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Implementation of Fuzzy Inference System for Production Planning Optimisation

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***Abstract*—Activities in manufacturing become uncertain and complex as there is always ambiguity in different states due to their diversity. In other words, the uncertainty can make the operations in the manufacturing companies become finite and result in unnecessary waste of resources in terms of money, labour or time. Therefore, production planning are essential activities to accurately predict production in the manufacturing sector. In the context of such factors, the purpose of this research is to introduce the Fuzzy Inference System (FIS) as an effective method that can assist in determining an optimal result to production variable. The fuzzy variables of customer demand, production and inventory are used to practice the theory, synthesising the activities in manufacturing in order to attain an effective and efficient operation in the industry. However, assumptions have been made that capacity of resources, machines and warehouse are not considered in this study. The finding of production data show the comparison performance between actual production and FIS Tsukamoto production, where FIS Tsukamoto production show a stable graph compared to actual production. Moreover, total production for FIS Tsukamoto is less than actual production. In general, FIS Tsukamoto is a simple method that can help to determine the optimal and appropriate quantity of manufactured goods to be handled within the operation by using the variables in the form of fuzzy numbers.**

Keywords: Decision Making, Fuzzy Inference System, Optimisation, Production Planning, Tsukamoto Method

I. INTRODUCTION

The changing market [1], requirements of the customers change over time [2]; [3], and lack of knowledge or insufficient information [4] contributes to uncertainties in the manufacturing sector. [5] indicated that, categorises this type of uncertainty as environmental uncertainty. Meanwhile, the production planning data can be catagorised as variability due to variations or differences in a process or quantity. This is due to the fact that assigning an exact value for a quantity is difficult because it depends on many parameters [4]. The uses of advanced information from corporate activities can support management to make more efficient and accurate decisions in order to achieve the control of operating processes, to improve the operational efficiency, and to reduce the costs of operating processes while increasing revenue in the sector [1].

Fuzzy logic theory provides a very useful solution to understanding, quantifying and handling vague, ambiguous and uncertain data [4]. This is supported by [6], who stated that artificial intelligence-based models are of particular interest to practitioners in order to address the production planning problems under uncertainty. The fuzzy logic expresses that nothing can be firmly stated as being right or wrong; such a statement is too extreme with only two available answers. Besides that, fuzzy logic is the study of methods which correspond to a set of of principles in giving meaningful information on unconditional or approximate reasoning that can be understood in human languages [7].

Author [8] stated that an ideal optimization in each activity of production is very important to ensure that the operations in the company run for a longer period of time. This can also reduce any surplus or shortage in the inventory provision. The implementation of FIS with the Tsukamoto method improves the quality of strategies in manufacturing from received of an order to supplying the needs of the marketplace by providing a fast and on- time delivery [9]. Therefore, the aim of this research to implement FIS with the Tsukamoto method in a manufacturing sector company to help to determine an optimal quantity of production based on inventory and demand capacities, in order to assist with operational decision making. Assumptions have been made that capacity of resources, capacity of machines and capacity of warehouse are not considered in this study.

The paper is organised as follows: it starts with a review of the literature on FIS Tsukamoto and framework. Following that is the explanation of FIS Tsukamoto steps. While in the last section some concluding remarks are then attained.

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II. MATERIAL AND METHODOLOGY

The fuzzy inference system is known by numerous of other names, such as fuzzy expert system, fuzzy model, fuzzy associative memory, and simply fuzzy system [10] based on the concepts of fuzzy set theory, fuzzy if-then rules, and fuzzy reasoning [11]. The basic structure of FIS is that it consists of a fuzzification unit, a fuzzy logic reasoning unit (process logic), a knowledge base, and a defuzzification unit, as illustrated in fig.1. According to [10] the basic structure of FIS consists of three conceptual components: a "rule base", which contains a selection of fuzzy rules; a "data base" (or "dictionary"), which defines the membership functions used in the fuzzy rules; and a "reasoning mechanism", which performs the inference procedure upon the rules and given facts to derive a reasonable output or conclusion.

A. Fuzzy Theory/Fuzzification

The concept of fuzzy theory infers that it is always impossible to live without ambiguity. It is hard to know and control everything on hand all the time. This is because of sudden and unforeseen occurrences, even if we may have scheduled and outlined a direction beforehand. The reality is that uncertainty or something that is unexpected still exists.

