AN ANALYSIS AND DESIGN OF PREDICTIVE MAINTENANCE SYSTEM USING ASSOCIATION RULE MINING IN MOULDING MACHINE PT X

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BOGOR
2015

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ABSTRACT

IMAM MUHARAM ALITU. An Analysis and Design of Predictive Maintenance System Using Association Rule Mining in Moulding Machine PT X. Supervised by: TAUFIK DJATNA

One of the challenges in the implementation of Total Productive Maintenance (TPM) in the manufacturing industry is a slow managerial decision-making to respond the condition in the factory. This research investigates the answers of these challenges by analyzing and modeling the equipment condition and the response of actions required in a wooden door manufacturing industry. TPM implementation in this company has deployed the Overall Equipment Effectiveness (OEE) measurement as an indicator of the equipment utilization and condition. Through an analysis and modeling of the OEE value obtained from the factory, the formulation of Association Rule Mining (ARM) aims to find a rule that shows the well computed relationship between measurable indicators of OEE with the response of action required to take in certain condition of machine utilization. Results obtained from ARM accelerate the decision to establish an appropriate TPM management strategy based on the rules. The generated dynamic rules form and facilitate the process of decision-making by related stakeholders. Furthermore, relying on these rules the action taken by the company induced to a higher reliable and increasing the effectiveness of response and efficiency of time and costs.

Keywords: *Overall Equipment Effectiveness, Association Rule Mining, Data Mining, Total Productive Maintenance*

ABSTRAK

IMAM MUHARAM ALITU. Analisis dan Perancangan Sistem *Predictive Maintenance* Menggunakan Association Rule Mining pada Mesin Moulding PT X. Dibimbing oleh: TAUFIK DJATNA

Salah satu tantangan dalam pelaksanaan *Total Productive Maintenance* (TPM) dalam industri manufaktur adalah pengambilan keputusan manajerial yang lambat untuk menanggapi kondisi di pabrik. Penelitian ini menjawab tantangan tersebut dengan menganalisis dan memodelkan kondisi peralatan dan respon tindakan yang diperlukan dalam industri manufaktur pintu kayu. Implementasi TPM di perusahaan ini telah menggunakan *Overall Equipment Effectiveness* (OEE) sebagai indikator pengukuran pengukuran penggunaan dan kondisi peralatan. Melalui analisis dan pemodelan dari nilai OEE yang diperoleh dari pabrik, perumusan *Association Rule Mining* (ARM) bertujuan untuk menemukan aturan yang menunjukkan hubungan di antara indikator terukur dari OEE dengan tindakan yang diperlukan untuk diambil dalam kondisi tertentu pada penggunaan mesin. Hasil yang diperoleh dari ARM mempercepat pengambilan keputusan untuk menetapkan strategi manajemen TPM yang tepat berdasarkan aturan yang telah dibuat. Aturan dinamis yang dihasilkan membentuk dan memfasilitasi proses pengambilan keputusan oleh para pengambil kebijakan terkait. Selanjutnya, mengandalkan aturan ini tindakan yang dilakukan oleh perusahaan diharapkan untuk lebih dapat diandalkan dan meningkatkan efektivitas tindakan yang diambil dan efisiensi waktu dan biaya.

Keywords: *Overall Equipment Effectiveness, Association Rule Mining, Data Mining, Total Productive Maintenance*

AN ANALYSIS AND DESIGN OF PREDICTIVE MAINTENANCE SYSTEM USING ASSOCIATION RULE MINING IN MOULDING MACHINE PT X

IMAM MUHARRAM ALITU

Undergraduate Thesis
as partial fulfillment of the requirements
for the degree of Bachelor in Agricultural Technology
in the Agroindustrial Technology Study Program

DEPARTMENT OF AGROINDUSTRIAL TECHNOLOGY
FACULTY OF AGRICULTURAL TECHNOLOGY AND ENGINEERING
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PREFACE

Praise to Allah *Subhanahu Wa Ta'ala* for His blessings and generosity given to me, so I can stand a chance for completing my work as a requirement to achieve an academic title of Bachelor of Agricultural Technology from Department of Agroindustrial Technology, Bogor Agricultural University. Peace be upon Prophet Muhammad *shallallahu 'alaihi wa sallam* and all of his best friends for giving the inspiration and being the most suitable figures to be followed.

About one years ago, I took a capstone course as my research. At that time, I believe that everything will be normal. But, it turned out to be a long battle against my procrastination habit and the self-limitation. It pushed myself into a different level and taught me a new knowledge, and a new perspective to solve the issues around myself. For all of that, I would like to express my sincere appreciation to Dr Eng Taufik Djatna STP MSi, not only for his support and patience in supervising me to conduct the research, but also for his guidance for my personality improvement.

My deepest love and appreciation is for my parents, Wisno A. Alitu and Rahmin Utia, for their love, support, and pray for me, to pursue my dream overseas to get a higher and better education. I would like to thank my beloved siblings Ikram Syawal, Aqila Fitri, and Atikah Nursyawal for their encouragement and inspiration to complete my study. Wish you all always under protection of Allah *Subhanahu Wa Ta'ala.*

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Truth be told, this undergraduate thesis is a brief report of this long one year process. However, this undergraduate thesis cannot shows the long way spent in lab with my research fellow, Denny Rahmady, Raja Ihsan, Yudhistira Chandra, Delmar Zakaria, and Septian Ventura. It cannot visualize the hard time of internship program with Alfiyan Hudan and Hanif Pramudya. It cannot shows the three years joy of life in Kopadjo with Bagas Sakti, Aji Wibowo, Tio Nandika, Rian Wijaya, Irkham Triaji, and Andika Rachman. It cannot beat my Dota party Irham Raenaldi, and Ade Supriatna. It cannot replace the code jam of MAPRES 2014 Purwa Ari, Ajeng Rosecha, Hardianti Achas, Nabila An Nadjib, Salman Al Farisi, Putri Wulandari and our supervisor Isma Apupianti. It cannot erase the memories with AF2013 organizing committee Ari Adinugraha, Fadila, Reza Rochili, Zefika Zahlinar, Camelia Hilma, Ian Nurdiansyah, and the others crew. Thank you all for supporting me to pursue this degree along with all members of Tinformers, P2, Matatta, Himalogin, Matipala, and Labkom fellow.

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Finally, thanks to you to be a reader of my thesis. I wish this work will give a benefit for all of us. Correction and recommendation are gladly accommodated for the sake of science and knowledge. Because Steve Jobs says: "Stay hungry. Stay Foolish."

Carpe diem. Cogito ergo sum.

Bogor, June 2015

Imam Muharram Alitu

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INTRODUCTION

Background

As one of the global company in wooden door manufacturing industry which is located in Gunung Putri, West Java, PT X sells high-variation products that are fully exported across the world to fulfill market demand. It has been identified during internship program from June to August 2014 that with limited number of machine and limited production capacity, this high variation production leads to high a changeover rate in the main factory. To adjust the production machine from one type of product to another one, the machine must be turned off which resulted to a higher downtime. Early 2015 data from maintenance department in PT X shows that 33% of planning production time is the downtime. High percentage of downtime in this company results to a slower production rate and higher overtime.

In fact since 2013, PT X management has been implemented a Total Productive Maintenance (TPM) program to maintain the factory plant and its equipment. Defines by Nakajima (1988), as described in Wajkira and Singh (2013), TPM is manufacturing program designed primarily to maximize the effectiveness of equipment by participation and motivation of the entire workforce. TPM strategy implemented in this company is a benchmarked strategy from another manufacturing company. But, due to lack of human resources, the implemented strategy could not significantly affect the machine performance.

As a part of capstone program which leads to real industry problem solving, this research is a follow up to internship program during June to August 2014 in PT X. Using three courses from Department of Agroindustrial Technology to support the program namely Production Planning and Controlling, Operation Research, and System Analysis and Decision Making, this research aims to solve the PT X maintenance problem using structured research approach. It has been by literature review that data mining is one of the appropriate approach to solve the maintenance problem in PT X.

According to a brief explanation in Bastos *et. al* (2012), data mining techniques supports the development of predictive maintenance system to improve plant and machine condition in industry. Due to the ability to show the dependencies between attributes and define it in association rule as described in Arrahman (2011), Azima (2013), and Thamrin (2015), this research use Association Rule Mining (ARM) as a distinct method to another works, like Putri (2013) did using AHP, to solve manufacturing industry maintenance problem.

Nowadays, information and communication technology (ICT) has made much impact on everyday life. The manufacturing industry for example has experienced a major change from manual to automated manufacturing processes (Rosman *et. al* 2014). According to this fact, there is a requirement to develop the predictive maintenance system on a certain platform that can improve the system functionality and usability. Furthermore, data mining technique that is used in this research works by applying algorithms for extracting patterns from the data stored in a data warehouse. A mobile application has been developed in this research to fulfill that requirement.

The rest of this thesis is organized as follows: Chapter 2 describes the methodology of the research, the research procedure and applied theory. Chapter 3 describes the result of this research, and the explanation about the outcomes. Finally, the conclusion and recommendation for this research provided in Chapter 4.

