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FUZZY ASSESSMENT SIMULATION FOR CLASSIFYING PRODUCTION EQUIPMENT IN PRACTICE OF TOTAL PRODUCTIVE MAINTENANCE

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ABSTRACT

This paper describes how to develop a decision support system for classifying production equipment by considering a Multi Criteria Decision Making (MCDM) Method for Productivity, Quality, Cost, Delivery, Safety (PQCDS) indicators based on its condition. The study was conducted by using fuzzy assessment approach. The purposes of this study are: to define each criterion of each indicator; to determine fuzzification of value of each criterion; to design appropriate fuzzy rule base; and to develop a decision support system. The Categories of equipment were divided into 3 classes, such as: critical, mayor, minor. In this study, fuzzy rules were designed based on expert's knowledge and experiences. Finally, the results were simulated and compared with conventional method.

Keywords: decision support system, fuzzy, equipment, PQCDS.

INTRODUCTION

Technology developments require companies that want to compete in global scope to prepare human resources that are reliable and able to quickly respond as well as take right decision. In knowledge-based economy era, to win the competition is no longer that they had a high and advanced technology only, but in fact they had to be able to manage their knowledge and experience and to respond appropriately regarding any changes in the industrial system (integrated between labor, equipment, processes, methods, environment, and even Information Technology). Surely these things will reduce losses that incurred.

Nowadays, every industry generally concentrates on offering quality products at affordable prices. Quality, cost, and delivery are vital aspects in determining successful of an industry. In fulfilling these factors, any policy should be straightforward and firmly so that decisions can be made quickly and accurately. At operational level, which supports operation of equipment must be able to work optimally. Therefore, maintenance system must be built from step of planning to implementation and controlling.

Asset management and production facilities are crucial in manufacturing industries so that production targets can be achieved as planned. In productive maintenance needs to be known clearly, where the facilities are entered in category of "critical unit" that is needed preventive maintenance or implemented maintenance handling as soon as possible if its failure occurs.

This study discusses Multi-Criteria Decision Making Model based fuzzy knowledge taking into consideration of key success factors, such as: productivity, quality, cost, delivery, and safety, applied for classifying the priority level of maintenance handling on equipment in manufacturing (case study in a global automotive industry). How to develop a decision support system for classifying an equipment whether is included in critical class, major class, or minor class? What criteria can be used for classifying equipment? The main purpose of this study is to develop a decision support system for classifying production facility or production equipment which considers based PQCDS factors on its condition. The aims of this study are: to define each score of each criterion; to determine fuzzification for value of each criterion; to design appropriate fuzzy rule base.

LITERATURE REVIEW

a) Introduction of fuzzy logic

Fuzzy system is a knowledge-based system which is modeled on the expertise and experience in the form of fuzzy IF-THEN rules. Fuzzy logic was first introduced by Prof. Lotfi A. Zadeh in 1965. The base of fuzzy logic is fuzzy set theory. Recently, application of fuzzy logic are many and increasingly widely applied in industrial applications. According to Bowles and Pelaez (1995), Javier Puente, et.al. (2002), K. Xu, et.al. (2002), M. Braglia, et.al. (2003), Yeh & Hsieh (2007) that fuzzy system could be used as a decision support system in industrial applications [10]. Selection of fuzzy approach compared with other MCDM methods such as AHP, ANP, and PVA, because fuzzy might construct and model the experts knowledge [9]. According to Cox (1994), there are several reasons why people use fuzzy logic, among others [7]:

- The concept of fuzzy logic is easy to understand. Mathematical concepts underlying fuzzy reasoning is very simple and easy to understand.
- Fuzzy logic is very flexible, meaning able to adapt to changes or uncertainties which accompanies problems.
- Fuzzy logic can tolerate incorrect data.
- Fuzzy logic is able to model complex non-linear function.
- Fuzzy logic can develop and apply the experiences of experts directly without having to go through the training process.

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- Fuzzy logic can work with conventional control techniques.
- Fuzzy logic is based on natural language. Fuzzy logic uses everyday language so easily understood.

