A manufacturing quality assessment model based-on two stages interval type-2 fuzzy logic

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Abstract. This paper presents the development of an assessment models for manufacturing quality using Interval Type-2 Fuzzy Logic (IT2-FL). The proposed model is developed based on one of building block in sustainable supply chain management (SSCM), which is benefit of SCM, and focuses more on quality. The proposed model can be used to predict the quality level of production chain in a company. The quality of production will affect to the quality of product. Practically, quality of production is unique for every type of production system. Hence, experts opinion will play major role in developing the assessment model. The model will become more complicated when the data contains ambiguity and uncertainty. In this study, IT2-FL is used to model the ambiguity and uncertainty. A case study taken from a company in Yogyakarta shows that the proposed manufacturing quality assessment model can work well in determining the quality level of production.

1. Introduction

In recent years, Supply Chain Management (SCM) has received considerable attention from various parties [1]. SCM is an approach which used to achieve an efficient integration between supplier, manufacture, distributor, retailer and consumers [2]. It can be said that SCM is a business philosophy which trying to integrate various activities, parties or stakeholders and resources which connected between different level in an organization [3]. Various big companies in the world has applied SCM's concept in their system. SCM's concept highly favoured because it's able to integrate various business activities in a company and able to help the company for achieving competitive advantage [4]. In practice, SCM needs sustainable development in order to make it works successfully according to the company's expectation. Sustainable development in SCM has known as Sustainable Supply Chain Management (SSCM) which becomes hot issue for companies who have applied SCM in their company's system [3], [5].

SSCM is a strategy, transparency integration and the achievements of organisation's social, environment and economy goals in the systemic coordination of key business processes across the organization to improve long-term performance from individual and its supply chain in a company [6]. SSCM referred to as a key success of implementation of SCM, it's because the sustainable goals in SCM only able to obtained when the company has applied SSCM in their practice [7]. Knowing the importance of SSCM's practice in SCM's sustainable development in a company, it's necessary to assess SSCM [1]. The assessment of SSCM based on 7 building blocks which become factors in implementation of SSCM. The 7 building blocks in SSCM are reasons for SSCM, performance criteria

employed for SSCM, greening supply chains, characteristics of suppliers, managerial approaches for SSCM, barriers for SSCM, and benefits for SSCM [1].

In this study, the assessment is conducted based on one of building blocks, that is benefits for SSCM, and focus with one variable in that building blocks. The benefits for SSCM is a building blocks contains various advantages that can achieve by applying the SSCM. There are six variables from the benefits of SSCM which have big effect in SSCM, those variables are customer satisfaction, innovation capability of supplier, quality, trust, managing supply risk, and fill rate [1]. Among those variables, this research only focus on quality.

Based on ISO 9000, quality is defined as thorough character from a product or service which affect the ability of the product to meet the specific needs. Another definition, quality is thorough character of product and service which involve marketing, engineering, manufacture, and maintenance where the usage will meet the needs and expectation of customers [8]. In other words, quality is a variable which affect to customer satisfaction which becomes the goal of implementation of SSCM. Knowing the importance of quality, many companies do various approaches to control, fix, improve, and maintain the quality.

Some researchers have carried out studies to control, improve and maintain quality. Jain and Samrat (2015) have carried out a quality study overall at one of company in Gujarat to investigate and give recommendation that could be applied by other companies [9]. Thombansen et al. (2014) have carried out a quality setup and maintenance research on CO_2 laser cutting to propose an improvement for better quality [10]. The previous studies only assessed, analysed and proposed improvement at one time and the result still can't help the company to know their quality in the future. Therefore, it is required to do a study to assess and analyse quality in the future. This study answers such requirement by developing a prediction models for the quality. Quality prediction models is an approach to explain the relationship between operational manufacture and level of quality product. Quality prediction models is a key to enable the ability to estimate the level of product quality during operational manufacture goes on [11].

