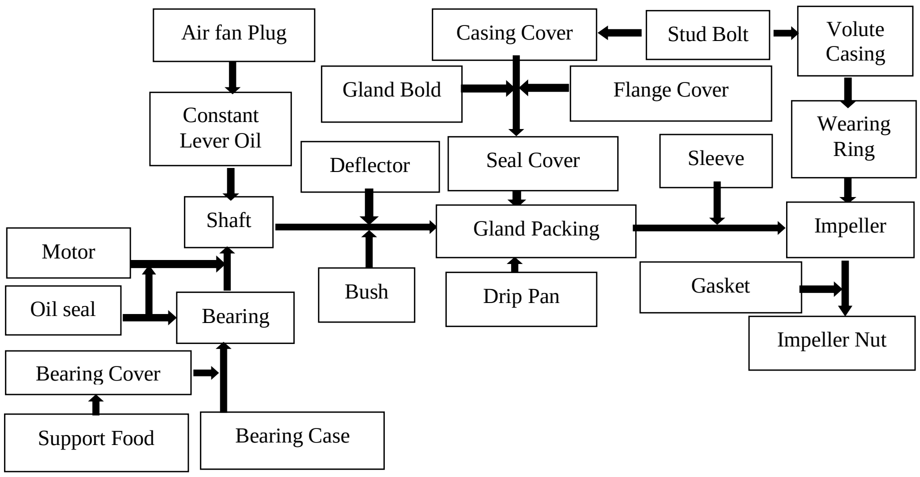

Figure 1. Functional block diagram of the cooling water pump.

The pump converts mechanical energy into hydraulic or compressed energy. This pump works based on the principle of the centrifugal force, which is an outward force generated by the rotating component, shown in Table I . The magnitude of the centrifugal force is heavily dependent on the rotational speed, mass of the object, and radius of the path [21], [33].

The FBD shows the working system of the centrifugal pump, starting from the flow of electric power to the pump motor, which serves to drive it. The rotation of the motor will be transmitted to make the shaft rotate. The shaft rotation will be supported by the bearing system as a load-bearing on the shaft. Bearings are needed to reduce friction and wear on the shaft and bearing case, and an oil seal is required to avoid leakage. The rotation of the shaft is transmitted to the impeller. Components such as shafts and impellers equipped with deflectors, and gland packings function as leak detectors at the pump. Gaskets and wearing rings are useful for preventing liquids from entering the impeller gap. The impeller rotation will carry liquid through the suction nozzle, past the volute casing, and into the discharge nozzle. Furthermore, the 10 components selected are very influential for the system functions, shown in Table II.

TABLE I. RECAPITULATION FUNCTION OF THE COOLING WATER PUMP.

No.	Comp. name	Function	No.	Comp. name	Function
1	Volute Casing	Directing the flow toward the impeller	13	Deflector	Reducing turbulence at the pump
2	Casing Cover	Shielding rotating elements	14	Level Oiler	Showing the level of lubrication in the pump
3	Support Foot	Foundation of the pump	15	Drip Pan	Leakage fluid reservoirs
4	Shaft	The successor of the rotation moment of the propulsion; supports the impeller.	16	Impeller	Sucking in the fluid and changing the mechanical energy of the pump and the velocity energy of the liquid
5	Stud Bolt	The link between the volute casing and the casing cover	17	Vane	The gate in the impeller through which fluid passes
6	Bearing	Support shaft to hold position	18	Gland Bolt	Locking between mechanical seal and casing cover
7	Bearing Case	Houses bearing system	19	Air Vent Plug	Releasing air in the pump
8	Bearing Cover	Protecting the bearing	20	Impeller Nut	Locking the impeller in position
9	Gasket	Preventing fluid from flowing into the engine when operating	21	Gland Packing	Seals fluid in the impeller so it is passed out the discharge nozzle
10	Oil Seal	Sealing lubricant in bearing systems	22	Seal Cover	Seal protector
11	Flange Cover	Protects flanges	23	Bush	Reducing friction
12	Wearing Ring	Preventing leakage due to gaps between the casing and impeller	24	Sleeve	Protecting shafts from tightening mechanical seal screws

TABLE II. RCM II RECAPITULATION INFORMATION WORKSHEET.

