OPERATIONAL RISK ANALYSIS IN OFFSHORE PRODUCTION FACILITY (OPF): APPLICATION OF RISK FAILURE MODE AND EFFECT ANALYSIS

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Abstract:
Declining oil and gas production has created significant operational challenges, particularly unplanned shutdowns that reduce the availability of Offshore Production Facilities (OPF). This study applies the Risk Failure Mode and Effect Analysis (RFMEA) method to prioritize equipment failures causing production losses. Eleven critical risks were identified, with three major ones: PLC module fault, instrument regulator problem, and leak in tubing connection, which were classified as the highest priorities for mitigation.

Keywords: Risk Analysis, Oil and Gas, FMEA, FFTA, Production Facility, Operational Risk

INTRODUCTION

The oil and gas industry is divided into two primary activities: upstream and downstream. Upstream operations involve inherently high-risk and critical processes intricately intertwined with upstream activities. These upstream operations are crucial as they precede the processing and refining of hydrocarbons. These activities include exploration, conceptual development, and production. The upstream exploration and production sector represents the most significant investment in new product development, with expenditures allocated to reservoir discovery, production and operational activities, drilling, and completion. As a non-renewable energy source with limited resource availability, the oil and gas industry faces high uncertainty in its development, particularly regarding annual oil and gas production volumes.

Therefore, the industry must develop risk management strategies, from risk identification to mitigation, to help achieve its objectives. Proactive efforts to enhance production involve strengthening operational risk management at production facilities (Affandi Firdaus, 2017).

One of the causes of the decline in availability is downtime. In the oil and gas production process, downtime occurs when damage and maintenance are required for the system at the facility, especially unplanned shutdowns. From 2021 to 2024, there were 58 incidents of disruption at production facilities, as shown in Figure 1. These incidents resulted in temporary shutdowns ofproduction facilities, such as compressor shutdowns, instrumentation failures, well shutdowns, strainer cleaning, and fire detection in enclosures. One of the critical production facilities is the operational gas turbine compressor.

Disruptions can cause production shutdowns in most wells, particularly gas lift wells, leading to production losses or loss of production opportunities.

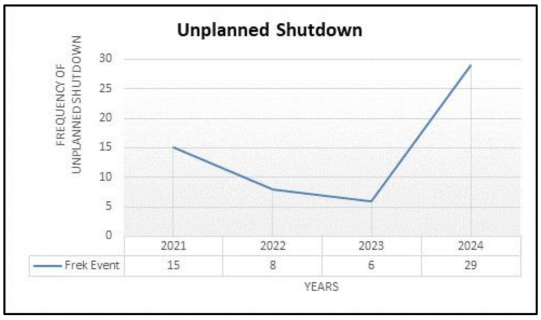

Fig. 1 Unplanned Shutdown 2021 – 2024

Figure 1 shows that several pieces of equipment experienced unplanned shutdowns that directly impacted production loss. However, under the existing conditions in the field, several important aspects have not yet been fully managed well and contribute to the increased operational risk, particularly unplanned shutdowns. One of them is the still-limited inspection and reliability-based maintenance management system. Maintenance activities tend to be reactive or time-based, without considering the actual condition of components or historical performance data of the equipment. This leads to decreased reliability of vital components such as instrument regulators, tubing connections, and PLC I/O control modules, which are not detected early. This condition indicates that the existing preventive maintenance activities are not yet fully practical or optimally scheduled, resulting in some potential failures not being detected earlier.This impacts the decrease in the facility availability and increases the risk of overall production operation disruptions. Based on the identified issues, the main risks in the operational activities at Poleng Field include (1) production disruptions due to non-operational equipment, (2) equipment damage causing loss of oil or gas production, (3) high repair costs, and (4) the need for spare part replacements. This research aims to determine risk mitigation actions based on established critical risk parameters. System identification is carried out using the Risk Failure Mode and Effect Analysis (RFMEA) method, which is used to evaluate various shutdown events related to production facility failures.