This study took place at a company in Yogyakarta, Indonesia. The company is one of *spiritus* factory. Actually, the company is one of production unit of sugar company in Yogyakarta, Indonesia, which has been established since 1995. In the implementation of quality control activities, the investigated company has three kinds of quality, such as material quality, process quality and final product quality. Actually, there are several factors to be considered for those qualities. However, in practice, the company only considers one or two factors to assess the quality. This is because of the limited of controlling time to accommodate all of affecting factors. To overcome such problems, this study develops prediction models for quality assessment by considering all of affecting factors which can help the company to assess and analyze the quality completely.

During preliminary study, it is found that there are several ambiguity and uncertainty factors in the quality system. Such factors can't be modelled using formal mathematical model as in the normal quality assessment system. The condition become more complicated when there are different expert opinions. Therefore, in this study, interval type-2 fuzzy logic (IT2-FL) is proposed as the basis of the quality assessment system. IT2-FL is an expansion and generalisation of the established fuzzy logic proposed by Lotfi A. Zadeh in 1975, which sometime is called as type-1 fuzzy logic (T1-FL). IT2-FL is stronger to deal with uncertainties than T1-FL [12] so that the result of IT2-FL will be more moderate to all of the experts in the investigated system.

2. Literatures review

2.1. Quality
Quality is one of multifaceted concept which describe how great the service, process, materials, or product has compatibility with the desired attributes or standard [13]. Some of quality definitions which described before show that quality is one of important aspects which cover almost all of parts in company. Quality of operational manufacture is one of quality aspect which becomes a special

attention for company. Operational manufacture's quality is a quality which covers the entire process of making product from raw materials, processing until end product.

Many organisation have created a standard and specification to help the quality assessor to be consistent [14]. Quality assessment on operational manufacture becomes an aspect which need to be performed by company because it can help the company to identify and analyse the operational manufacture's performance. By performing quality assessment, the company will be able to know their technical manufacturing condition, besides, it allows the company to do improvements if the anaylsis shows a low performance.

In this study, development of assessment models for a manufacturing quality adopts a study about quality that has been carried out by previous researchers [15]. Such quality study utilises three kinds of quality factors namely quality of raw materials, process and final product. Each quality factor has various attributes which become consideration in the assessment. The quality of raw materials has two attributes namely density with a *brix* unit and the percentage of glucose levels in raw materials. The raw materials to produce *spiritus* is molasses. The quality of process in the manufacture of *spiritus* has five important attributes namely initial density, final density, alcohol levels, pH and temperature. Whereas for the quality of final product, the attributes which used are those which appropriate with the Indonesian Standard (SNI). There are three considered attributes namely ethanol levels, barbet or *permanganate* test, and *fusel* oil.

2.2. IT2-FL

It's impossible to achieve great performance using traditional controller when the process which need to handle has high nonlinearity and uncertainty. It requires a specific approach which able to accommodate a process with high nonlinearity and uncertainty. One of approach that has proven able to accommodate a process with high nonlinearity and uncertainty is fuzzy logic controller (FLC) which the success is due to the resilience and its ability to handle nonlinear system [16].

FLC usually is developed using T1-FL [17]. Although has been widely recognised for its ability to handle uncertainty in a system, some previous research show that there is limitation in its ability to model and minimise effects of uncertainty [18]. This is because the membership function of T1-FL is crisp values [19]. To improve the limited capability of T1-FL in overcoming the ambiguity and uncertainty, recently there is a type of fuzzy controller called IT2-FL [20], which has a better performance to overcome all kinds of nonlinearity and uncertainty that appeared in a system.

IT2-FL is very useful to solve a case which has difficulty in determining the exact membership function or in modelling the various arguments from different individuals [19]. The IT-2FL has used in various area of controlling, such as control in [16], control in robot mobile autonomy [21], control in anaesthesia [22], control for quarter vehicle with active suspension [23], and level control [24] which all of implementations have been successfully demonstrated and confirmed superiority of IT2-FL more than T1-FL [16].