RCM II information worksheet			Cooling water pump	Production process	
No.	Comp.	Function (F)	Functional failure (FF)	Failure mode (FM)	Failure effect
1	Bearing	Supports shaft to remain in position	Fails to support shaft; direct contact with metal occurs	Overloading in the pump	Noise and vibration at the pump
2	Vane	The gate in the impeller through which fluid passes	Cooling water flow is not perfect	Dirty vane	Decreased pump performance
3	Shaft	The successor of the turning moment of the force and position of the impeller	Cannot perfectly proceed rotate moments	Shaft unbalance	Bearing temp. increase, vibration, noise
4	Oil Seal	Pressure indicator	No pressure detection device in water	Oil gauge is leaking	Lubrication does not circulate
5	Gearbox	Transfer and changes power from a rotating motor	Becomes clogged, a failure to the oil seal	Gearbox abrasion	High noise in the pump
6	Oil Gauge	pressure indicator	no pressure detection device on water	Oil Gauge is leaking	the lubrication does not circulate
7	Gland Packing	Controls fluid leakage	Fails to block water from entering the pump	Packing is leaking	Seepage in cooling water
8	Wearing Seal	Minimizes failure due to gaps between the casing and impeller	Fails to prevent direct contact between impeller and casing	Loose seal	Pump flow is blocked
9	Gasket	Prevents leakage due to gaps in the casing and impeller	Fails to block the fluidfrom entering the pump	Gasket is leaking	Water enters the pump
10	Motor	Converts electrical energy into motion energy	Fails to convert electrical energy into motion energy	The motor cannot start	Motor on fire

The next stage is the preparation of the decision worksheet for the components of the cooling water pump. The construction of the decision worksheet will yield the base of the previous decision diagram. From the decision diagram, the consequences of failure modes from the FMEA are evaluated, shown in Table III. The consequences contained in the decision worksheet include hidden failure (H), safety (S), environmental (E), operational (O), and nonoperational (N) consequences [19], [34]. Furthermore, the evaluation of the worksheet will determine the proper maintenance activities for each engine component in the cooling water pump.

Based on the decision diagram, some maintenance activities are specified for the condition task, scheduled restoration task, scheduled discard task, failure-finding task, and no-maintenance task [6]. The information reference contains information obtained from FMEA; this consists of functions(F), failure functions (FF), and failure modes (FM). Following this, the preparation of the decision worksheet of the cooling water pump component will be shown in Table IV.

TABLE III. PROACTIVE TASK REQUIREMENTS.

Proactive task	Proactive task requirements
H1/S1/O1/N1 Scheduled on Condition Task	Early symptoms of failure with early detection. Monitoring carried out to reduce functional failure, and take preventive measures.
H2/S2/O2/N2	The majority of components can survive at that age.
Scheduled Restoration Task	It is identified by the addition of the failure speed.
H3/S3/O3/N3	It is identified by the addition of the failure speed
Scheduled Discard Task	The majority of components can survive at that age.
H4/S4/O4/N4	Component detection must be performed to find hidden failures.
Scheduled Failure Finding Task	Tasks assigned to components can reduce multiple failures.
H5 Redesign	Hidden failure prevented by changing the design of the engine
S4 Combination Task	Safety effects prevented by combining activities between proactive tasks.

TABLE IV. RCM II DECISION WORKSHEET RESULTS.