Problem Definition

PT X has a problem with their productivity due to their ineffective maintenance system. Currently, implemented TPM strategy is required to be improved using structured research approach. By using data mining techniques to make predictive maintenance system, there is a requirement to build an information system as platform/infrastructure for the system works.

Research Objectives

This research aims to solve the problem in previous section with the following objectives:

(1) To analyze the requirement of the maintenance system in PT X
(2) To develop a predictive maintenance system based on the requirement analysis
(3) To integrate the predictive maintenance system into information system and to evaluate the functionality of the system

Research Boundaries

This research is bounded only to analyze and develop a predictive maintenance system for a PT X's moulding machine in the third line production of factory A and to build information system using the developed predictive maintenance system.

Research Benefits

The maintenance system developed in this research is a predictive maintenance system built in information system that can be used to improve maintenance system in manufacturing company, especially PT X, because this system was developed using their data. This research also provides a breakthrough solution about how data mining techniques can be used to solve operation management problem in manufacturing industry. For the author itself, this research is undergraduate thesis as a final assignment to pursue his degree in Agroindustrial Technology Department. The knowledge and experience obtained from this research, during internship program to thesis writing, has improved the author's skill itself.

METHODOLOGY

To accomplish the research objectives, a methodology was designed with structured research approach. The flowchart of this research methodology as presented in Figure 1. The research began with analyzing the research requirement and collecting data from PT X company record, especially the production department, and maintenance department to accomplish the first objective. The second objective accomplished by implementing ARM to make a predictive maintenance system. Finally, a software has been built and verified using JavaScript programming language to accomplish the third objective. All of this research process has been conducted since January to May 2015 in PT X and Bogor Agricultural University.

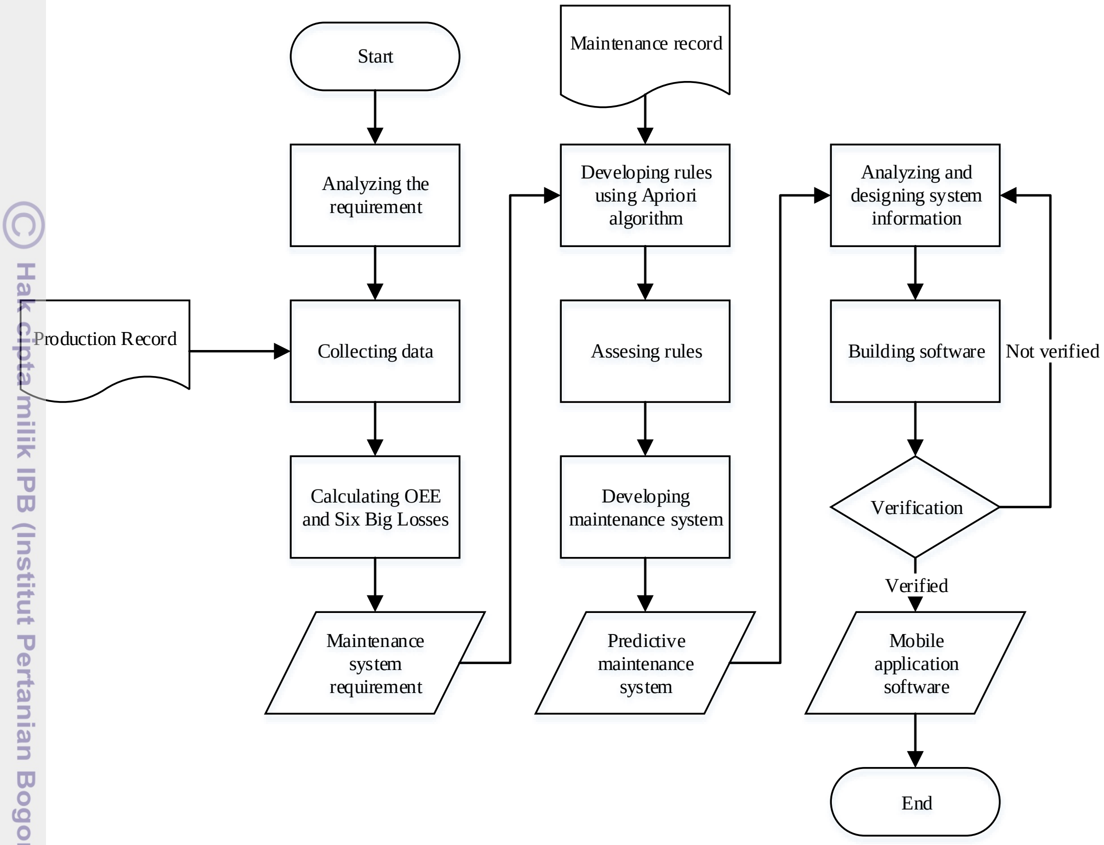

Figure 1 Research flowchart

Requirement Analysis

Requirement analysis is a method that is concerned with determining the goals, functions, and/or constraint of certain problem (Laplante 2007). In this research requirement analysis was conducted to determine the system requirement with analyze the business process of maintenance system and current condition of the machine.

System Entity Analysis

Wasson (2006) defines that system entity is one method that can represent input, process and output of system. By knowing system entity of a system, the requirement of the system can be known. The basic framework of system entity is illustrated in Figure 2. The identification of system analysis has been conducted by field observation and interview in PT X.

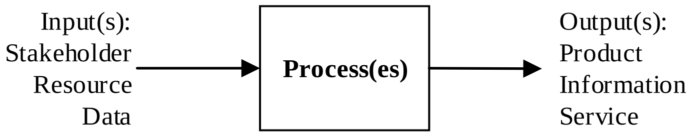

Figure 2 Basic framework of system entity

Business Process Analysis

To analyze the business process mechanism, Business Process Model and Notation (BPMN) has been made using a couple of templates in Microsoft Visio. White and Miers (2008) defines that development of BPMN aimed to identify the business process stages in detail and completely in the digital system, or in this case, predictive maintenance system. The output of this analysis are roles of each stakeholders, rules in business process, and data flow in the system.

Machine Condition Analysis

The moulding machine has been chosen as research target due to its importance as component profiler that make this machine has high changeover rate. The data used in this analysis is secondary data collected from PT X production department record. First, the data was processed with OEE measurement. OEE is a key performance index to measure the effectiveness of the used equipment, plant, or machine (McCharty and Rich 2004). The formula of OEE defined by Nakajima (1998) in McCharty and Rich (2004) is shown below.

$$OEE = A \times P \times Q \tag{1}$$

Wherein:
A : availability (%)
Pe : performance efficiency (%)
Qr : quality rate (%)

Availability means the actual available time to produce goods using a machine. Performance rate shows the products produced according to the available time. Then the quality rate concludes the good products produced along the available time into OEE score (Kumar and Suresh 2008). Each of the factors that compose the OEE formula can be calculated by processing production data and machine condition.

$$A = OT \div POT \tag{2}$$

Wherein:
OT : operating time (minutes)
POT : planned operating time (minutes)

$$Pe = RRR \div IRR \tag{3}$$

Wherein:
RRR : real run rate (pieces/minutes)
IRR : ideal run rate (pieces per minutes)

$$Qr = GP \div TP \tag{4}$$

Wherein:
GP : good product (pieces)
TP : total product (pieces)

McCharty and Rich (2004) also shows the relation of major three components of OEE, A-P-Q, with Six Big Losses. These losses are categorized by asset availability, performance and quality issues. Each of these being sub-divided under planned and unplanned loss headings, as summarized in Table 1. This relation is used to discover the main problem of the moulding machine.

Table 1 Six Big Losses classification

Type	Availability	Performance	Quality
Planned	Setup and adjustment	Reduced speed	Startup losses
Unplanned	Breakdowns	Idling and minor stoppages	Defects and rework

Predictive Maintenance System Development

Basically, three types of maintenance are corrective, preventive, and predictive maintenance. The strategy developed in this research is predictive maintenance. This research focused on predictive maintenance system than other maintenance system, like autonomous maintenance and preventive maintenance, due to the capability of data mining (Bastos *et. al* 2012). Using measurable parameters when breakdown is eminent, predictive maintenance intends to make an intervention to the machine itself or related factors before harmful events may occur (Ahmed *et. al* 2010). Data mining could clarify the relationship between the parameters and the response variable observed with intervention response that will be taken by the related stakeholder.

One of data mining techniques is ARM. Arrahman (2011) shows the implementation of ARM to determine customer relationship management strategy. Azima (2013) shows the implementation of ARM in cross-selling in a mobile application. Thamrin (2015) uses ARM to determine the relation between variable in smart packaging color indicator. All of these previous works shows the application of ARM due to its ability to show the dependencies between attributes and define it in association rule. According to facts above, ARM became the focus of this research.