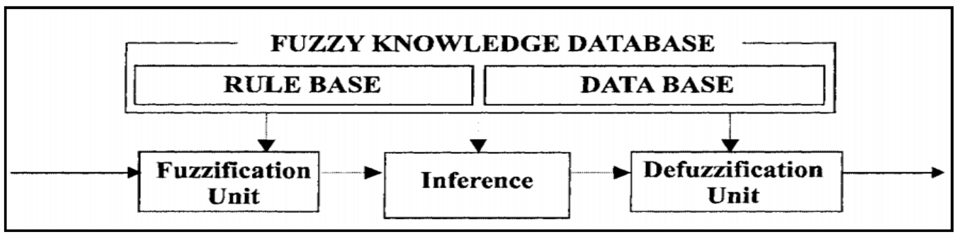

Fig. 1. Basic structure of FIS [12]

B. Fuzzy if-then rule

Reference [10] stated that the "fuzzy if-then rule" is also known as "fuzzy rule", "fuzzy implication", or "fuzzy conditional statement". The most common and widely used interpretation considers a fuzzy rule "**if** x is A **then** y is B" where A and B are linguistic values defined by fuzzy sets on universes of discourse X and Y, respectively. Often "x is A" is called "antecedent" or "premise", while "y is B" is called the "consequence" or "conclusion". An example of the fuzzy if-then rule in production-planning linguistic expressions is *if demand decreases then production is low*.

C. Fuzzy reasoning/Inference

Fuzzy reasoning, also known as approximate reasoning, is an inference procedure that derives conclusions from a set of fuzzy if-then rules and known facts [10]. The fuzzy reasoning unit performs various fuzzy logic operations to infer the output (decision) from the given fuzzy inputs.

D. Defuzzification

Defuzzification typically involves weighting and combining a number of fuzzy sets resulting from the fuzzy inference process in a calculation, which gives a single crisp value for each output [12]. Reference [12] also mentioned that the most commonly used defuzzification methods are mean of maximum, centroid, and centre of sum of areas.

According to [13], FIS can be used to predict uncertain systems and its application does not require knowledge of the underlying physical process as a precondition. Moreover, [14] mentioned that the success of FIS is due to its closeness to human perception and reasoning, as well as its intuitive handling and simplicity, which are important factors for acceptance and usability of the systems.

There are three types of FIS; Mamdani, Sugeno, and Tsukamoto. The *Mamdani* method, also known as the Max-Min method, was introduced by Ebrahim Mamdani in 1975. Meanwhile, the *Segeno* method - also known as the TSK method - was introduced by Takagi-Sugeno Kang in 1985. The third one is the *Tsukamoto* method, first introduced by Tsukamoto in 1979. The differences between the three methods are as follows; the antecedents for, and consequences of the Mamdani and Sugeno are fuzzy sets while in the Takagi–Sugeno–Kang models, the antecedent consists of fuzzy sets but the consequence is comprised of linear equations [15].

Based on previous studies, the Tsukamoto method has been widely applied in education [16]; [17], production [18], marketing [19], healthcare [20], and banking [21].

The study is conducted in several steps illustrated in Fig. 2. There are three steps for the FIS method - Fuzzification, Inference and Defuziffication. The Fuzzification technique begins with determining the input and output characters from the dataset of production planning. A fuzzy set is assigned for each of the input variables determined.

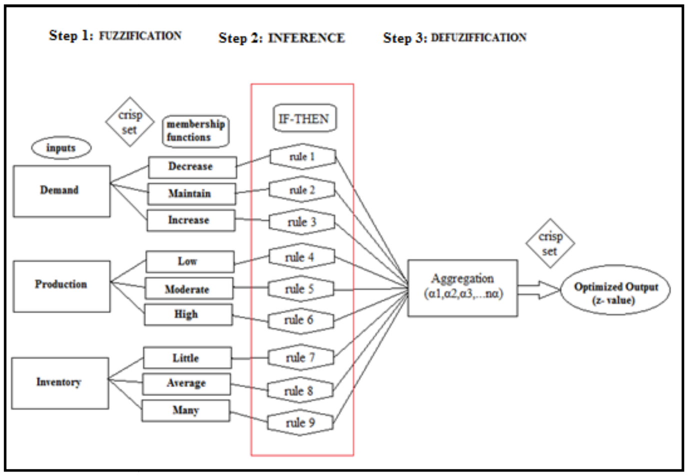

Fig. 2. The Framework FIS Tsukamoto for this study

III. DATA ANALYSIS

Fig. 3 shows the data of product demand, production and inventory for nine consecutive months. The minimum and maximum product demands from month 1 (n1) to month 9 (n9) are 468,460 units and 921,600 units. Next, the minimum and maximum productions are 483,840 units and 871,680 units. Meanwhile, the minimum and maximum inventory products are 105,600 units and 245,760 units as shown in fig. 4.