RCM II worksheet		Subsystem: cooling water pump										Date	
Information reference		Consequence evaluation				H1	H2	H3	Default action			Proposed task	Can be done by
						S1	S2	S3					
No	Equipment	H	S	E	O	E1	E2	E3	H4	H 5	S4		
						O1	O2	O3					
1	Bearing	Y	N	N	Y	N	N	Y				Scheduled discard task, new bearing	Operator
2	Vane	Y	N	N	Y	N	N	Y				Failure finding interval, checking vane	Operator
3	Shaft	Y	N	N	Y	N	Y					Scheduled restoration task, repairs	Operator
4	Oil Seal	Y	N	N	Y	N	N	Y				Scheduled discard task, new oil seals	Operator
5	Gearbox	Y	N	N	Y	N	N					Failure finding interval, checking	Operator
6	Oil Gauge	Y	N	N	Y	N	N	Y				Scheduled discard task, new	Operator
7	Gland Packing	Y	N	N	Y	N	N	Y				Scheduled discard task, new packing	Operator
8	Wearing Seal	Y	N	N	Y	N	N	Y				Scheduled discard task, new seal	Operator
9	Gasket	Y	N	N	Y	N	N	Y				Scheduled discard Task, new gasket	Operator
10	Motor	N				N	Y					Scheduled restoration task, repair	Operator

Data are obtained from historical and direct observations of engine failure; this is the time-to-failure data, shown in Table V. This data is processed to obtain the best distribution fitting (Weibull ++ 6 software) and calculate the MTTF for each component.

This MTTF value is used to determine the appropriate maintenance interval for the component, shown in Table VI.

Below are some MTTF calculations from the components in the cooling water pump. Here, for the two-parameter Weibull distribution, the bearing components have Eta (η): 3,741,23 and Beta (β): 2,12. The MTTF bearing components are = η x Γ(1+ 1/β) = 3,741,23 x Γ(1+ 1/2,12) = 3,313,61. This means that the MTTF value of the bearing component 3,313,61 hours. Likewise, for MTTR, data are obtained from historical and direct observations. Here, for the two-parameter Weibull distribution, the bearing components, Eta (η): 3,9 and Beta (β): 4,74. MTTR = η x Γ(1+ 1/β) = 3,9 x Γ(1+ 1/4,74)= 3,574. This means that the MTTR value of the bearing component is 3,574 hours, shown in Table VII.

TABLE V. TIME TO FAILURE.

Time to Repair	Bearing	Vane	Shaft	Oil Seal	Gear box	Oil Gauge	Wearing Seal	Gland Packing	Gasket	Motor
1	0	0	0	0	0	0	0	0	0	0
2	2.5	2	3.5	1.89	2.5	1.34	2	2.76	4.45	4.45
3	3	3	4	2	3.5	2	2.99	3.64	4.5	3
4	3.25	3.5	4.45	2.15	5	3.58	3.42	4.45		
5	4	3.5	3.5	3.56	3	3.62	3.88			
6	4.35	3.5	4	4.23	4	3.76	4.73			
7	4.42	4.45	3	5		4.43				

TABLE VI. MEAN TIME TO FAILURE (MTTF)

No	Component	Distribution	η	β	μ	σ	Rho	MTTF
1	Bearing	Weibull 2	3,741.,23	2,12			0,96	3,313,61
2	Vane	Normal			2,936	1541.17	0,93	2,935,99
3	Shaft	Weibull 2	4,194,82	1,76			1	3,731,72
4	Oil Seal	Lognormal			7,94	0.61	0,99	3,391,24
5	Gearbox	Lognormal			8,23	0.64	0,97	4,575,48
6	Oil Gauge	Normal			2,842,17	2.137.84	0,99	2,842,17
7	Gland P.	Lognormal			8,38	0.05	0,99	4,347,15
8	Wearing Seal	Lognormal			8,17	0.28	0,96	3,678,36
9	Gasket	Weibull 2	6,705,15	3,77			1	6,064,13
10	Motor	Weibull 2	4,798,09	2,15			1	4,249,19

TABLE VII. MEAN TIME TO REPAIR (MTTR)