Apriori Algorithm

ARM start with mining frequent items with their support values using frequent item mining algorithm like Apriori algorithm. This algorithm works over numeric or non-numeric data because the data itself will be converted into code (Zaki and Meira 2014). All of the attributes were pre-processed with discretization in a certain range. Measurable parameter like OEE measurement result was converted into antecedent code, while response activities converted into consequent code. The data of each attributes was compiled and converted into discrete binary data. Then, after combining the item-sets to combination 2-item sets up to 4-item sets, Apriori algorithm formed the candidate item set, then it generated large item set consist of rules (Agrawal and Srikant 1994). Each combination of generally called as transaction.

Rule Assessment

Although there are many rules obtained, most of the rules were discarded or eliminated due to their low value with rule assessment. Rule assessment is a method consist of different rule interestingness measures to quantify the dependence between the antecedent and consequent (Webb and Wrycza 2006). There are 4 measures used in this assessment: support, confidence, lift, and bond.

According to Zaki and Meira (2013), as example an association rule $X \longrightarrow Y$, where X is antecedent and Y is consequent, the support (sup) of this rule is defined in (5). With $|t(XY)|$ is a total of transaction contain both X and Y in a combination.

Relative support (rsup) or support value compared relatively to the size of database was defined in (6), with |D| is a total of transaction in database.

$$sup(X \rightarrow Y) = sup(X \cap Y) = |tXY| \quad (5)$$

$$rsup(X \rightarrow Y) = sup(X \cap Y)/|D| \quad (6)$$

Confidence (conf) of a rule is the conditional probability that a transaction contains the consequent Y given that it contains the antecedent X.

$$conf(X \rightarrow Y) = sup(X \cap Y)/sup(X) \quad (7)$$

Lift of a rule is a ratio of the observed joint probability of X and Y to the expected joint probability if they were statistically independent.

$$lift(X \rightarrow Y) = conf(X \rightarrow Y)/sup(Y) \quad (8)$$

Bond shows the strength of item set with comparing conjunctive (combination contain only true value) and disjunctive (total of all combination) of each transaction.

$$bond(X \rightarrow Y) = conjunc(X \cap Y)/disjunctive(X \cap Y) \quad (9)$$

All of these measures must be determined with user threshold to get qualified rules. User threshold determined with trial and error method. If the user threshold too high, the rules resulted by rule assessment is too few, and if it too low, there will be too many rules and the assessment will be uncomprehensive. The qualified rules obtained from ARM has been developed into predictive maintenance system.

System Information Design

System design is the process of planning a new business system or one to replace or complement an existing system. While the analysis specifies what the system should do, design states how to accomplish the objective (Bajaj and Wrycza 2009).

Unified Modeling Language

System design stages are conducted using Unified Modelling Language (UML) to present the visualization of information system of predictive maintenance system developed by ARM. Unified Modelling Language (UML) is a group of diagram used for visualizing a model design of a system or software (Walzawick 2013). Based on BMPN that developed in previous phase, use case, sequence, and class diagram has been made using a couple of templates of Microsoft Visio.

Mobile Application Development

As a result of components design and its interoperability. The application is developed on Intel XDK IDE (Integrated Development Environment) using JavaScript programming language, while the interface design is handled using HTML5 (HyperText Markup Language 5) and CSS3 (cascading Style Sheets 3). To store the data, a SQL database has been used. The database itself uploaded into web-hosting server to store the data on internet so it can ease the implementation on the field and increase user experience.

System Verification

Wasson (2006) defines that a system must be verified to ensure compliance with the requirements. In this research, the mobile application has been tested and the functionality of ARM model in the predictive maintenance system has been verified. The verification stages conducted by comparing the implemented system with the system requirement determined in requirement analysis.

RESULT AND DISCUSSION

Requirement Analysis

System Entity Analysis

The system entity of PT X predictive maintenance system shows that three stakeholder that will be the user of information system: machine operator, maintenance department, and PT X high-management. Using rules and pattern of machine condition, this system process inputted machine and production data into machine status defines in OEE and suggested response to be taken by user.

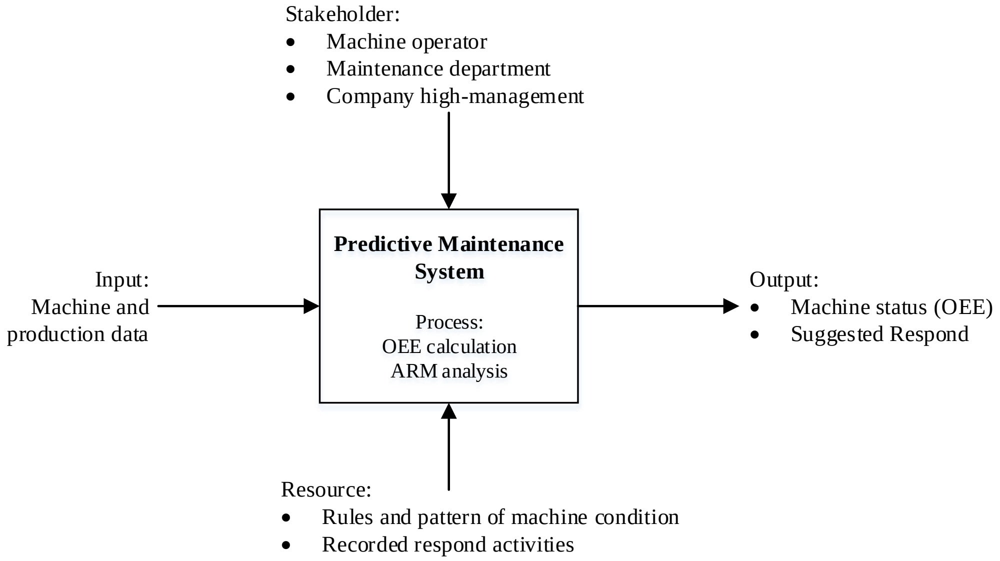

Figure 3 System entity of PT X predictive maintenance system

Business Process Analysis

Figure 4 illustrates the business process of PT X predictive maintenance system. The business process with the beginning of the production. In this system, the stakeholder that responsible to input the required data is the machine operator. The inputted data will be saved to database and shared across the user in the system. As the stakeholder that responsible to maintain the machine, equipment, and plant in the company, the maintenance department regularly check and monitor the machine condition through the system and processed data in database. If in a case the machine condition is low, the maintenance department will maintain and/or repair the machine. High management in PT X like general manager (GM), production manager, quality manager, and production planning manager evaluate the machine condition through the system. In addition, the high management could take the suggested response from the system to help in decision making process to solve the problem in the field or improve the productivity of the machine.

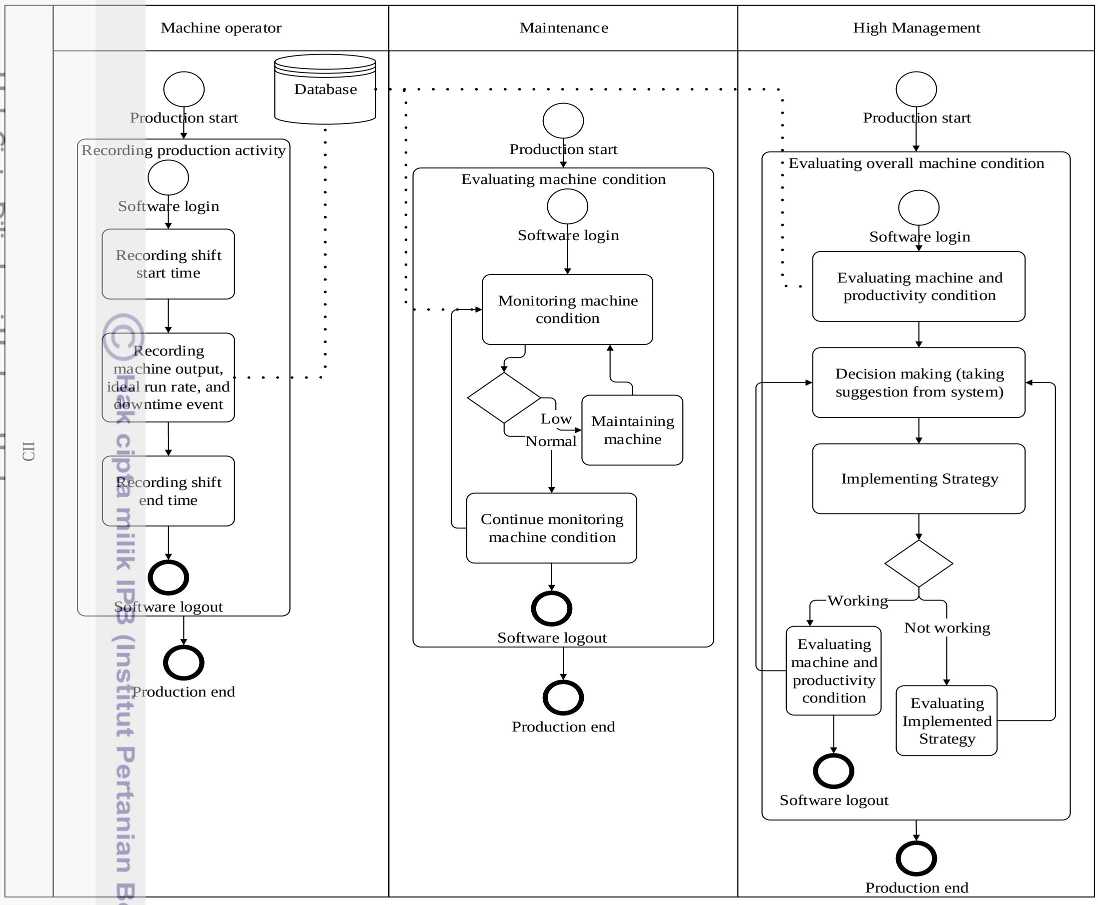

Figure 4 Business process of predictive maintenance system in PT X

Machine Condition Analysis

According to production department data of PT X for February 2015, moulding machine has average availability score 67% which is below the world class availability score 90% (Wajkira and Singh 2013). Linear trend line gradient shows negative value -0.0015, which means a declining machine's availability. An unexpected breakdown may occurs if this condition still continue that will disrupt production and lead to losses.