Figure 1 bellow shows the schematic diagram of an IT2-FL. It is similar to the T1-FL, the major difference is the fuzzy sets in the IT2-FL will be interval curve instead of crisp curve. Consequently, the output of IT-2FL will be interval fuzzy area and type reducer is required to get centroid point of the area. Similar with T1-FL, the crisp output will be obtained through a de-fuzzy-fication process.

Figure 1. Schematic diagram of IT2-FL in converting input to be output

3. The method

3.1. Two stages IT2-FL framework

In this study, the manufacture quality of the investigated company is affected by 3 factors namely material quality, process quality and final product quality. Such information is obtained from 2 experts in the company. All of those factors are uncontrollable factor. Material quality factor is affected by two controllable sub factors namely density of the material and glucose level. Process quality is affected five controllable sub factors namely initial density of the materials, final density of the material, alcohol level, pH and temperature. Final product quality is affected by three sub factors namely ethanol level, permanganate level and *fusel* oil content.

Based on the explanation above, there are two stages in predicting the manufacture quality. The first stage is used to predict material quality, process quality and final product quality while the second stage is used to predict the manufacture quality based on the material, process and final product quality. Figure 2 shows the diagram of the proposed two stages IT2-FL.

Figure 2. Diagram of two stages IT2-FL
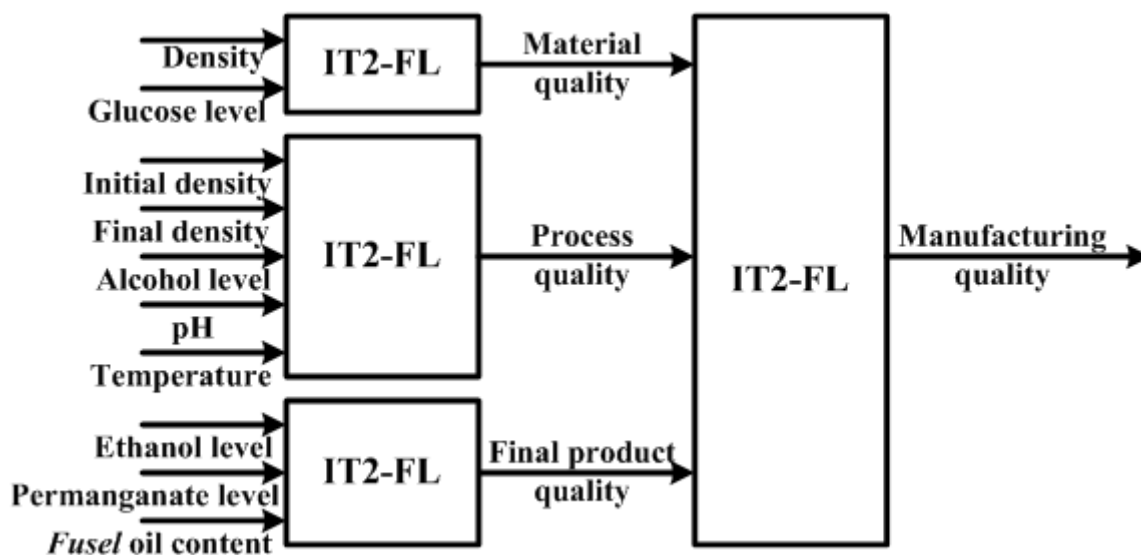
3.2. Material quality