No	Component	Distribution	α	η	β	μ	λ	σ	ɤ	Rho	MTTR
1	Bearing	Weibull 2		3,9	4,74					0,98	3,574
2	Vane	Normal				3,33		0,85		0,94	3,325
3	Shaft	Weibull 2		3,96	7,85					0,98	3,719
4	Oil Seal	Weibull 2		3,5	2,73					0,92	3,117
5	Gearbox	Log normal				1,25		0,31		1	3,667
6	Oil Gauge	Weibull 2		3,55	2,41					0,95	3,152
7	Gland P.	Weibull 2		3,98	4,02					1	3,614
8	Wearing Seal	Weibull 2		3,81	3,24					0,99	3,418
9	Gasket	Weibull 2		4,49	11,3					1	4,466
10	Motor	Weibull 2		4,17	3,21					1	3,740

The calculation of the MTTF for each component varies; the highest MTTF is for the gasket (6,064,13 hours), and the lowest MTTF is for the oil gauge (2,842,17 hours). Likewise, for MTTR, the highest is for the gasket (4.466 hours), and the lowest is for the oil seal (3,117 hours). These MTTF and MTTR values are used to determine the proposed maintenance task and maintenance calendar. The maintenance recommendation method with RCM will sort out maintenance based on the maintenance time of each component. Some components undergo maintenance twice in one year; other components can go an entire year without maintenance.

The identification and selection of maintenance tasks is the most appropriate maintenance program because it is based on the criticality of components and their failure modes. Companies need to select a maintenance methodology based on identifying dependencies in the FBD and task requirements. The task of preventive and predictive maintenance aims to define a maintenance calendar to reduce the risk of failure.

V. CONCLUSIONS

The concept of RCM presented in this paper results in better quality, offering a competitive advantage. With the application of RCM, selecting critical equipment using FMEA is possible. The involvement of operators for the RCM program indicates the increasing control and operational requirements of the equipment. RCM is a proven methodology that successfully achieves company goals. Training and certification of maintenance staff are essential for measuring performance. The availability of spare parts is optimized, thereby reducing costs. RCM also allows all tasks to be planned, thereby reducing overtime. This paper how's six components of preventive maintenance with scheduled discard tasks, three components with failure-finding intervals, and two components with scheduled restoration tasks.

The concept of adaptability, and customized maintenance, using the RCM framework presented in this paper, is described to initialize the RCM its implementation. The first step in of implementing RCM is manual documentation, which is then transferred to the base computer system. Thus, preparing an adapted concept is necessary so that if the any changes that occur will suit the needs of the company. RCM is a proven methodology for achieving company goals.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

In writing this paper, each author has their respective duties, although in general, all authors participate together to complete this paper. Supriyanto and Kurniati separately and together prepare the material to be written, analyze and prepare the scriptwriting. Jointly carry out data processing, analysis and complete this paper.

ACKNOWLEDGMENT

The author would like to thank the Department of Industrial and Systems Engineering - faculty of Industrial Technology and Systems Engineering for all material and financial support.

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H. Supriyanto, born in Trenggalek, February 23, 1960. He got the bachelor degree from S1 Mechanical Engineering ITS, Surabaya and continued his Masters in Industrial Engineering ITB Bandung, in 1992. He is a permanent and senior lecturer in the Department of Industrial Engineering from 1985 until now. He is devoted to quality improvement for manufacturing and service and gives lectures on manufacturing processes, quality control technique, reliability and quality improvement, and six sigma so that the research is not far from quality improvement.

N. Kurniati is a fulltime Faculty Member at Department of Industrial and Systems Engineering, Institut Teknologi Sepuluh Nopmeber (ITS) Indonesia. She got the PhD degree from Department of Industrial Management, National Taiwan University of Science and Technology (NTUST), Taiwan. She earned B.S in Industrial Engineering from Institut Teknologi Sepuluh Nopember (ITS) Indonesia, and Masters in Industrial Engineering and Management from Institut Teknologi Bandung (ITB) Indonesia.

Her research interests include quality engineering, reliability engineering, maintenance management, data analytics for manufacturing, and warranty analysis. Currently she is the Deputy of Chairman at Department of Industrial and Systems Engineering, ITS.

M. F. R. Supriyanto was born in Surabaya, October 9, 1989, taking an undergraduate education majoring in Economics and then continuing his master's education in accounting at UNAIR Surabaya Indonesia. Now he is continuing his doctoral education, and a side job as a free teacher.