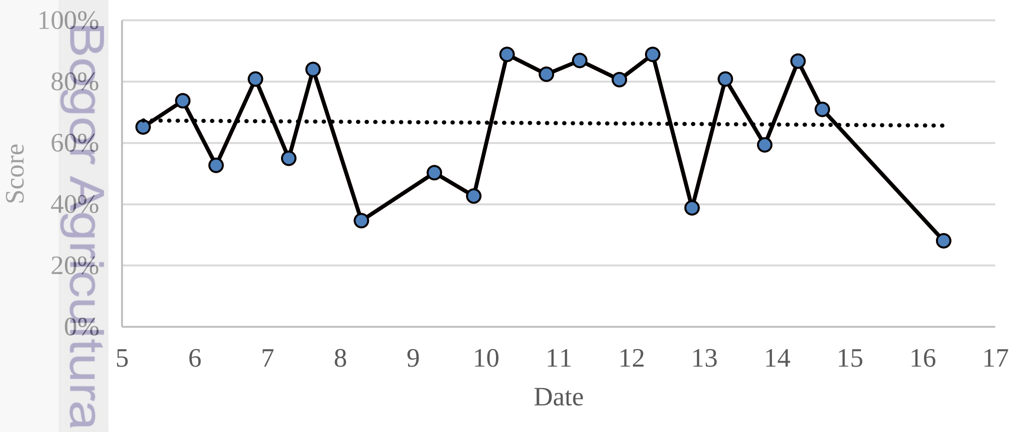

Figure 5 Moulding machine availability during February 2015

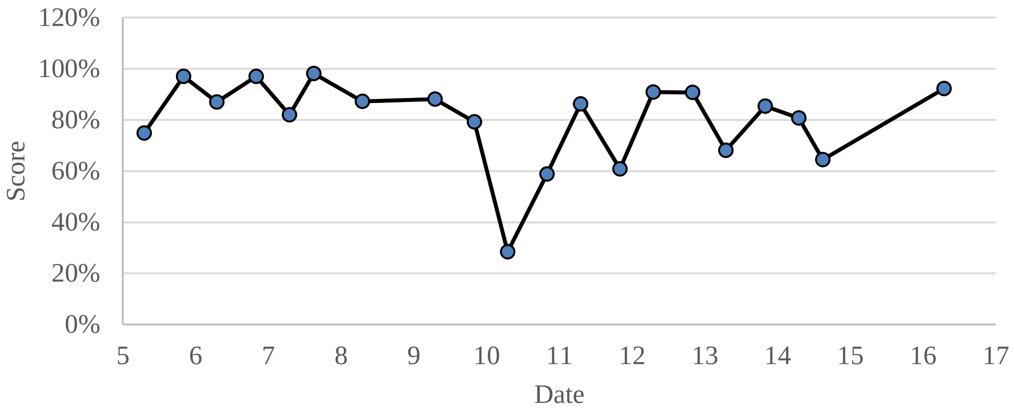

Figure 6 Moulding machine performance during February 2015

The average performance score of moulding machine is 80%, which also below world class performance efficiency. Linear trend line gradient is -0.0103 which means a declining condition of machine performance. Inefficiency in machine performance can also means a resource wasting, slow working labor, and/or low productivity.

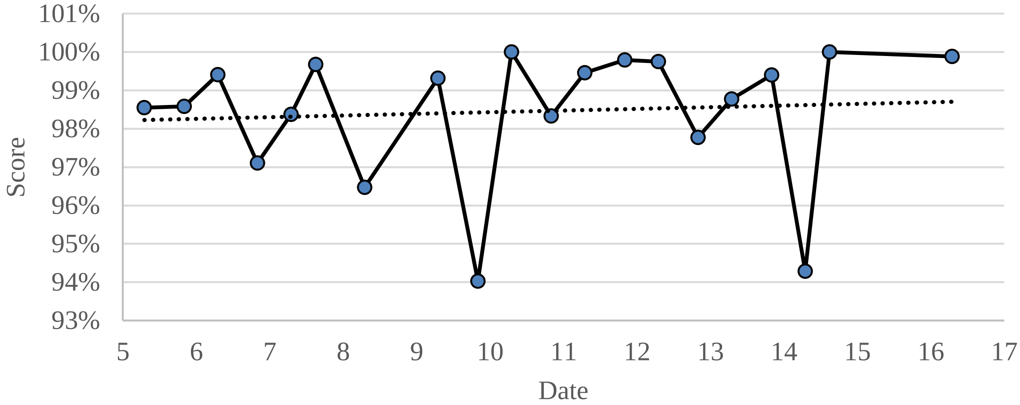

Figure 7 Moulding machine quality during February 2015

Contradicted with two previous factors, average quality score of moulding machine is 98% which is nearly approach the world class quality rate 99%. The linear trend line gradient 0.0004 shows a positive inclining of machine output quality. The positive trend also shows the successfulness of quality department in PT X that has been focused to guarantee their product quality for recent 3 years using a Total Quality Management (TQM) program.

Using three factors above, availability, performance efficiency, and quality rate, OEE of moulding machine has been calculated. Average OEE score of moulding machine is 51% which is far from world class OEE 85%, even with world average 60%. A dangerous declining OEE of the machine also shows in linear trend line gradient -0.0106. It indicates improvements are required urgently. The comparison of average score of availability, performance efficiency, quality rate, and OEE are summarized in Figure 9.

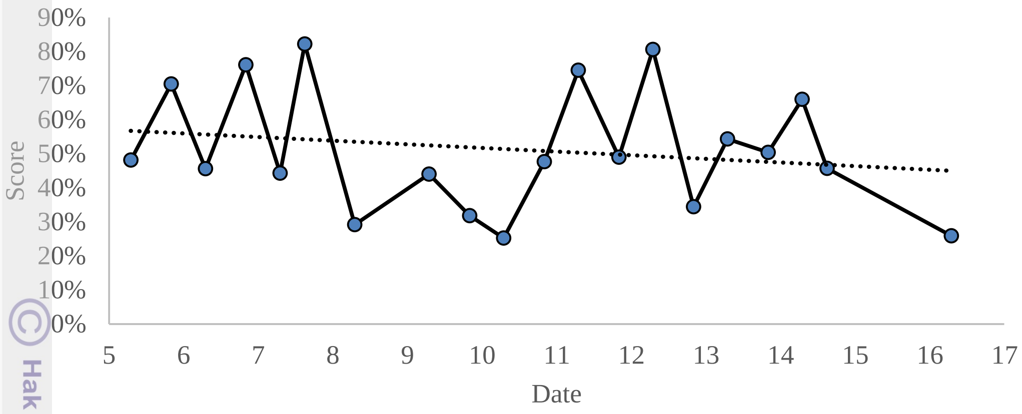

Figure 8 Moulding machine OEE during February 2015

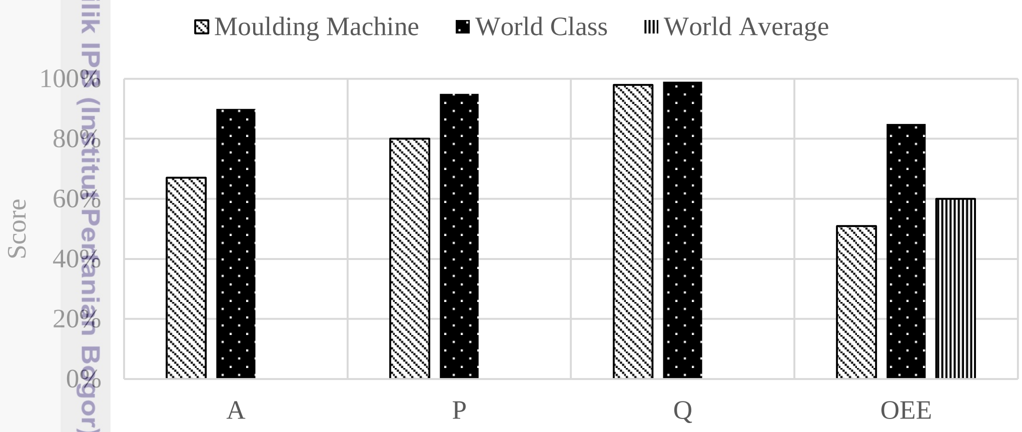

Figure 9 Average comparison of moulding machine

Assuming that quality rate not a main issue due to its positive trend and has been solved with TQM implementation, the availability and performance efficiency of moulding machine is the main reason of this low OEE. However, to find the main causes, a Six Big Losses assessment has been conducted.