In order to get steady state pattern, data from three periods of production at end of year 2014 is collected. The numerical data is then being converted into interval fuzzy set with experts assistance. Figure 3 bellow is the interval fuzzy set for every sub factors that affect to the material quality.
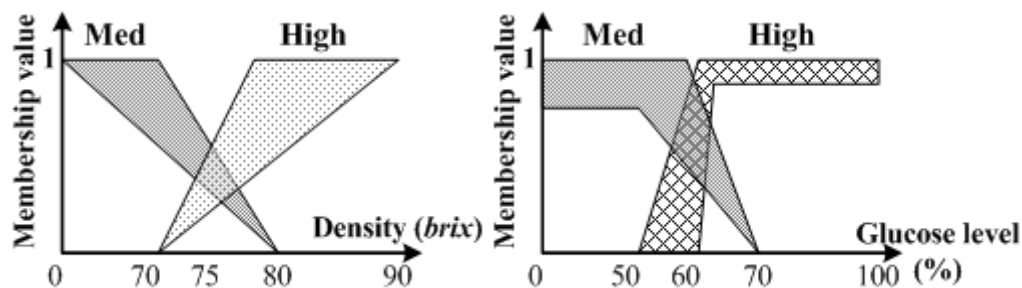

Figure 3. Interval fuzzy sets for density and glucose level

There are three fuzzy rules to predict material quality, as follows:

R_1: IF Density is HIGH AND Glucose level is HIGH THEN Material quality is HIGH (88-95)
R_2: IF Density is HIGH AND Glucose level is MEDIUM THEN Material quality is MEDIUM (68-73)
R_3: IF Density is MEDIUM AND Glucose level is MEDIUM THEN Material quality is MEDIUM (63-70)

3.3. Process quality

In this study, data to predict production process quality is collected during inspection of *spiritus* distillation process from August to December 2014. Fuzzy sets for input data namely initial density, final density, alcohol level, pH value and temperature are shown in Figure 4.
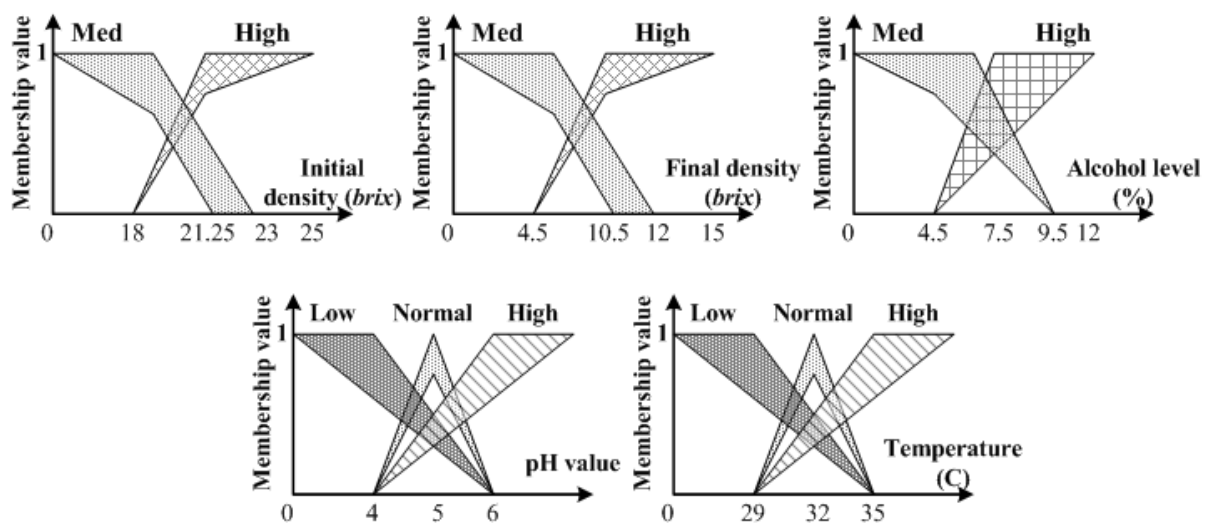

Figure 4. Fuzzy sets for every input of process quality prediction

To predict process quality, there are 9 selected fuzzy rules as follows:

R_1: IF Initial density is MEDIUM AND Final density is MEDIUM AND Alcohol level is MEDIUM AND pH value is NORMAL AND Temperature is NORMAL THEN Process quality is HIGH (87-93)
R_2: IF Initial density is MEDIUM AND Final density is MEDIUM AND Alcohol level is MEDIUM AND pH value is LOW AND Temperature is LOW THEN Process quality is LOW (67-73)
R_3: IF Initial density is MEDIUM AND Final density is MEDIUM AND Alcohol level is MEDIUM AND pH value is HIGH AND Temperature is HIGH THEN Process quality is LOW (65-77)
R_4: IF Initial density is HIGH AND Final density is HIGH AND Alcohol level is HIGH AND pH value is NORMAL AND Temperature is NORMAL THEN Process quality is MEDIUM (79-82)
R_5: IF Initial density is HIGH AND Final density is MEDIUM AND Alcohol level is MEDIUM AND pH value is NORMAL AND Temperature is NORMAL THEN Process quality is HIGH (83-92)
R_6: IF Initial density is MEDIUM AND Final density is HIGH AND Alcohol level is MEDIUM AND pH value is LOW AND Temperature is HIGH THEN Process quality is LOW (63-68)
R_7: IF Initial density is HIGH AND Final density is HIGH AND Alcohol level is HIGH AND pH value is LOW AND Temperature is HIGH THEN Process quality is LOW (60-65)

R$_8$: IF Initial density is HIGH AND Final density is MEDIUM AND Alcohol level is MEDIUM AND pH value is NORMAL AND Temperature is LOW THEN Process quality is MEDIUM (80-85)

R$_9$: IF Initial density is HIGH AND Final density is HIGH AND Alcohol level is MEDIUM AND pH value is HIGH AND Temperature is LOW THEN Process quality is LOW (63-65)

3.4. Final product quality

In the investigated manufacturing process, there are several independent variables that affect to the final product quality. Therefore, the final product quality must be predicted and will be one of the input in assessing manufacturing quality of the investigated company. Figure 5 shows the fuzzy sets for every input of the final product quality prediction.
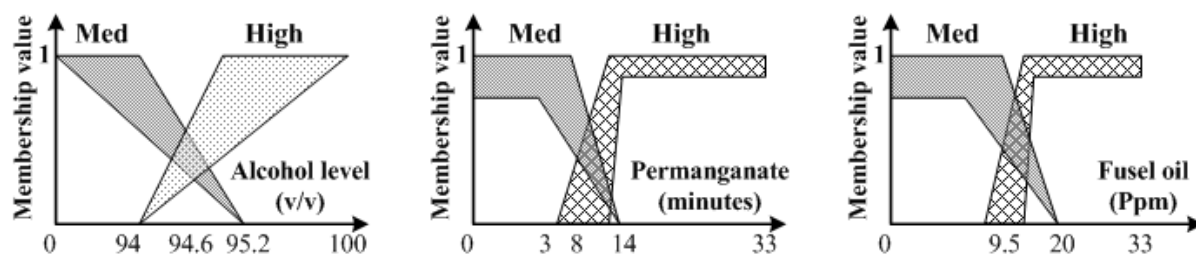

Figure 5. Fuzzy sets for every input of final product quality prediction

To predict final product quality, there are 5 selected fuzzy rules as follows:

R$_1$: IF Alcohol level is MEDIUM AND Permanganate is MEDIUM AND Fusel oil is MEDIUM THEN Final product quality is MEDIUM (63-67)

R$_2$: IF Alcohol level is MEDIUM AND Permanganate is HIGH AND Fusel oil is MEDIUM THEN Final product quality is MEDIUM (67-73)

R$_3$: IF Alcohol level is HIGH AND Permanganate is HIGH AND Fusel oil is HIGH THEN Final product quality is HIGH (80-85)

R$_4$: IF Alcohol level is MEDIUM AND Permanganate is MEDIUM AND Fusel oil is HIGH THEN Final product quality is HIGH (77-81)