There are many ways to determine critical risks in production facilities and risk mitigation strategies, one of which is using the Risk Failure Mode and Effect Analysis (RFMEA) method. In 2013, Mahmood et al. (2013) introduced the Fault Tree Analysis model in fuzzy numbers. This theory presents values as fuzzy numbers, which are used to determine the probability of top events in fuzzy (Qiu et al., 2022)

METHODOLOGY

Offshore Production Facility

The Offshore Production Facility aims to separate three-phase flows from offshore. These flows are processed through various types of main system equipment, including separators, hydrocyclones, sump tanks, surge tanks, pumps, and compressors, which are integrated into a single system that processes the three-phase flows into air, oil, and gas.

This study identifies the impact of operational failures in the production process. The production process involves several stages. In the first stage, the company receives a request and negotiates with the client to determine the amount of crude oil and natural gas required. The negotiations determine how long the company will meet the client's crude oil and natural gas needs.

In the second stage, the production process takes place. This activity is the core of the offshore processing business, which processes crude oil obtained from offshore wells. This activity is closely related to maintenance to prevent machine breakdowns and disrupt production. The next stage is product distribution and payment to the client, with revenue generated according to the previously agreed-upon agreement.

Table 1. Risk Factors for Failure Mode of Offshore Production Facility

No	Sub System	Failure Mode	Refrence
1	Piping	Fuel gas system failure	(Deyab et al., 2018) (Brito & de Almeida, 2009) (Arifin et al., 2019) (Bariha et al., 2016) (Rusin et al., 2021) (Majid et al., 2010)
		Gas Leak	
2	Separation	Pipe leak	(Devold, n.d.)
		Control Valve broken	
		Broken electrical system	
3	Water Treatment	Lube oil leak	(Devold, n.d.)
4	Gas compression unit	Gas leak	(Devold, n.d.) (Mokhtari & Poe, 2012)
		Starting system failure	
5	Storage Tank	Oil leak	(Chang & Lin, 2006) (kazmi et al., 2021)
		Overfill	
		Heater Failure	
6	Gas dehydration unit	Pump Wear	(Mokhatab & Poe, 2012) (Anyadiegwu et al., 2014))
7	Turbine Compressor	Degradations Mechanisms (Erosi, Korosi, Fouling)	(Alqallaf et al., 2020) (Farrahi et al., 2011)
		Rotary turbine blades	
8	Instrument	Air Compressor Failure	(Somonggal & Novani, 2022)
		Instrumentation Valve Problem	
		Equipment Malfunctions	

Main Concept Risk Failure Mode and Effect Analysis (RFMEA)

The primary goal of RFMEA is to identify possible failures by combining Failure Mode and Effect Analysis (FMEA) principles with measuring and eliminating (or reducing) risks in the project environment, which expands risk priority planning with the addition of a Risk Score value that is then calculated with the Risk Priority Number (RPN) value to obtain critical risks (Deyab et al., 2018). RFMEA improves upon the shortcomings of the Risk Priority Number method by assigning proportional weights to each factor. In industrial practice, the available failure data is limited for a variety of basic events. This method has been demonstrated to provide helpful information for assessing risk and making decisions considering uncertainty in the probability of basic events (Rajakarunakaran et al., 2015).

Table 2. Risk assessment scale RFMEA

Scale	Description	Likelihood	Impact	Detection
1	Unlikely to happen	0 < x ≤ 20%	n ≤ 20% × Risk Limit	No detection method provides a warning
2	Rare	20 < x ≤ 40%	20% × Risk Limit < n ≤ 40% × Risk Limit	The detection method has not been measured over time
3	Possible	40 < x ≤ 60%	40% × Risk Limit < n ≤ 60% × Risk Limit	Moderate effective
4	Very likely to occur	60 < x ≤ 80%	60% × Risk Limit < n ≤ 80% × Risk Limit	Highly effective
5	Almost certain to occur	80<x ≤ 100%	80% × Risk Limit < n ≤ 100% × Risk Limit	Very practical and can be detected in a timely manner

Production Processing Platform

In this process, the production platform begins by mining oil wells. The mined product is still a mixture of oil, water, and gas (and contains a small amount of H_2S), commonly called gross liquid. The gross liquid is then processed by separating the oil, water, and gas components, with the oil and gas components sold and the water component discharged into the sea. This separation process is carried out at a facility known as a production processing platform. More specifically, gross liquid in a three-phase fluid flow is sent from wells on the production platform to the processing platform through a subsea pipeline. This gross liquid is then separated into oil, water, and gas components through three-stage separators: the High-Pressure separator (HP Separator), Medium-Pressure separator (MP Separator), and Low-Pressure separator (LP Separator). These three separation stages ensure that no water components are carried over into the oil that will eventually be sold.