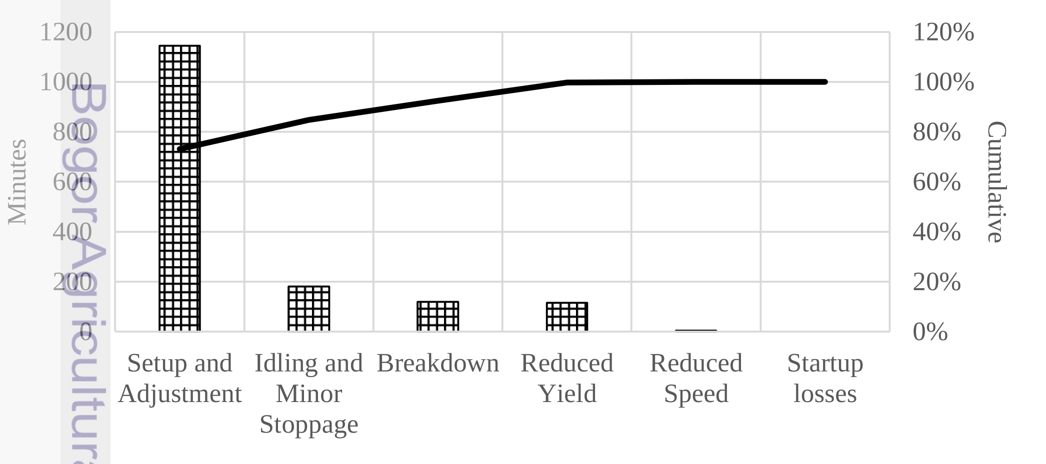

Figure 10 Pareto chart of Six Big Losses

As presented in Figure 10, according to the PT X maintenance department data, 73% of productivity loss in moulding machine is setup and adjustment loss. The setup and adjustment loss occur when the production must be stopped to prepare the machine for subsequent production (Ahmed *et. al* 2010). The causes of setup and adjustment losses has been identified and visualized using causal-effect (fishbone) diagram.

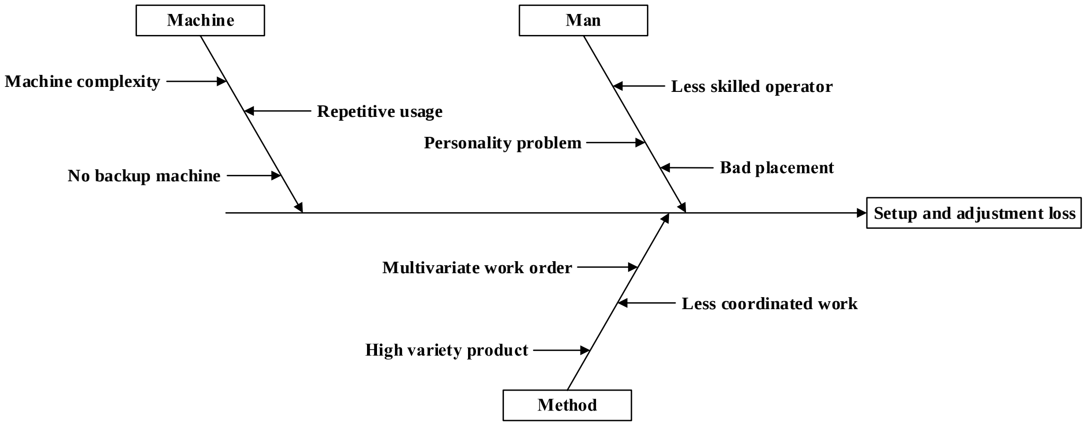

Figure 11 Causal-effect (fishbone) diagram showing setup and adjustment factors

OEE calculation, Six-Big Losses assessment, and source problem identification using fishbone diagram was aimed to identifying used machine condition, and provide a better visualization of current moulding machine condition.

Predictive Maintenance System Development

Apriori Algorithm

To ease the combination process using Apriori algorithm, every attributes has been grouped into certain range and labeled through discretization. Discretization, also called binning, converts numeric attributes into categorical ones. Discretization can also help in reducing the number of values for an attribute, especially if there is noise in the numeric measurements (Zaki and Meira 2014). The measurable parameter of moulding machine has been determined as rule antecedent, while response activities of PT X management has been determined as rule consequent.

Table 2 If (Antecedent) label

If (Antecedent)								
Parameter	Range	Label	Parameter	Range	Label	Parameter	Range	Label
Setup and Adjustment per day	0-25% DT*	S1	Availability (Av) per day	0-40	A1	Quality rate (Qr) per day	<90	Q1
	26-50% DT	S2		40-60	A2		90-95%	Q2
	51-75% DT	S3		60-90	A3		95-99%	Q3
	76-100% DT	S4		>90%	A4		>99-100%	Q4
Material Delay per day	0-25% DT	M1	Performance efficiency (Pe) Occurrence per day	0-40	P1	OEE per day	0-40%	O1
	26-50% DT	M2		40-60	P2		41-60%	O2
	51-75% DT	M3		60-95	P3		61-85%	O3
	76-100% DT	M4		>5%	P4		>85%	O4
Break Down per day	0	B1	Setup Occurrence per day	0-5 x	C1			
	1x	B2		6-15 x	C2			
	>1x	B3		>15 x	C3			

*DT=Down Time

The used attribute in antecedent code is determined according to the OEE calculation of field data. While according to the requirement analysis using fishbone diagram in previous phase, the response target has been determined into three object: the moulding machine itself, the machine operator, and the used method included the implemented production strategy. The response activities has been classified by defining the source problem into an actionable activities, as presented in Table 3.

Table 3 Then (Consequent) label

	Then (Consequent)	
Response target	Response activities	Label
Machine	Targeted Machine Monitoring	X1
	Full Performance Monitoring	X2
	Planned Maintenance	X3
Man	Operator Evaluation	Y1
	Operator Shifting	Y2
	Operator Training	Y3
Method	Prioritize One Type Product	Z1
	Work-Order Evaluation	Z2
	Management Meeting	Z3

The result of discretization then has been represented in binary database. A binary database is a binary relation on the set of tids (transaction identifiers) and items (Zaki and Meira 2014). If certain value in an attributes has been qualified into certain discrete range, the value will be represented as true value (1), while the rest of other range will get false value (0). The example of binary table is presented in table 4.

Table 4 Availability score Represented in binary Table

Availability	0-40	40-60	60-90	>90%
65%	0	0	1	0
74%	0	0	1	0
53%	0	1	0	0
81%	0	0	1	0
55%	0	1	0	0
84%	0	0	1	0
35%	1	0	0	0
50%	0	1	0	0

To generate the rules, each antecedent has been combined with consequent, with limitation 4-set combination. The example of antecedent-consequent combination is presented in Table 5. The result of this combination is 30228 rules.

Table 5 Combination of antecedent A-P-Q and consequent X-Y-Z

2-set combination	3-set combination	4-set combination
A1⟶X1	A1-P1⟶X1	A1-P1-Q1⟶X1
A1⟶Y1	A1-P2⟶Y1	A1-P1-Q2⟶Y1
A1⟶Z1	A1-P3⟶Z1	A1-P1-Q3⟶Z1
....	....	....
A3⟶Z3	A3-Q3⟶Y3	A3-P3-Q3⟶Z3.

Rule Assessment

To get qualified rules, a rule assessment has been conducted. Using trial and error method, the user threshold has been determined. The minimum relative support, confidence, lift, and bond used in this research is 0.2, 1, 2, and 0.2. By using this threshold, the rule assessment was resulting 83 qualified rules. Table 6 below shows the summary of top 15 qualified rules ranked by bond.