R$_5$: IF Alcohol level is HIGH AND Permanganate is HIGH AND Fusel oil is MEDIUM THEN Final product quality is MEDIUM (70-76)

3.5. Manufacturing quality assessment

The manufacturing quality assessment is carried out by combining the three inputs which are material quality, process quality and final product quality through 7 selected fuzzy rules as follows:

R$_1$: IF Material quality is MEDIUM AND Final product quality is MEDIUM THEN Manufacturing quality is LOW (35-38)

R$_2$: IF Material quality is MEDIUM AND Final product quality is HIGH THEN Manufacturing quality is LOW (37-45)

R$_3$: IF Material quality is HIGH AND Process quality is HIGH AND Final product quality is HIGH THEN Manufacturing quality is HIGH (83-87)

R$_4$: IF Material quality is MEDIUM AND Process quality is LOW AND Final product quality is HIGH THEN Manufacturing quality is MEDIUM (69-73)

R$_5$: IF Material quality is MEDIUM AND Process quality is MEDIUM AND Final product quality is LOW THEN Manufacturing quality is LOW (32-37)

R$_6$: IF Material quality is HIGH AND Process quality is MEDIUM AND Final product quality is MEDIUM THEN Manufacturing quality is MEDIUM (70-75)

R$_7$: IF Material quality is MEDIUM AND Process quality is HIGH AND Final product quality is HIGH THEN Manufacturing quality is HIGH (78-84)

3.6. Fuzzy type reducer and de-fuzzy-fication
Output of T2-FL is still in the form of interval. In order to get the Crisp output, before de-fuzzy-fication, a type reducer is required. In this study, Karnik-Mendel algorithm is used as the IT2-FL type reducer. See [18] for the detail algorithm. In this study, a simple average *de-fuzzy-fication* method is used to convert the output of IT2-FL into a Crisp value.

4. System testing
Since the proposed assessment system is prediction system, then validation of the system is required. The proposed assessment system is developed based on primary data collection and experts opinion. Therefore, the validation method used in this study is experts confirmation. Such validation method is carried out by confirming the prediction result to the experts. A historical data set consists of ten data is used as the basis of the confirmation. Table 1 shows result of the experts confirmation.

Table 1. Confirmation result of IT2-FL in stage 1 and stage 2

Stage 1			Stage 2
Material quality	**Process quality**	**Final product quality**	**Manufacturing quality**
87 (high)	83 (high)	84 (high)	85 (high)
73 (medium)	75 (low)	79 (high)	75 (medium)
89 (high)	**78 (low)**	81 (high)	80 (high)
89 (high)	87 (high)	78 (high)	86 (high)
72 (medium)	75 (low)	**77 (high)**	74 (medium)
73 (medium)	77 (low)	76 (high)	75 (medium)
89 (high)	89 (high)	79 (high)	80 (high)
88 (high)	87 (high)	76 (high)	**76 (medium)**
70 (medium)	80 (medium)	70 (medium)	74 (medium)
87 (high)	82 (medium)	**73 (medium)**	78 (high)
Accuracy: 90%	Accuracy: 90%	Accuracy: 80%	Accuracy: 90%

Note: bold text is the wrong prediction

Based on Table 1 above, it can be said fairly that the proposed IT2-FL in stage 1 and stage 2 has high accuracy. Therefore, it can be proposed as a fast tool to assess manufacturing quality of a supply chain.

5. Conclusion and suggestion
Based on the explanation above, it can be concluded that manufacturing quality assessment in the investigated company can be carried out step by step. IT2-FL can be used as one of the tool to model the assessment system. IT2-FL also has interval in the fuzzy sets and consequent of the fuzzy rules. The interval helps the experts to be flexible in determining the fuzzy rules based on their logic and intuition. Accuracy of the proposed IT2-FL in every stage is quite high, that means it can be used as the assessment tool for the investigated manufacturing system.

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