In crisp set, membership functions of a variable only have 2 possibilities, i.e. 1 or 0 (as step function). For instance, variable of temperature was divided into 3 categories (as seen in Figure-1), such as: Cool temperature starts from 10°C until less than 26°C; Normal temperature from 26°C until 32°C; Hot temperature greater than 32°C until 50°C.

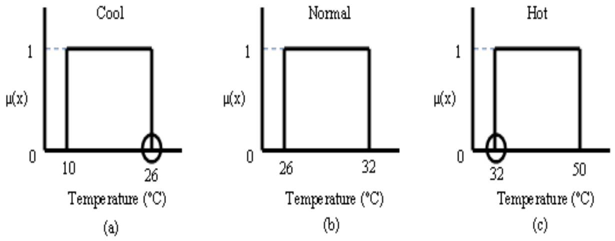

Figure-1. Illustration of crisp sets: (a) cool; (b) normal; (c) hot.

Figure-1 shows that each criterion has a measurement scale with fixed interval. It means that if a condition with temperature26°C less a half degree, it would be categorized into cool temperature. As well as, if a condition with temperature 32°C plus one degree, it would be categorized into hot temperature. In essence, it isn't fair. In fact, there is the idea that normal temperature can't be expressed in a interval of 26°C to 32°C. Sometimes, normal is defined as a temperature, where it can't be expressed either too cool or too hot. Thus, temperature of a condition allow it to be categorized into cool temperature and normal temperature, or it can be into normal temperature and hot temperature (as illustrated in Figure-2). In Figure-2, shows that cool temperature in a set with interval [10, 26]; normal temperature in a set with interval [22, 32]; and hot temperature in a set with interval [26, +∞]. In the fuzzy set theory, membership function become the main characteristic of reasoning of fuzzy logic.

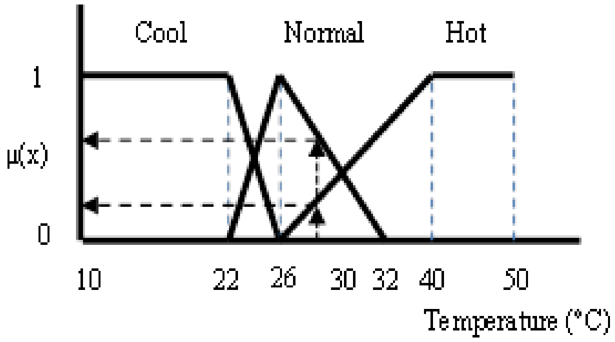

Figure-2. Illustration of a fuzzy set

b) PQCDSM indicators in manufacturing practice

Performance of an industry is measured by assessing how effective and efficient, a business process runs in fulfilling satisfaction of customer. Many methods can be used to measure performance. In manufacturing industry, operational performance was evaluated by measuring the indicators of productivity, quality, cost, delivery time, safety, and morale (PQCDSM). Toyota Co.is a world class automotive industry, successfully develop and implement lean manufacturing, which is known as Toyota Production System (TPS). The main goal of the system is to improve excellence in performance of PQCDSM indicators. In fact, the "Toyota Way" has become a role model in manufacturing system in the world. In simple, it could be mentioned that the performance would go up if achieved highest in productivity, best in quality, lowest cost, shortest delivery time, best safety and high morale. Here is the definition of each indicator:

a) **Productivity**
APIC Dictionary (2010) defines productivity as an overall measure of the ability to produce a good or service, or it can also be defined as a ratio between actual output that is generated and usage of actual resources. In other words, productivity is the ratio between effectiveness and efficiency.

b) **Quality**
Quality depends on the effort to meet customer needs. According to Joseph Juran (1988) in the Quality Control Handbook defines quality as "fitness for purpose." 3M aspects –namely man, machinery, and material – have high impact to the results of quality performance.

c) **Cost**
Here, costs are not only related to cost of production, but also cover manpower cost, inventory cost, maintenance cost, quality cost, and so on.

d) **Delivery**
Nowadays, not only price and quality which become customer requirements, but also the speed in fulfilling customer needs become a vital aspect in improving its competitiveness and win the competition.

e) **Safety**
Safety depends on the physical condition of facilities and working environment. Concern for safety would reduce rate of accidents that occur in the workplace.

f) **Morale**
Morale deals with motivation of workers to engage in a personal or group in performing value-added activities. In essence, this aspect creates a climate of harmony in workplace, which gives a significant impact in improving the effectiveness and efficiency of work of employees. But, this indicator wasn't used as a consideration in this study.