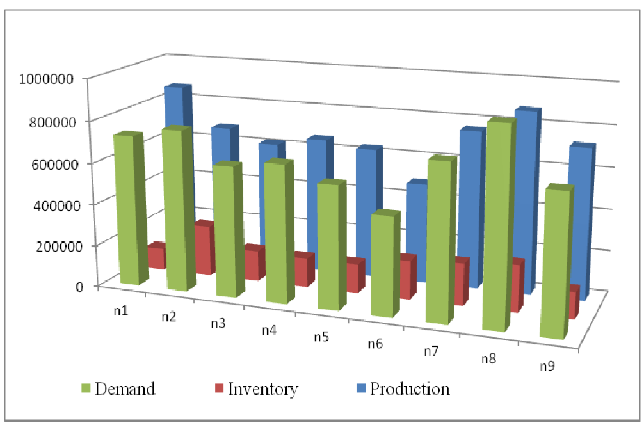

Fig. 3. Product demand, production and inventory for nine months

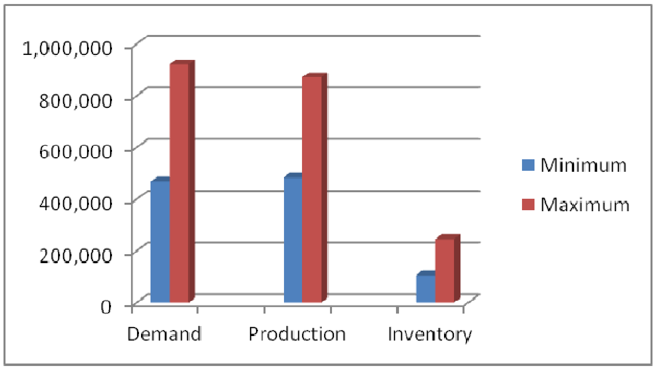

Fig. 4. Maximum and minimum unit for each variable

Table 1 shows the criteria of input and output variables. The input variables are Demand, Production and Inventory data. All these data are obtained from the production department. Meanwhile, the output is the optimised value for production, demand and inventory data.

TABLE I Criteria of Input and Output Variables

Criteria	Description	Functions
Demand	Customer Demand	Variable Input
Production	Production based on customer demand	Variable Input
Inventory	Stock	Variable Input
OD	Optimized Demand	Variable Output
OP	Optimized Production	Variable Output
OI	Optimized Inventory	Variable Output

Fuzzy sets for input variables are shown in Table 2. Fuzzy sets for Demand are DECREASE, MAINTAIN and INCREASE. Next, the sets for Production are LOW, MODERATE and HIGH. Meanwhile those for Inventory are LITTLE, AVERAGE and MANY.

TABLE II Fuzzy Sets for Input Variable

Input Variable	Fuzzy Sets
Demand	Decrease
	Maintain
	Increase
Production	Low
	Moderate
	High
Inventory	Little
	Average
	Many

Membership Functions

There is a need to apply a certain functional approach in obtaining the membership values in the fuzzy set. Author [22] state that, the membership function (MF) is a curve that shows the mapping of points of data input into the membership value that has the interval between 0 and 1. Membership functions for this study are three trapezoidal (low, moderate and high). The function used within this study is as follows:

i) Linear Representation

Linear Representation as shown below in (1) and Fig. 5, (2) and Fig. 6 is a set of grades which start with increasing form on the line from left to right within the domain for the increasing Linear Representation (Fig. 5). For instance, its membership grade probably began with 0, following which the domain values are leveled up with higher grades of membership. Meanwhile, Decreasing Linear Representation as shown below in Fig. 6 is the opposite of the Increasing Linear Representation. A highest grade of membership is leveling down from the left-hand side to the right hand side on a straight line which toward a smaller domain value.