Table 6 Top 15 rules ranked by bond

No.	rSup	Conf	Lift	Bond	If (Antecedent)			Then (Consequent)
					1st Condition	2nd Condition	3rd Condition	Response
1	0,25	1,00	2,22	1,00	OEE 40-60%			Work-Order Evaluation
2	0,30	1,00	3,33	1,00	OEE 60-85%			One-Type Focusing Production
3	0,30	1,00	4,00	1,00	OEE <40%			Management Meeting
4	0,30	1,00	2,22	0,67	Setup Occurrence 1-5x			Targeted Machine monitoring
5	0,30	1,00	2,50	0,63	Av 40-60%			Planned Maintenance
6	0,30	1,00	2,22	0,57	Setup Occurrence 6-15x	OEE 40-60%		Work-Order Evaluation
7	0,30	1,00	3,33	0,50	Av 60-85%	OEE 60-85%		One-Type Focusing Production
8	0,30	1,00	2,22	0,50	Setup Occurrence 1-5x	OEE 60-85%		Targeted Machine monitoring
9	0,30	1,00	2,22	0,44	Pe 60-90%	OEE 40-60%		Work-Order Evaluation
10	0,30	1,00	2,22	0,42	Setup Occurrence 1-5x	Av 60-85%		Targeted Machine monitoring
11	0,30	1,00	2,22	0,40	Av 40-60%	OEE 40-60%		Work-Order Evaluation
12	0,30	1,00	2,22	0,39	No Breakdown	OEE 40-60%		Work-Order Evaluation
13	0,20	1,00	2,22	0,39	Setup Occurrence 6-15x	Pe 60-90%	OEE 40-60%	Work-Order Evaluation
14	0,20	1,00	3,33	0,38	Material Delay 25% DT	OEE 60-85%		One-Type Focusing Production
15	0,20	1,00	3,33	0,38	No Breakdown	OEE 60-85%		One-Type Focusing Production

Using 83 qualified rules resulted by ARM, a model of maintenance strategy was developed. In this model, the antecedent of the rules consists of measurable parameters that describe the machine condition, up to three condition, while the consequent of the rules consists of response to be taken if the condition in antecedent was occurred. For example, if condition of the machine, in this case moulding machine, was showed OEE value 40-60%, then the management should conduct a work-order evaluation. OEE with value below 60% is lower than world average OEE. Manufacturing company with high changeover rate like PT X maybe has low OEE due to the current work-order. So, to prevent further decreasing in OEE value, the work-order should be evaluated.

Based on this model, improvement of TPM strategy in PT X is expected. Using the model as a tool to help in decision making process, management of PT X can make a decision to solve machine-related problems with considering the qualified rules. Even this rules could not show the absolute solution to the problem itself, this model can increase the probability of successfulness of predictive maintenance. Using ARM, the dependencies between variables has shown clearly, and the decision to be taken to respond machine-related problems on the factory, can be easily considered not only based on observable parameters like machine sound and vibration, but also to unobservable parameters like OEE.

System Analysis and Design

Unified Modeling Language

The use case below shows the usability of predictive maintenance system mobile application (app). The machine operator use the mobile app in recording subsystem meanwhile the high-management and maintenance act use FOEEC in reporting subsystem. The interaction between mobile app systems with all users has illustrated in Figure 12.

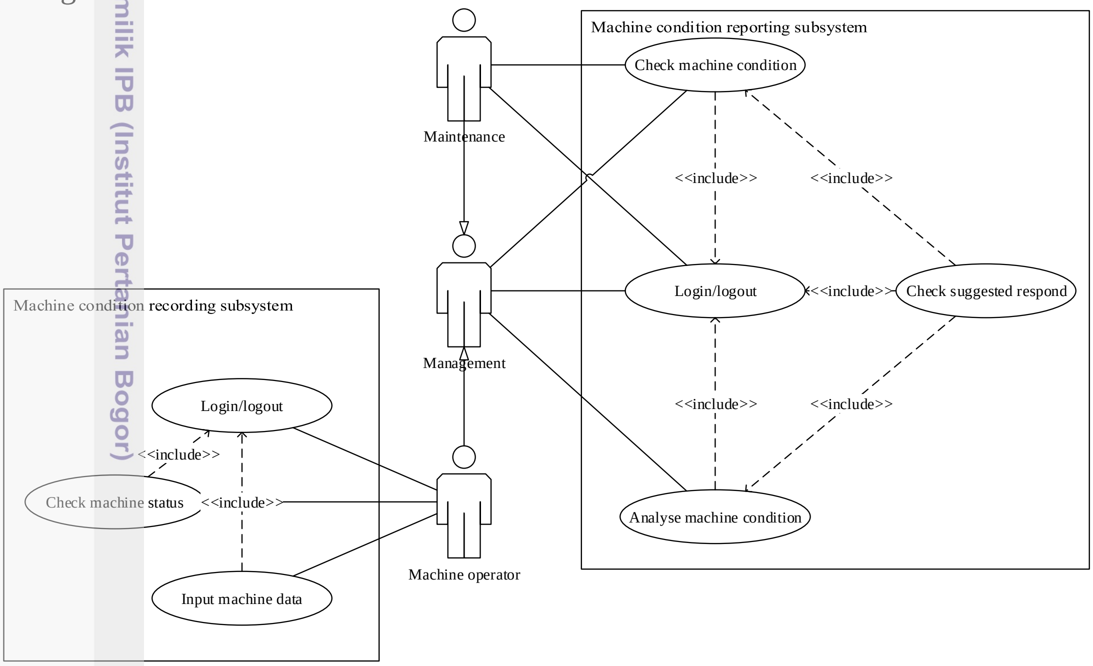

Figure 12 Use case diagram of predictive maintenance system mobile app

The activity in predictive maintenance system mobile app is consist of account login, checking status, inputting data, and taking suggestion, and account logout. These activity works on few pages like login page and machine status page. The user activity in the FOOEC system has illustrated in Figure 13.

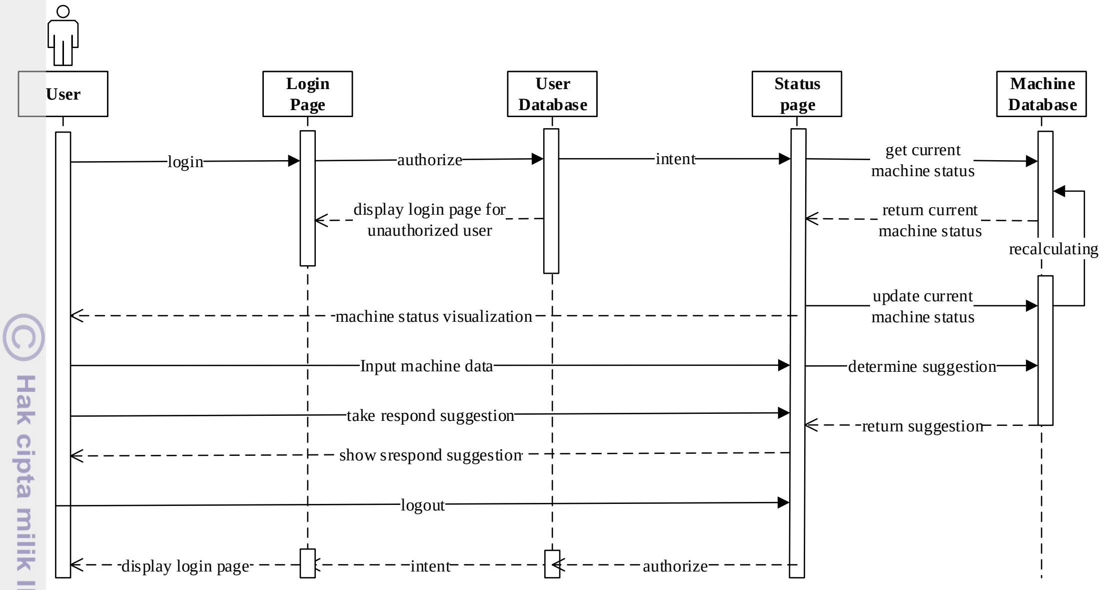

Figure 13 Sequence diagram of predictive maintenance system mobile app

To illustrate the relation between object in database in predictive maintenance system mobile app, a class diagram has been made and presented in Figure 13.

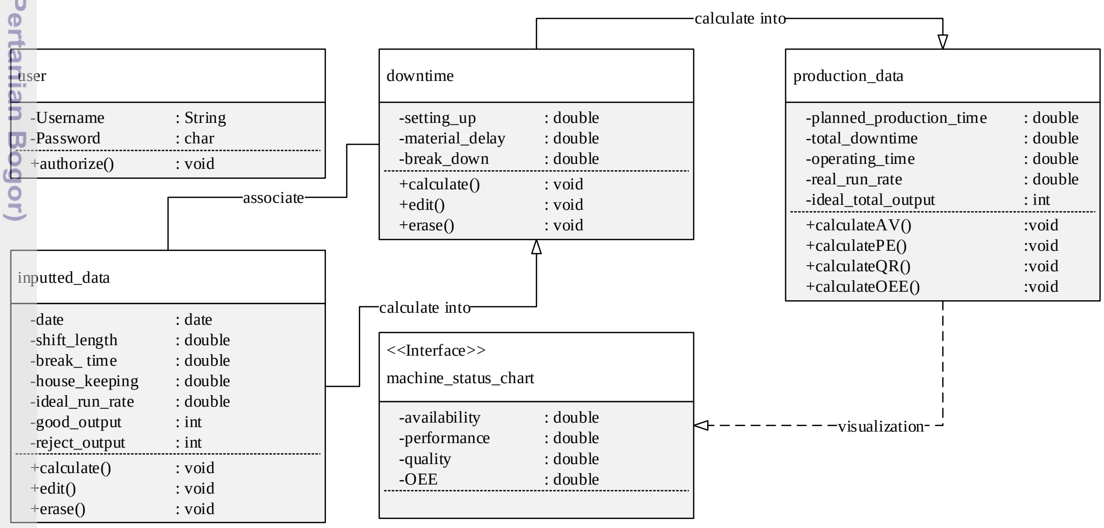

Figure 14 Class diagram of predictive maintenance system mobile app

Mobile Application Development

The predictive maintenance system mobile application has been built using JavaScript programming language to handle the system logic data flow, HTM5 to handle main interface, and CSS3 to handle animation and user interface style. By using Google Fusion Chart as the application chart handler, this mobile application named FOEEC (Fusion Overall Equipment Effectiveness Chart).