METHOD

According to Nippon Zeon Co., classification of equipment based on score of PQCDS criteria as illustrated in Figure-3. There is particular production equipment which is regulated by law, if not then it would be considered whether including as a critical class or major class or minor class based on score obtained from each criterion. The proposition of this study is in practice, all criteria should not have same importance level (weight). So that priority level (rank) of an equipment can be expressed by following mathematical equation:

Rank of equipment = function (productivity, quality, cost, delivery, safety) (1)

The fuzzy inference method was used Mamdani Method (as seen in Figure-4). The stages of this research are divided into 5 (five) steps, as follows: First step: to determine fuzzy input membership function for each criterion; Second step: to determine fuzzy output membership function for each class; Third step: to design appropriate fuzzy rule base; Fourth step: to build Fuzzy inference system; Last step: to perform simulations and trial-error. Fuzzy rule base was designed based on the results of discussion and sharing of experiences from experts. Simulation based Fuzzy knowledge was done by using Matlab Fuzzy Toolbox. The model simulation would be conducted to investigate reliability of the system in providing solutions by performing trial-error test. And then the result was evaluated or confirmed whether it had been appropriate.

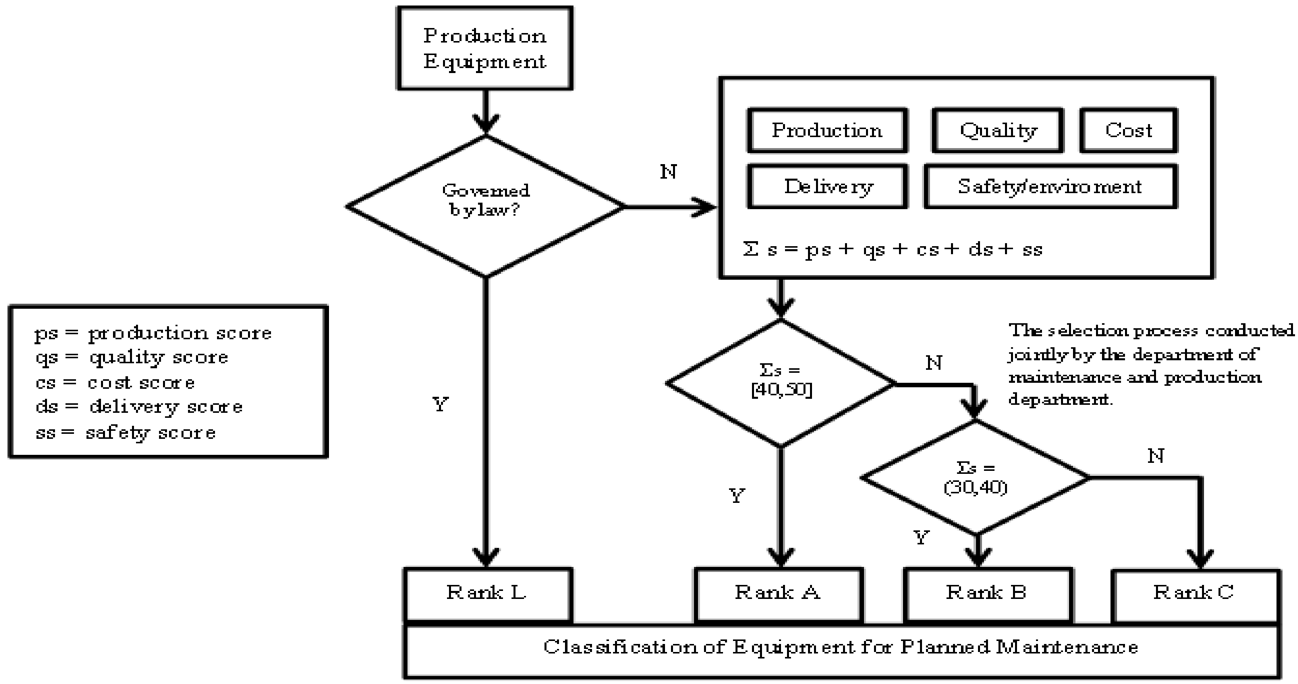

Figure-3. A Schematic illustration of classification of production equipment according to Nippon Zeon Co., PM prize lecture digest (as Theoretical framework).