$$\mu[z] = \begin{cases} 0 & x \le a \\ \frac{x-a}{b-a} & a \le x \le b \\ 1 & x \ge b \end{cases} \quad (1)$$

$$\mu[x] = \begin{cases} 1 & x \le a \\ \frac{b-x}{b-a} & a \le x \le b \\ 0 & x \ge b \end{cases} \quad (2)$$

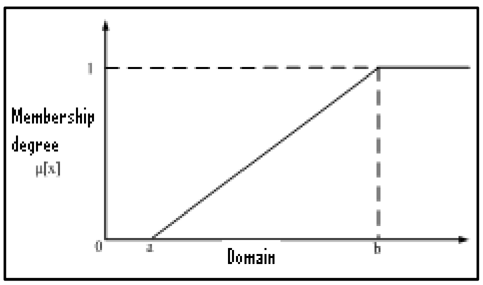

Fig. 5. Fuzzy Set on an Increasing Linear Representation

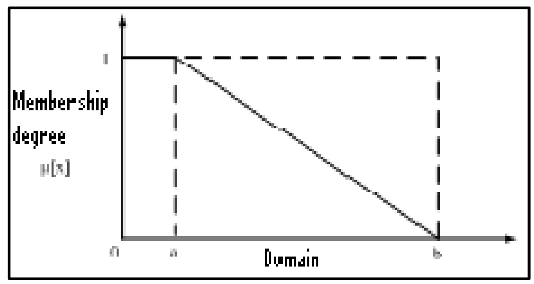

Fig. 6. Fuzzy Set on a Decreasing Linear Representation

ii) Triangle Curve Representation

Triangle Curve Representation is basically a merger between two linear representations which are the Increasing Linear Representation and the Decreasing Linear Representation as shown below in (3) and Fig. 7.

$$\mu[x] = \begin{cases} 0 & x \le a \text{ and } x \ge c \\ \frac{x-a}{b-a} & a \le x \le b \\ \frac{c-x}{c-b} & a < x < b \end{cases} \quad (3)$$

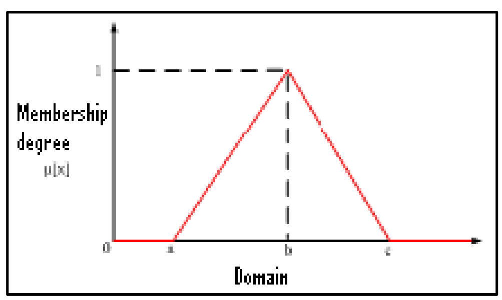

Fig. 7. Triangle Curve Representations

iii) Shoulder-shaped Curve Representation is a region which is located in the middle between variables represented within an outlined triangle as show in Fig. 8.

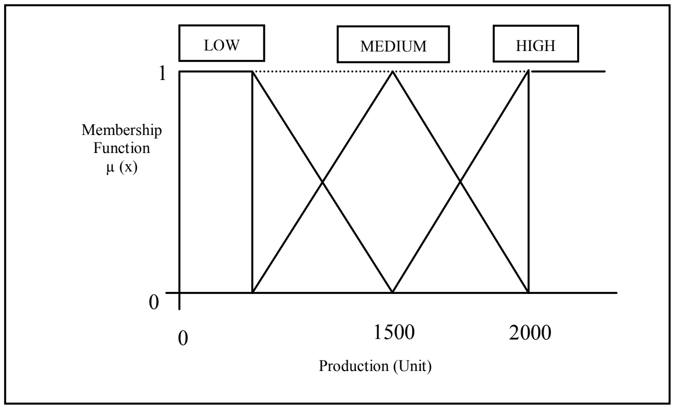

Fig. 8. Shoulder-shaped Curve Representation

iv) Operator of Fuzzy Set (AND)

There are several operations specifically defined for combination of, and modification to, conventional fuzzy sets. A two-operational set results in membership values which named as fire strength or α- predicates. For AND operator, the smallest membership function value among the aspects of the set is taking in order to practice it.