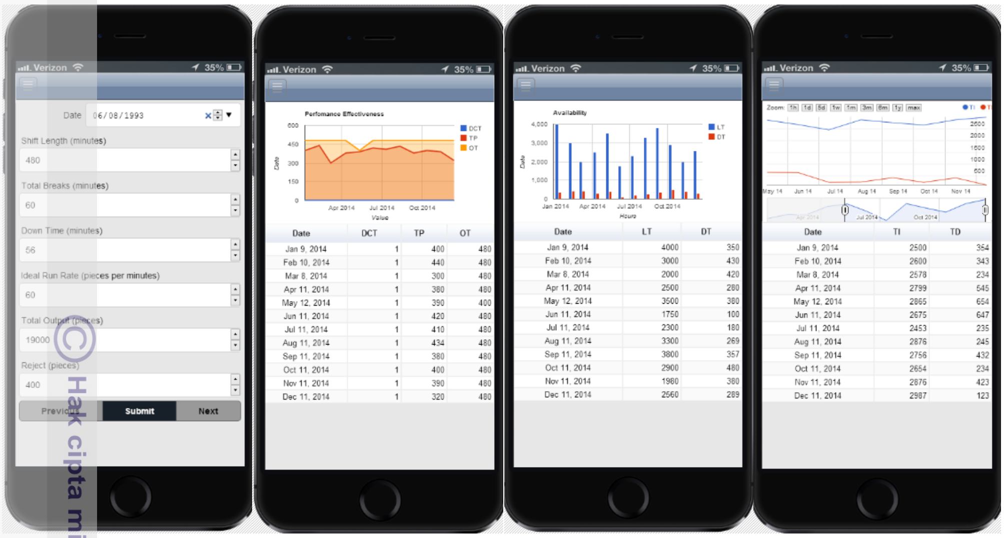

Figure 15 Interface of FOOEC

Figure 15 shows four functional pages of FOOEC application, input data pages with three machine status pages with chart, while figure 16 shows the main function of FOEEC that show the machine condition in OEE chart with suggested response to be taken by the management.

Figure 16 Suggested response of FOOEC

System Verification

Verification is conducted by checking the functionality of the mobile application, in this case the OEE calculation and suggested response, and comparing the developed mobile application with BPMN in Figure 4. The result of system verification has been presented in Table 7.

Table 7 System verification

No	BPMN Model	Implementation in mobile application	Status
1	Account authorization (login/logout)	Implemented by providing an login page and logout button	Done
2	Machine condition measurement	Implemented by automatically calculate the OEE using the inputted data	Done
3	Machine status visualization	Implemented by visualize the OEE and the constituent factors using Google Chart API	Done
4	Support the decision-making process	Implemented by using if-else algorithm developed by the rules generated by the ARM to suggest a response to be taken by the user	Done

Overall, the functionality of FOEEC mobile application has been fulfill the requirement of predictive maintenance system. Furthermore, FOEEC will be implemented in PT X to be tested by the real user with real problem in real condition.

Advantage and Disadvantage

The implementation of ARM to develop TPM strategy is very potential. To implement ARM model to develop TPM strategy for other machine in PT X or even in another manufacturing company, the management can change used attributes and data in ARM so it will generated rules that fit and suit with the machine condition itself. The advantage of this model is generated dynamic rules that always updated by the data changing comparing to other strategy development tool like Analytic Hierarchy Process that uses static data (Bastos *et. al* 2012).

As one of data mining technique, the implementation of ARM to the TPM is a right choice, due to its ability to handle big-data with high velocity and volume that is generated by machine condition. But, the velocity of the data used in this research is low due to the manual data acquisition. This research also shows the necessity of ICT implementation to optimize the usability of data mining techniques to solve manufacturing industry problem like machine maintenance. Without ICT implementation as shown this research, the functionality of data mining techniques like ARM is hardly to be verified and directly implemented to the field.

CONCLUSION AND RECOMMENDATION

Conclusion

This research presents a new concept of implementation of data mining techniques to solve real industry problem especially in machine maintenance. This research was conducted in a wooden door manufacturing industry targeting moulding machine as research sample machine. Using TPM tool to solve the problem in the company, OEE calculation of moulding machine shows a lower OEE score than world average due to low machine availability caused by high setup and adjustment loss. To make a better understanding of the problem and to find the solution, The OEE calculation result and other machine parameters was processed with ARM using Apriori algorithm and generates 30228 if-then rules. Rule assessment has conducted to qualify rules using user threshold to limit support, confidence, lift, and bond value. According to 83 qualified rules, a predictive maintenance strategy has been built by developing the qualified rules. As addition, the model itself has been mounted to information system. Using if-then rules generated by ARM, an if-else looping algorithm has been developed to mount the model to the mobile application. The system information has been developed in a form of mobile application to make it more user-friendly, flexible, and increase the usability.

Recommendation

The OEE measurement itself can be improved using sensor to ease data acquisition and increase data velocity. To ease the implementation of data mining techniques like ARM in the field, it is advisable to implement ICT such as mobile application. Furthermore, using the same approach this ARM and other data mining techniques model can also be modified to be implemented in corrective and preventive maintenance.

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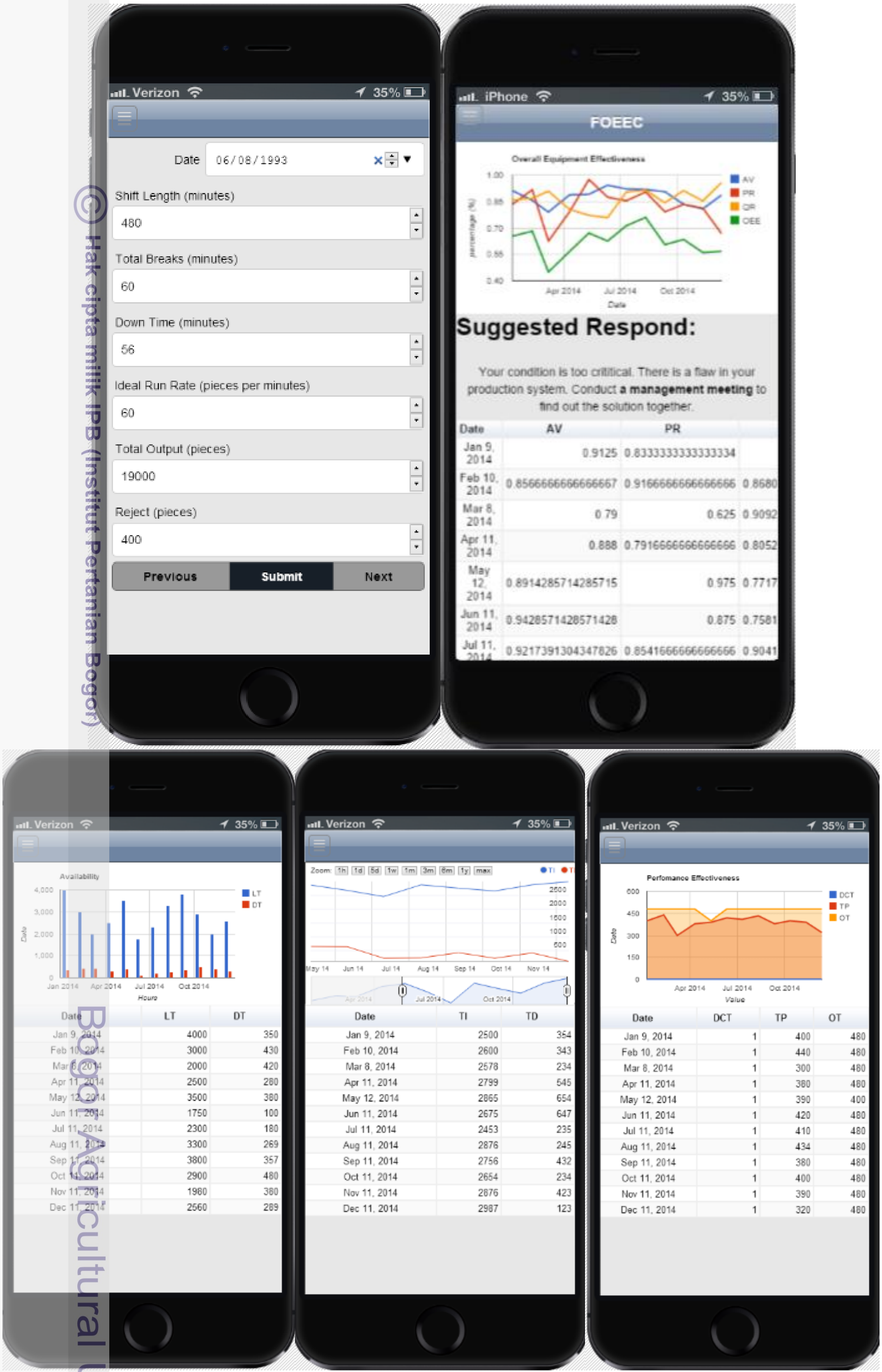
Appendix 1 Table of OEE calculation result