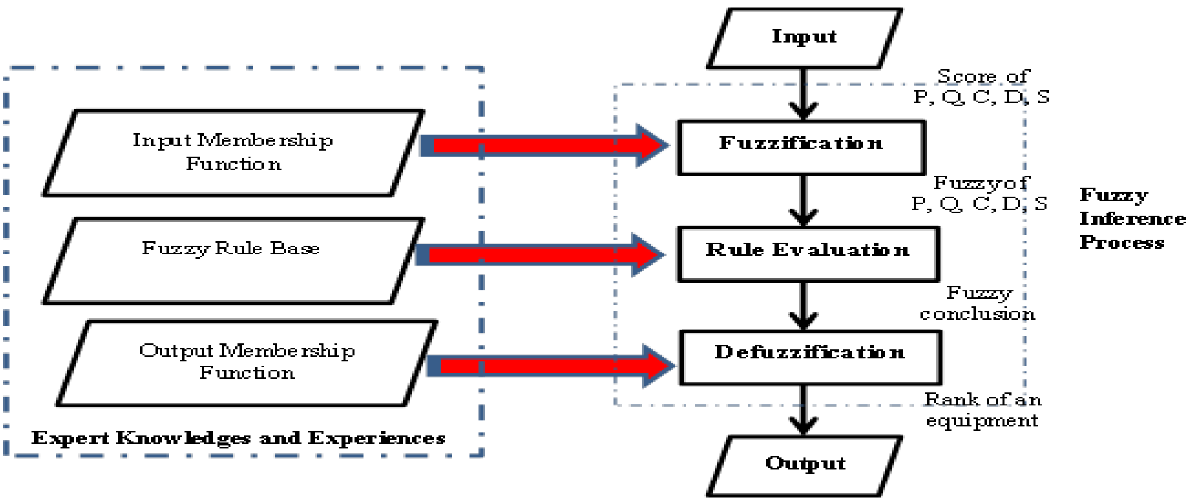

Figure-4. Applied fuzzy assessment framework (adapted from [10]).

DISCUSSION AND RESULT

Mentioned in previous section, overall the stages of Mamdani Method are divided into 4 (four) steps, as follows: 1) Fuzzy membership function; 2) Fuzzy rule bases; 3) Fuzzy inference process; 4) Defuzzification.

a) Fuzzy membership function

Furthermore in this research, fuzzy membership functions used are triangular curve and trapezoidal curve. And then, all indicators use rating scale with ordinal scale from 1 to 10.

Quality

This quality score is determined from the defective product rate which is produced by production equipment when it is either damaged or decline in performance.

Table-1. Categories of fuzzy linguistic variable for quality indicator.

Fuzzy	Linguistic variable	Score	Criteria
1.	Very low	1	Damage of equipment does not cause either failure of the process or defects in the product, or in other words its effect emerge 3.4 defects in one-million units output.
2.	Low	2	Damage of equipment causes in one defect in 150,000 units of output.
		3	Damage of equipment causes in one defect in 15,000 units of output.
3.	Medium	4	Damage of equipment causes in one defect in 2,000 units of output.
		5	Damage of equipment causes in one defect in 400 units of output.
		6	Damage of equipment causes in one defect in 80 units of output.
4.	High	7	Damage of equipment causes in one defect in 20 units of output.
		8	Damage of equipment causes in one defect in 8 units of output.
5.	Very high	9	Damage of equipment causes in one defect in 3 units of output.
		10	Damage of equipment causes defects which is not less than one in two units of output.

Cost

Score of cost is determined based on an opportunity cost arising from lost production time due to equipment is damaged or gets breakdown. Here, cost does not consider the cost of maintenance either repair or replacement.