Risks were identified based on Focus Group Discussion (FGD) methods, with expert judgement and parties involved in operations. The sources participating in this discussion were personnel directly responsible for the implementation and decision-making of company operations.

The discussion respondents are professionals directly accountable for the execution and decision-making of the company's operations, including seven technical specialists in dependability, availability, and maintenance, as shown in Table 3.

After careful consideration of secondary data, including daily production reports, lost production opportunities, healthy activities, main production optimization worksheets, asset recovery, and discussions, it was found that several risks exist within the production facility. The results of the risk identification were used to determine the values of Likelihood, Impact, and Detection to calculate the RPN value in the critical risk analysis using the FMEA method. The RPN value was calculated as follows:

$$RPN = Likelihood \times Impact \times Detection$$

RESULTS AND DISCUSSION

The object of this study is one offshore field using a qualitative expert judgment approach. Then, to support the analysis of root cause failures and their mitigation, a quantitative approach was used as a questionnaire for expert opinions. The Poleng Field production process is engaged in upstream oil and gas, which has significant inherent risks; therefore, effective and efficient risk management is required.

Table 3. Expert judgement

Respondent	Category		
	Position	Divisi	Experien ce Year
1	Assistant Manager RAM	RAM	15
2	Assistant Manager Production	Production	9
3	Mechanical Senior Supervisor	RAM	15
4	Senior Supervisor		9
5	Electrical Technician		5
6	Staff Operational		5
7	Staff Operational		10

A. Scope, Context, and Criteria

Data and information related to the research writing were collected through field studies to understand the production platform activities in Poleng Field, which consists of several production facilities, as shown in Table 4.

B. Identification Risk Operational

In this study, risk identification was carried out through documents and operational history of production facilities classified as unplanned shutdowns. These operational failures resulted in production losses, repair costs, and unexpected spare parts costs.

To assign a score to complete the Risk Failure Mode and Effect Analysis method, data were collected using the following methods:

1. A preliminary survey based on field data related to the operational failure history of production facilities, namely Loss of Production Opportunity (LPO) data from the Production Platform and the PPP-AW Poleng Field Process.
2. The focus group discussion aimed at validating the selected risk agent and analyzing the risk using the FMEA to evaluate the risk using an impact-probability matrix to determine risk severity and determine responses to risk priorities.
3. Questionnaire: Processing data from the questionnaire results to determine probabilities based on expert opinions to determine risk treatment.

C. Risk analysis

RFMEA provides a more accurate matrix by combining Likelihood and Impact (Rp/USD/MMBTU) from the total production loss. It identifies events that frequently fail and which events cause significant losses if they fail.

$$Risk\ Score = Likelihood \times Impact$$

Table 4. Risk variable assessment

Category	**Code**	**Failure Mode**	**Total Incidents**	**RPN**	**Risk Score**
Gas Turbine Compressor	C01	Temperatire High High	3	8	8
	C02	Underspeed (Suction Low)	6	6	6
	C03	Thrust Bearing Temperature High	2	2	1
	C04	False Alarm (Enclosure Fire Detection)	3	4	4
	C05	Transmitter Failure	2	12	3
	C06	Module Fault	9	15	15
	C07	V-Belt tear (Lube Oil Cooler)	1	3	1
	C08	Discharge Valve Failure	1	6	3
	C09	Seal Gas Drop	1	3	1
	C10	No Power	1	9	3
	C11	Fuel Injector Problem	1	1	1
Panel or Electrical	E1	Failure in the battery charger controller	1	6	2
Gas Engine Generator	GE1	Radiator Problem	1	12	4
	GE2	Loosen Clamp	1	9	3
	GE3	V-Belt Tear	1	12	4
	GE4	AVR Problem	1	12	4
	GE5	Alarm fault shutdown	1	9	3
	GE6	Selenoid Fuel Shutoff	1	6	2
	GE7	MCB Panel Breakdown	1	6	3
	GE8	Exciter Failure	1	15	5
Gas Turbine Generator	GT1	Pressure Transmitter Failure	1	2	2
	GT2	Module Fault (ABB)	4	8	8
	GT3	False Alarm	1	6	2
Instrument & Control	I1	Leak Tubing Connection	7	36	9
	I2	Regulator Instrument Problem	3	27	12
	I3	High-Level Scrubber	1	1	1
	I4	Icing Problem	1	8	2
	I5	Smart Gaslift Error	1	6	2