No.	Shift Work Start	Availability (%)	Perfomance (%)	Quality (%)	OEE (%)
1	05/02/2015 7:00	65%	75%	98,55%	48%
2	05/02/2015 20:00	74%	97%	98,59%	71%
3	06/02/2015 7:00	53%	87%	99,41%	46%
4	06/02/2015 20:00	81%	97%	97,10%	76%
5	07/02/2015 7:00	55%	82%	98,37%	44%
6	07/02/2015 15:00	84%	98%	99,68%	82%
7	08/02/2015 7:00	35%	87%	96,48%	29%
8	09/02/2015 7:00	50%	88%	99,32%	44%
9	09/02/2015 20:00	43%	79%	94,02%	32%
10	10/02/2015 7:00	89%	28%	100,00%	25%
11	10/02/2015 20:00	82%	59%	98,33%	48%
12	11/02/2015 7:00	87%	86%	99,46%	75%
13	11/02/2015 20:00	81%	61%	99,79%	49%
14	12/02/2015 7:00	89%	91%	99,75%	81%
15	12/02/2015 20:00	39%	91%	97,78%	34%
16	13/02/2015 7:00	81%	68%	98,78%	54%
17	13/02/2015 20:00	59%	85%	99,40%	50%
18	14/02/2015 7:00	87%	81%	94,29%	66%
19	14/02/2015 15:00	71%	64%	100,00%	46%
20	16/02/2015 7:00	28%	92%	99,89%	26%

Appendix 2 Table of qualified rules resulted by ARM

No.	rSup	Conf	Lift	Bond	If (Antecedent)			Then (Consequent)
					1st Condition	2nd Condition	3rd Condition	Response
1	0,25	1,00	2,22	1,00	OEE 40-60%			Work-Order Evaluation
2	0,30	1,00	3,33	1,00	OEE 60-85%			One-Type Focusing Production
3	0,30	1,00	4,00	1,00	OEE <40%			Management Meeting
4	0,30	1,00	2,22	0,67	Setup 1-5x			Targeted Machine monitoring
5	0,30	1,00	2,50	0,63	Av 40-60%			Planned Maintenance
6	0,30	1,00	2,22	0,57	Setup 6-15x	OEE 40-60%		Work-Order Evaluation
7	0,30	1,00	3,33	0,50	Av 60-85%	OEE 60-85%		One-Type Focusing Production
8	0,30	1,00	2,22	0,50	Setup 1-5x	OEE 60-85%		Targeted Machine monitoring
9	0,30	1,00	2,22	0,44	Pe 60-90%	OEE 40-60%		Work-Order Evaluation
10	0,30	1,00	2,22	0,42	Setup 1-5x	Av 60-85%		Targeted Machine monitoring
11	0,30	1,00	2,22	0,40	Av 40-60%	OEE 40-60%		Work-Order Evaluation
12	0,30	1,00	2,22	0,39	No Breakdown	OEE 40-60%		Work-Order Evaluation
13	0,20	1,00	2,22	0,39	Setup 6-15x	Pe 60-90%	OEE 40-60%	Work-Order Evaluation
14	0,20	1,00	3,33	0,38	Material Delay 25% DT	OEE 60-85%		One-Type Focusing Production
15	0,20	1,00	3,33	0,38	No Breakdown	OEE 60-85%		One-Type Focusing Production
16	0,20	1,00	3,33	0,38	No Breakdown	Av 60-85%	OEE 60-85%	One-Type Focusing Production
17	0,20	1,00	3,33	0,38	Setup 75-100% DT	OEE 60-85%		One-Type Focusing Production
18	0,20	1,00	3,33	0,38	Setup 75-100% DT	Material Delay 25% DT	OEE 60-85%	One-Type Focusing Production
19	0,20	1,00	3,33	0,38	Setup 75-100% DT	Av 60-85%	OEE 60-85%	One-Type Focusing Production
20	0,20	1,00	2,50	0,36	Av 40-60%	Pe 60-90%		Planned Maintenance
21	0,20	1,00	2,22	0,36	Setup 1-5x	Qr >99%		Targeted Machine monitoring
22	0,25	1,00	2,22	0,36	Qr >99%	OEE 40-60%		Work-Order Evaluation
23	0,25	1,00	3,33	0,35	Material Delay 25% DT	Av 60-85%	OEE 60-85%	One-Type Focusing Production
24	0,25	1,00	3,33	0,35	Setup 75-100% DT	No Breakdown	OEE 60-85%	One-Type Focusing Production
25	0,25	1,00	2,22	0,35	Material Delay 25% DT	Setup 6-15x	OEE 40-60%	Work-Order Evaluation
26	0,20	1,00	2,22	0,35	No Breakdown	Setup 6-15x	OEE 40-60%	Work-Order Evaluation
27	0,20	1,00	3,33	0,33	Material Delay 25% DT	No Breakdown	OEE 60-85%	One-Type Focusing Production
28	0,20	1,00	2,22	0,33	Material Delay 25% DT	OEE 40-60%		Work-Order Evaluation
29	0,20	1,00	2,22	0,33	Setup 75-100% DT	OEE 40-60%		Work-Order Evaluation
30	0,30	1,00	2,22	0,33	Setup 75-100% DT	Material Delay 25% DT	OEE 40-60%	Work-Order Evaluation
31	0,25	1,00	2,50	0,33	Setup 6-15x	Av 40-60%		Planned Maintenance
32	0,25	1,00	3,33	0,33	Setup 1-5x	Av 60-85%	OEE 60-85%	One-Type Focusing Production
33	0,25	1,00	2,86	0,33	Av 40-60%	OEE 40-60%		Operator Shifting
34	0,25	1,00	2,50	0,33	Av 40-60%	OEE 40-60%		Planned Maintenance
35	0,25	1,00	2,22	0,33	Setup 1-5x	Av 60-85%	OEE 60-85%	Targeted Machine monitoring
36	0,25	1,00	2,22	0,32	Material Delay 25% DT	No Breakdown	OEE 40-60%	Work-Order Evaluation
37	0,25	1,00	2,22	0,32	Setup 75-100% DT	No Breakdown	OEE 40-60%	Work-Order Evaluation
38	0,25	1,00	2,22	0,31	Material Delay 25% DT	Setup 1-5x		Targeted Machine monitoring
39	0,25	1,00	2,22	0,31	Material Delay 25% DT	Setup 1-5x	OEE 60-85%	Targeted Machine monitoring
…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…
80	0,20	1,00	2,22	0,21	No Breakdown	Qr >99%	OEE 40-60%	Work-Order Evaluation
81	0,20	1,00	2,22	0,21	Setup 6-15x	Av 60-85%	OEE 40-60%	Work-Order Evaluation
82	0,20	1,00	2,22	0,20	Material Delay 25% DT	Setup 6-15x	Av 40-60%	Work-Order Evaluation
83	0,20	1,00	2,22	0,20	No Breakdown	Setup 6-15x	Qr >99%	Work-Order Evaluation

Appendix 3 User interface of FOOEC



BIOGRAPHY

Imam Muharram Alitu was born on June 28th 1993 at Gorontalo, Indonesia. He is the first child of Wisno A. Alitu and Rahmin Utia. He completed his elementary education in SDN 4 Gorontalo, his junior high education in SMPN 1 Gorontalo, and his senior high education in MAN Insan Cendekia Gorontalo. He was accepted in department of Agroindustrial Technology, Bogor Agriculture University at 2011 through direct invite SNMPTN.

During his study in Department of Agroindustrial Technology, he was mandated to be Computer Application lab assistant, Operation Research course assistant, System Analysis and Decision Making course assistant, and Technology of Bio industry lab assistant. His organization experience is achieved through his participation in Department of Academic and Achievement of Himalogin, as staff at 2013 and as head of department at 2014. He is a project officer of Agroindustrial Fair 2013, a national event which introduced agroindustry to the society through student papers competition, innovation exhibition, and scientific seminar. In 2014, he was conducted his internship program at PT. Corinthian Industries Indonesia by the topic of project management.

He is interested in data mining, operation management, project management, and sustainable community development. His achievement during his study are mandated to be Gorontalo province delegation at National Children Forum in Surakarta in 2011, and second winner of Agroindustrial Information and Technology Challenge in 2014. His interest in information and communication technology development and startup company development encourages him to participate in Startup Weekend Bandung in 2015, and became the co-founder of Distiku, a startup company which bypass premium commodity supply chain using mobile application. In addition, he is also interested in photography, game development, and digital creativity movement.