Tabel-2. Categories of fuzzy linguistic variable for cost indicator.

Fuzzy	Linguistic variable	Score	Criteria
1.	Very low	1	Damage of equipment does not cause any losses in production time at all and its process is still in control.
		2	Damage of equipment causes a change in its settings so this equipment requires a little bit adjustment, and its process is still in control.
2.	Low	3	Damage of equipment causes out of control of a process so it needs some setup requirements.
		4	Damage of equipment causes a downtime occurs during less than 30 minutes.
3.	Medium	5	Damage of equipment causes a downtime occurs during 30 mins to 60 mins.
		6	Damage of equipment causes a downtime occurs during a hour to 2 hours.
4.	High	7	Damage of equipment causes a downtime occurs during 2 hours to 4 hours.
		8	Damage of equipment causes a downtime occurs during 4 hours to 8 hours.
5.	Very high	9	Damage of equipment causes a downtime occurs during 8 hours to 24 hours.
		10	Damage of equipment causes a downtime occurs during more than 24 hours.

Delivery (or productivity)

Delivery indicator is closely related to the level of productivity on the equipment or system to meet production targets. Delivery score is determined based on how the impact of equipment failure affects the speed losses, so that it might cause a delay of delivery to the next work-station or to customer.

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Tabel-3. Categories of fuzzy linguistic variable for delivery indicator.

Fuzzy	Linguistic variable	Score	Criteria
1.	Very low	1	Damage of equipment does not cause a decrease in production speed at all.
2.	Low	2	Damage of equipment causes the speed of production decreased by no more than 5%.
		3	Damage of equipment causes the speed of production decreased by 5.01% till 10%.
3.	Medium	4	Damage of equipment causes the speed of production decreased by 10.01% till 15%.
		5	Damage of equipment causes the speed of production decreased by 15.01% till 20%.
		6	Damage of equipment causes the speed of production decreased by 20.01% till 25%.
4.	High	7	Damage of equipment causes the speed of production decreased by 25.01% till 30%.
		8	Damage of equipment causes the speed of production decreased by 30.01% till 35%.
5.	Very high	9	Damage of equipment causes the speed of production decreased by 35.01% till 40%.
		10	Damage of equipment causes the speed of production decreased by more than 40%.

Safety

Safety score is determined by the severity of impact damage to the equipment that would provide a disruption or harmful risk to the environment, operators, and production system.

Tabel-4. Categories of fuzzy linguistic variable for safety indicator.

Fuzzy	Linguistic variable	Score	Criteria
1.	Very low	1	Damage of equipment does not cause any impact on safety.
2.	Low	2	Damage of equipment causes little disruption either on equipment or system that is not significant, but it continues to operate safely. The impact can only be known by experienced operators.
		3	Damage of equipment causes little disruption and the equipment or system continues to operate safely. The impact can be known by some operators in general.
3.	Medium (or Significant)	4	Damage of equipment causes minor disruption and the equipment or system continues to operate safely. The impact can be known by all operators.
		5	Damage of equipment causes some defect of the product. The equipment or system continues to operate safely, but the operator is dissatisfied due to the performance level decline.
		6	Damage of equipment causes some defect of the product. The equipment or system continues to operate safely, but the operator is very dissatisfied with its performance.
4.	High	7	Damage of equipment causes the equipment or system is not safe, and it isn't able to operate fully. Even, the operator is very dissatisfied.
		8	Damage of equipment causes the equipment or system is not safe to be operated. And, the equipment has lost its main function.
5.	Very high	9	Damage of equipment causes the equipment or system fails to operate, as well as does not fulfill with safety regulations.
		10	Damage of equipment causes the equipment or system is not feasible to operate due to it is catastrophic, and contrary to the occupational health and safety regulations.