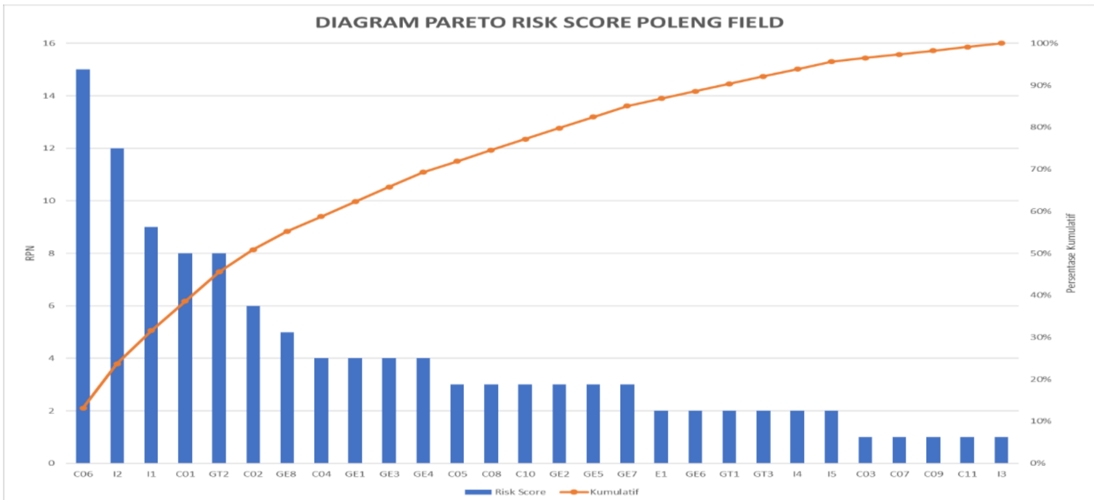

Fig. 2 Pareto Diagram Risk Score

D. Risk Evaluation

Risks were identified based on focus group discussions (FGD) with various experts and parties involved in operations. The sources participating in these discussions were personnel directly responsible for the implementation and decision-making of company operations. After careful consideration of secondary data, including daily production reports, lost production opportunities, healthy activities, primary production optimization, asset recovery worksheets, and discussions, it was found that several risks exist within the production facility. The critical values of the RPN were obtained using the following formula:

$$RPN\ Critical\ Value = \frac{Total\ RPN}{Total\ Risk} = \frac{250}{28} = 8.93$$

the limit for critical category values in RPN, Based on the calculation results (8), is 8.93, while the critical category value for risk score refers to Table 5, which is a minimum value of 15 (based on the risk matrix) that serves as the boundary on the scatter plot.

Fig.5 classified as high risk (High Risk). A Pareto diagram analysis of Fig.5 was conducted to measure the critical values of each critical risk for the risk score and RFMEA, followed by a scatter diagram with the axis as the intersection of the two critical values to divide the risk values into four quadrants, where the critical zone (upper right) represents high and urgent risk values.

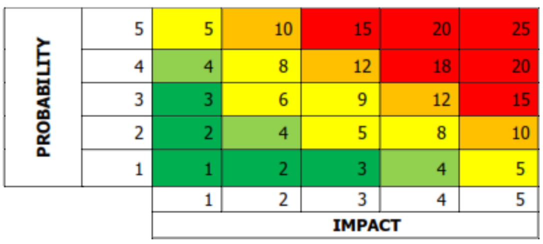

Fig. 3 Risk score Likelihood and Impact

Table 5 Risk Score Scale

Score	Probability	Impact
1-3	Rare	Low Risk
4	Unlikely	Low to Moderate Risk
5-9	Moderate	Moderate Risk
10-12	Likely	Moderate to High Risk
15-25	Almost Certain	High Risk