The second step is conducting inferences by making rules based on available data. In this stage, fuzzy rules that describe the local behaviour of the mapping are determined as follows:

[R1] IF Demand DECREASE And Inventory MANY Then Production LOW
[R2] IF Demand DECREASE And Inventory AVERAGE Then production LOW
[R3] IF Demand DECREASE And Inventory LITTLE Then Production LOW
[R4] IF Demand MAINTAIN And Inventory MANY Then Production LOW
[R5] IF Demand MAINTAIN And Inventory AVERAGE Then Production MODERATE
[R6] IF Demand MAINTAIN And Inventory LITTLE Then Production HIGH
[R7] IF Demand INCREASE And Inventory MANY Then Production HIGH
[R8] IF Demand INCREASE And Inventory AVERAGE Then Production HIGH
[R9] IF Demand INCREASE And Inventory LITTLE Then Production HIGH

Based on the rules, INFINITY and z values for each rule will be determined. INFINITY is a membership value of each rule antecedent, while z is the estimated value of goods to be produced from each rule. Each variable needed to identify a maximum value and minimum value of input variables. Table 3 shows result of z value for n4.

TABLE III Result of z value for n4.

i	αi	zi
1	0.2466	776038.66
2	0.4932	680397.31
3	0.5805	646538.88
4	0.2466	776038.66
5	0.4932	579481.34
6	0.7534	776038.66
7	0.2466	579481.34
8	0.4195	646538.88
9	0.4195	646538.88

The last step is defuzzification. This step determines the crisp output using an average Defuzzification Centralised method as shown in (4). The Z value obtained in this stage shows the amount of optimised production data for n4.

$$z = \frac{\sum_{i=1}^{n} w_i z_i}{\sum_{i=1}^{n} w_i} \quad (4)$$

$$= \frac{2649443.98}{3.8991}$$

$= 679{,}501.42$

$\approx 679{,}501$

The optimal production for n4 is 679,501 , meanwhile the actual production for n4 is 658,560. Therefore, the productions for n4 need to increase up to 19,941 to achieve optimise value. Fig. 9 shows comparison between actual production with Tsukamoto production for nine consecutive months. It shows that, the graph for Tsukamoto production is more stable than actual production. Moreover, the total production for Tsukamoto is less than actual production as shown on Fig. 10.

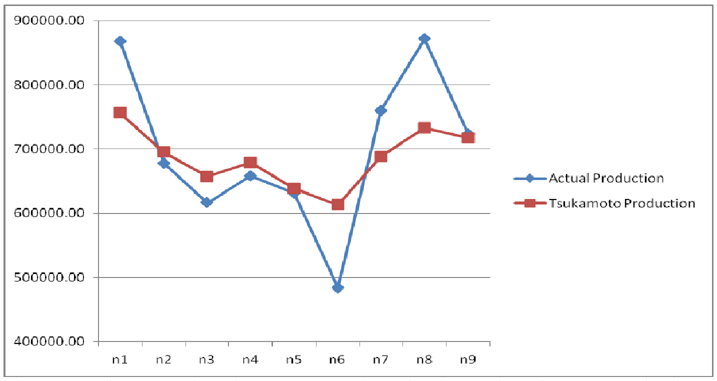

Fig. 9. Graph Comparison between Actual Production and Tsukamoto Production.

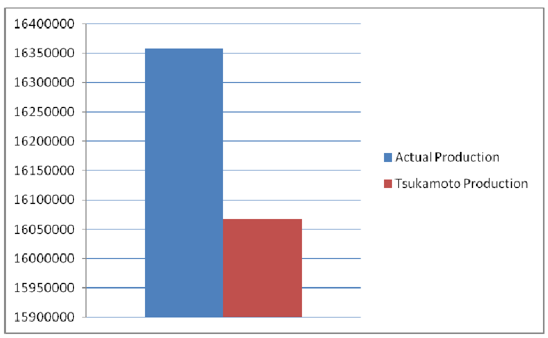

Fig. 10. Comparison of Total Production

IV. CONCLUSION

The paper focused on implemented the FIS with the Tsukamoto Method for production planning optimisation in electrical and electronics- related manufacturing company in order to achieve optimise production data in the environmental uncertainty and variability of data. FIS consists of three steps - fuzzification, inference, and deffuzzification. It is show that the production using FIS Tsukamoto produced stable production compared to actual production. Moreover, the total production for Tsukamoto is less than actual production. In nut shell, FIS Tsukamoto is a simple method that can help decision maker to determine the optimal and appropriate quantity of manufactured goods to be handled within the operation.

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