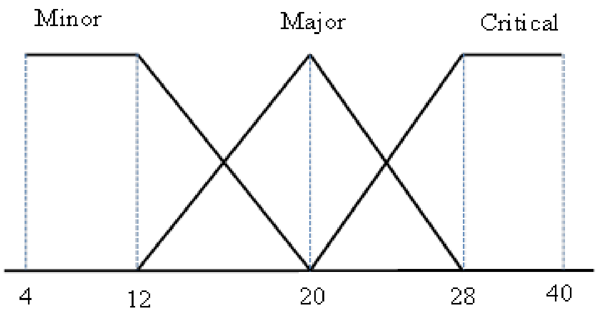

Figure-5. Fuzzy membership function for all inputs.

Rank

The rating of rank is obtained from the inference process of each composition of fuzzy rules that were developed as knowledge base.

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Tabel-5. Categories of fuzzy linguistic variable for rank (output).

Fuzzy	Linguistic variable	Score	Criteria
1.	Critical	28-40	If there is damage to this type of equipment, where would result in interruption of the production process as a whole. It would generate the opportunity costs of production, or high repair costs. This type of equipment requires close supervision and intensive treatment efforts.
2.	Major	12-28	This type of equipment that affect the smooth production process. If the equipment is damaged then this will not stop the production process as a whole. This type of equipment requires medium maintenance control.
3.	Minor	4-12	This equipment is supporting. Damage of this type of equipment may only decrease the efficiency of the local facilities, but does not interrupt the production process as a whole. This type of equipment requires only limited maintenance effort.

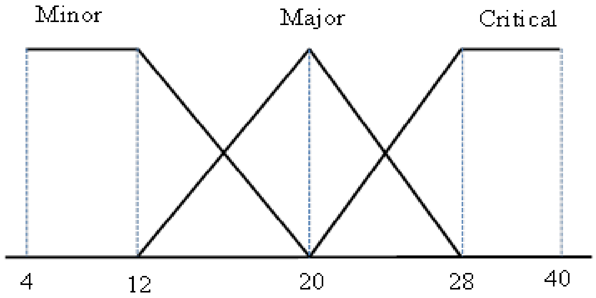

Figure-6. Output membership function.

b) Fuzzy evaluation rules and fuzzy inference process

Each rule in the fuzzy knowledge base would be dealing with a fuzzy relation. Compound statement which is used in developing the rules on fuzzy logic is the implication function (if-then rule). In fuzzy IF-THEN rule, the IF-part is antecedent as the fuzzy input variables, and the THEN-part is consequent as the fuzzy output variable. Thus, minimum inference engine is used to combine the fuzzy IF-THEN rules in fuzzy rule base and implicate the fuzzy conclusion. The minimum inference engine uses: (1) min operator for "and" in the IF-part of rules and max operator for the "or" in the IF-part of rules, (2) the union combination to aggregate the consequence of individual rules.Each indicator of QCDS has five (5) levels of fuzzy linguistic variable, namely "VL", "L", "M", "VH", "H" so that total combinations are 625 (5x5x5x5) rules. For example, fuzzy IF-THEN rule expressed as follows:IF Safety is Very High, and Quality is High, and Cost is Moderate, and Delivery is Low, THEN Fuzzy rank is critical.

Tabel-6. Designed fuzzy rules.

n rule	Safety	Quality	Cost	Delivery	Rank of equipment
1.	Very high	Very high	Very high	Very high	Critical
2.	Very high	Very high	Very high	High	Critical
3.	Very high	Very high	Very high	Medium	Critical
4.	Very high	Very high	Very high	Low	Critical
5.	Very high	Very high	Very high	Very low	Critical
6.	Very high	Very high	High	Very high	Critical
7.	Very high	Very high	High	High	Critical
8.	Very high	Very high	High	Medium	Critical
⁝			⁝		
362.	Medium	Very low	Medium	High	Major
363.	Medium	Very low	Medium	Medium	Major
364.	Medium	Very low	Medium	Low	Major
365.	Medium	Very low	Medium	Very low	Major
366.	Medium	Very low	Low	Very high	Major
⁝			⁝		
620.	Very low	Very low	Low	Very low	Minor
621.	Very low	Very low	Very low	Very high	Major
622.	Very low	Very low	Very low	High	Major
623.	Very low	Very low	Very low	Medium	Minor
624.	Very low	Very low	Very low	Low	Minor
625.	Very low	Very low	Very low	Very low	Minor

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c) Defuzzification

In this study, defuzzification process used centroid method, which crisp solution is obtained by taking the center of a fuzzy region. In general, it could be formulated as follows:

$$y^* = \frac{\int y.\mu(y)dy}{\int \mu(y)dy} \qquad (2)$$

Each score of QCDS which is inputted would give an output rating which can be translated into a linguistic variable. For example (as seen in Figure-7), if safety score is 7, and quality score is 5, and cost score is 8, and delivery score is 5 then rank score is 31.4. It means that this equipment can be categorized as "critical units."