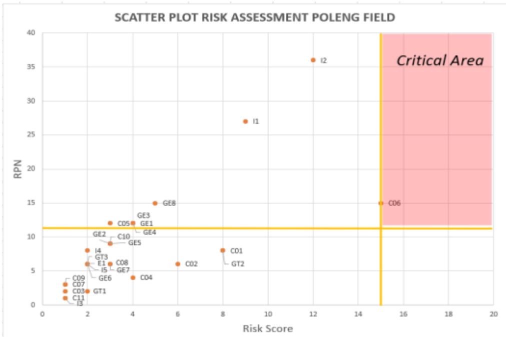

Fig. 4 Scatter Plot RFMEA (Risk Score and RPN)

Table 6 Risk critical RFMEA

Code	Failure Mode	Risk Score	RPN
C06	Module Fault	15	15
I2	Regulator Instrument Problem	12	36
I1	Leak tubing instrument problem	9	27

CONCLUSIONS

RFMEA is an extension of FMEA, as it adds quantitative elements, namely risk scores based on actual impact (Rp/USD/MMBTU) from total production loss. While FMEA with high RPN scores may be prioritized over major failures with high losses but low RPN, RFMEA provides a more accurate matrix combining likelihood and impact. It identifies events that frequently fail and those that cause significant losses if they

fail. Both critical risk values and risk scores are visualized and analyzed using a scatter plot. With a risk score threshold of 15 based on the risk matrix, the results identify module fault as the most critical risk, with a near-certain probability of occurrence, regulator instrument problem as a very likely risk, and leak tubing connection as a possible risk (moderate)..
The following conclusions were obtained:

1. The RFMEA method supports research objects with a dynamic scope. Suppose an FMEA with a high score can be prioritized over major failures with high losses but low RPN. In that case, RFMEA provides a more accurate matrix of the combination of likelihood and impact that considers the cost factors of product losses and maintenance costs.
2. Although the RFMEA method provides a matrix output that considers impact and likelihood separately, the results remain subjective if not supplemented with adequate historical data. Meanwhile, this research has continued by combining Fuzzy Fault Tree Analysis, which, although capable of logically mapping failure paths, has not yet comprehensively captured the probability dynamics under uncertainty conditions.

Suggestions that can be provided:

1. Future studies are recommended to further enhance the external validity and analytical robustness of RFMEA applications in Offshore Production Facilities (OPF).
2. Future research should re-evaluate the effectiveness of Risk Failure Mode and Effect Analysis (RFMEA) compared to other quantitative risk analysis methods, such as Bayesian Network or Monte Carlo Simulation. This comparison can help address the subjectivity of expert judgment and provide a deeper assessment of risk sensitivity.
3. A comparative analysis between offshore and onshore production facilities is suggested to identify differences in failure mode dominance and unique operational risk characteristics. Expanding the research scope will support the development of more contextual and targeted mitigation strategies.
4. Future work can also focus on developing a time-based risk evaluation model for systems or components with a high historical failure rate. This model should integrate post-intervention performance data and projections of Risk Priority Number (RPN) improvement over time, allowing continuous monitoring of mitigation effectiveness.

REFERENCES

Affandi Firdaus, I. (2017). Manajemen Risiko Operasional Onshore Processing FacilityDengan Menggunakan Risk Failure Mode And Effect Analysis Dan Fault Tree Analysis.

Alqallaf, J., Ali, N., Teixeira, J. A., & Addali, A. (2020). Solid Particle Erosion Behaviour And Protective Coatings For Gas Turbine Compressor Blades-A Review. In Processes (Vol. 8, Issue 8). MDPI AG. Https://Doi.Org/10.3390/PR8080984

Anyadiegwu, C. I. C., Kerunwa, A., & Oviawele, P. (2014). Natural Gas Dehydration Using Triethylene Glycol (TEG). Petroleum & Coal, 56(4), 407–417.

Www.Vurup.Sk/Petroleum-Coal Arifin, M., Cahyono, A., Putra, I., &

Munir, B. (2019). Assessment Of Offshore Piping Composite Repair Technology For Life Extension Program Case In Pertamina Hulu Energy West Madura Offshore. MATEC Web Of Conferences, 269, 06005. [Https://Doi.Org/10.1051/Matecconf/2 01926906005](Https://Doi.Org/10.1051/Matecconf/201926906005)

Bariha, N., Mishra, I. M., & Srivastava, V.