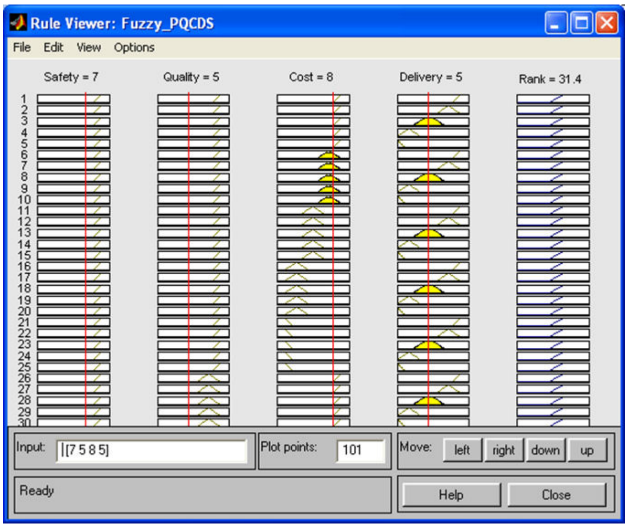

Figure-7. Rule viewer of fuzzy inference system by using Matlab toolbox.

Tabel-7. The results of equipment classification by comparing between conventional and fuzzy assessment.

Equipment	Safety (1)	Quality (2)	Cost (3)	Delivery (4)	Conventional Rank (1)+(2)+(3)+(4)	Fuzzy Rank	Appropriate (Y/N)
#1	9	8	8	7	Critical	Critical	Y
#2	8	3	3	3	Major	Critical	Y
#3	8	1	1	1	Minor	Critical	Y
#4	2	8	2	2	Major	Critical	Y
#5	4	4	4	9	Major	Major	Y
#6	2	2	2	8	Major	Major	Y
#7	1	1	1	8	Minor	Major	Y
#8	3	2	1	1	Minor	Minor	Y
#9	2	2	1	1	Minor	Minor	Y
#10	1	1	1	1	Minor	Minor	Y
#11	1	3	2	2	Minor	Minor	Y
#12	1	8	1	1	Minor	Critical	Y
#13	1	6	2	2	Minor	Major	Y
#14	1	1	8	1	Minor	Critical	Y
#15	7	5	8	5	Major	Critical	Y

CONCLUSIONS

This fuzzy model development was able to answer the challenge of the importance of expertise from the planning to the implementation, in order to achieve operational excellence. Fuzzy rules were designed and developed based on sharing knowledge and experience of the experts. In this study, indicators of productivity and delivery were considered equal. Due to the level of productivity related with the performance of the production equipment. And, delivery score is determined based on how the impact of equipment failure affects the speed losses, so that it might cause a delay of delivery to the next work-station or to customer. So, the delivery indicator is closely related to the productivity indicator of the equipment or system to meet production targets. Each indicator of Q-C-D/P-S has five (5) fuzzy linguistic variables, namely "VL", "L", "M", "VH", "H" so that overall there are 625 rules of combination. This model is able to cover the weaknesses in determining the classification of equipment which add up all scores from each indicator PQCDS. This means if a production equipment that has safety score of 9, but it has quality score of 1, cost score of 1, as well as delivery score of 1, so that it would be obtained a total score of 12. And, this equipment or facility would be categorized as "minor unit" or both "minor and major unit. "That is supposed that if the equipment has safety score of 9 then it should be considered to be "critical units. "The next study needs to consider the rating scale for each indicator with ordinal scale from 1 to 5, so it may reduce bias in the interpretation of each criterion.

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