C. (2016). Hazard Analysis Of Failure Of Natural Gas And Petroleum Gas Pipelines. Journal Of Loss Prevention In The Process Industries, 40, 217–226. [Https://Doi.Org/10.1016/J.Jlp.2015.1 2.025](Https://Doi.Org/10.1016/J.Jlp.2015.12.025)

Brito, A. J., & De Almeida, A. T. (2009). Multi-Attribute Risk Assessment For Risk Ranking Of Natural Gas Pipelines. Reliability Engineering And System Safety, 94(2), 187–198. [Https://Doi.Org/10.1016/J.Ress.2008. 02.014](Https://Doi.Org/10.1016/J.Ress.2008.02.014)

Chang, J. I., & Lin, C. C. (2006). A Study Of Storage Tank Accidents. Journal Of Loss Prevention In The Process Industries, 19(1), 51–59. [Https://Doi.Org/10.1016/J.Jlp.2005.0 5.015](Https://Doi.Org/10.1016/J.Jlp.2005.05.015)

Devold, H. (N.D.). Oil And Gas Production Handbook: An Introduction To Oil And Gas Production, Transport, Refining And Petrochemical Industry. Www.Wikimedia.Org.

Deyab, S. M., Taleb-Berrouane, M., Khan, F., & Yang, M. (2018). Failure Analysis Of The Offshore Process Component Considering Causation Dependence. Process Safety And Environmental Protection, 113, 220–232. [Https://Doi.Org/10.1016/J.Psep.2017. 10.010](Https://Doi.Org/10.1016/J.Psep.2017.10.010)

Farrahi, G. H., Tirehdast, M., Masoumi Khalil Abad, E., Parsa, S., & Motakefpoor, M. (2011). Failure Analysis Of A Gas Turbine Compressor. Engineering Failure Analysis, 18(1), 474–484. Https://Doi.Org/10.1016/J.Engfaila n al.2010.09.042

Kazmi, B., Taqvi, S. A. A., Naqvi, M., Ilyas, S. U., Moshin, A., Inamullah, F., & Naqvi, S. R. (2021). Process System Analysis On Oil Processing Facility And Economic Viability From Oil Well-To-Tank. SN Applied Sciences, 3(7). Https://Doi.Org/10.1007/S42452-021- 04635-Z

Mahmood, Y. A., Ahmadi, A., Verma, A. K., Srividya, A., & Kumar, U. (2013). Fuzzy Fault Tree Analysis: A Review Of Concept And Application. International Journal Of System Assurance Engineering And Management, 4(1), 19-32. Https://Doi.Org/10.1007/S13198-013- 0145-X

Majid, Z. A., Mohsin, R., Yaacob, Z., & Hassan, Z. (2010). Failure Analysis Of Natural Gas Pipes. Engineering Failure Analysis, 17(4), 818–837. [Https://Doi.Org/10.1016/J.Engfaila n al.2009.10.016](Https://Doi.Org/10.1016/J.Engfailanal.2009.10.016)

Mokhatab, S., & Poe, W. A. (2012). Handbook Of Natural Gas

Transmission And Processing: Vol. Second. Elsevier.

Qiu, R., Li, Z., Zhang, Q., Yao, X., Xie, S., Liao, Q., & Wang, B. (2022). A Realistic And Integrated Model For Evaluating Offshore Oil Development. Journal Of Marine Science And Engineering, 10(8). Https://Doi.Org/10.3390/Jmse100811 55

Rajakarunakaran, S., Maniram Kumar, A., & Arumuga Prabhu, V. (2015). Applications Of Fuzzy Faulty Tree Analysis And Expert Elicitation For Evaluation Of Risks In LPG Refuelling Station. Journal Of Loss Prevention In The Process Industries,33, 109–123. Https://Doi.Org/10.1016/J.Jlp.2014.1 1.016

Rusin, A., Stolecka-Antczak, K., Kapusta, K., Rogoziński, K., & Rusin, K. (2021). Analysis Of The Effects Of Failure Of A Gas Pipeline Caused By Mechanical Damage. Energies, 14(22). Https://Doi.Org/10.3390/En14227686

Somonggal, H. O., & Novani, S. (2022). Decision Analysis To Find The Best Solution To Overcome Instrumentation Problems By Using Analytic Hierarchy Process And SMART Method. Journal Of Integrated System, 5(2), 123–142. Https://Doi.Org/10.28932/Jis.V5i2.47 10