Manufacturing optimization using Tsukamoto fuzzy inference system method: A case study in block paving and solid concrete block industry

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Abstract. Fuzzy method has advantages in solving real-world problems that are mostly non-binary and non-linear, such as calculating the optimization of production quantities. A case study for the application of this method was applied in UD. Setia Kawan Company that run the production of solid concrete and block paving. The problems faced by this company is the high demand for products resulting in short stock and sometimes over stock due to unstable customer ordering and inaccurate management in production planning. From the calculations, the number of solid concrete block produced by the company on the period of October 2016, December 2016 and February 2017 was not optimal. According to Tsukamoto's FIS, the optimal number of solid concrete block in the third period is 9973, 9562 and 12.087 unit of solid concrete block. While the number of block paving produced by the company on the period of November 2016, December 2016 and January 2017 was also not optimal. According to Tsukamoto's FIS analysis, the optimal number of block paving in the third period should be 9.116, 10.113 and 7.120 unit of block paving

1. Introduction

Production planning is very important in the decision-making of a company strategy, particularly in manufacturing companies. The determination of the optimal number of products to be produced becomes the key to proper production planning. Production planning is conducted with the aim to meet consumer demand and to improve company productivity.. UD. Kawan Setia is one of the manufacturing companies engaged in the manufacture of solid concrete block and block paving. The problem faced by this company is the high demand for the product resulting in the company often experiencing short stock and some times over stock so that it is vulnerable to product damage. This is explained by the high demand data but the low inventory data and the amount of production in the period of October 2016 to March 2017 in demand, inventory and production data for both products. The problem occurs because of unstable ordering and lack of decision-making by

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the management in the production planning process. Fuzzy Inference System (FIS) is an approach which can be applied to aid the decision making and to resolve the issues [1-3].

In FIS, there are three methods, which are Tsukamoto, Mamdani and Sugeno. In Tsukamoto method, each consequence of IF-Then rules has to be represented with a fuzzy set with monotonous membership functions [2]. Accordingly, the output of the interference of each rule is explicitly given (crisp) based on α-predicate (fire strength). The end result is obtained by using a weighted average. In Mamdani method, input and output variables are divided into one or more fuzzy set(s). Consequently, the output of the interference of each rule uses the Max (maximum) method and the Additive (sum) method. The end result is numbers in the domain of the fuzzy set, where the data is processed by using some defuzzification methods on the composition rules to get the output. Conversely, in Sugeno method, which is similar to Mamdani method, the output (consequence) system is not a fuzzy set, but a constants or a linear equation [4].

The fuzzy inference system is a popular computing framework based on the concepts of fuzzy set theory, fuzzy if-then rules, and fuzzy reasoning. It has found to be a successful application in a wide variety of field, such as automatic control, data classification, decision analysis, expert systems, time series prediction, robotic, and pattern recognition [3][5]. This is because the Tsukamoto Fuzzy Inference System method can do reasoning on the same principle as human. The reasoning used by Tsukamoto's FIS is monotonous reasoning so that its output value can be calculated directly from the membership value associated with its antecedent [6]. In addition, this method has advantages that are very suitable for use in most real-world problems that are mostly non-binary and non-linear. Fuzzy Inference System Tsukamoto method is also one of a method for decision making. Especially in many uncertainties and vagueness situations, this method is very flexible and has a tolerance for any data existing [7]. The Fuzzy Inference System uses reasoning monotony in the process of solving problems. The workings of this method are to use the data production, inventory and demand data as input and then processed through the three stages of process to optimize the amount of the input of the third. The first phase, i.e. the transformation of Fuzzification input data be fuzzy sets. The second stage is the fuzzy inference process by entering the sets that has been formed into the rule. Finally, Defuzziification is the process of aggregation of fuzzy sets, fuzzy sets and changed into a crisp sets [8].

From the problem, the purpose of this research is to calculate the optimization of production number of solid concrete block and block paving by using Tsukamoto fuzzy inference system method.

2. Methodology

To obtain the optimal amount of production in order to remain stable so that it can increase the company profit, the following three stages of Tsukamoto's FIS were used:

I. *Fuzzification*. Fuzzification is the process of converting non-fuzzy variables (numerical variables) into fuzzy variables (linguistic variables) [4]. The variables that will be used must be defined first such as demand, inventory and production variable. Each variable has a fuzzy set. As an example, for inventory variable, the used fuzzy set is down, moderate, and up. Then, seek the membership value of each fuzzy set, on each variable. Membership value is obtained by representing each fuzzy set with a membership function. There are six functions that can be used which are, representation of Linear, triangular curve, the curve shape of the shoulder, s-curve, trapezoidal curve, and the curve of the oval shape

II. *Inference*. Inference is the process of combining many rules based on available data. Fuzzy inference system receives crisp input. This input is then sent to a knowledge base that contains n fuzzy rules in the form of IF-THEN. After determining the rules that will be used, then find the value of the antecedent membership or fire strength (α), and the estimated value of goods to be manufactured (z) of each rule, using the membership value of each fuzzy set. A Fuzzy inference system with a crisp output is shown in **Fig.1**.

III. *Defuzzyfication*. Determine the crisp output value will be the number of goods produced (Z), by changing the input (in the form of fuzzy sets derived from the composition of fuzzy rules) into a number of fuzzy sets in the domain. Defuzzyfication method used in the Tsukamoto method is centered average method. This formulation is to determine the crisp output value that will be the number of goods produced (Z), by changing the input (in the form of fuzzy sets derived from the composition of fuzzy rules) into a number of fuzzy sets in the domain. This is the centered average method equation:

$$Z = \frac{\sum_{i=1}^{n} aixi}{\sum_{i=1}^{n} ai} \qquad 1$$

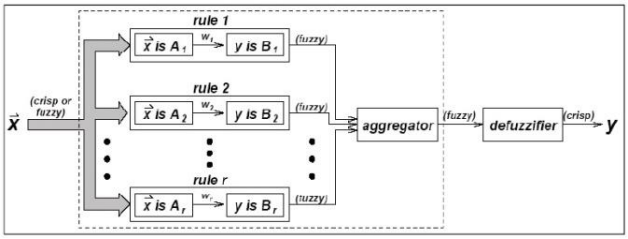

Fig. 1. Block diagram for a *Fuzzy Inference System*

3. Result And Discussion

The data of demand, stock and production amount of solid concrete block in the period Oct. 2016 – March 2017 can be seen in the **Table 1**, while the data of demand, stock and production amount of block paving in the same period can be seen in the **Table 2.**

3.1. Tsukamoto's FIS

The Tsukamoto's FIS basically consists of four steps i.e. Fuzzyfication, Rule 'IF-THEN', Inference, and Defuzzyfication. Each step has its own process to get an output. The process steps of Tsukamoto's FIS method as shown in **Table 3.**

Table 1. Data Demand, Stock And Amount of Production Solid Concrete Block

Period	Demand (units)	Amount of Production (units)	Stock (units)
Oct-16	7.373	12.500	450
Nov-16	5.805	7.538	5.577
Des-16	13.975	7.110	7.310
Jan-17	15.675	12.652	445
Feb-17	10.500	9.700	-2.578
Mar-17	11.900	12.124	-800

Table 2. Data Demand, Stock And Amount of Production Block Paving

Period	Demand (units)	Amount of Production (units)	Stock (units)
Oct-16	10.050	9.840	640
Nov-16	8.400	7.120	430
Des-16	10.850	9.800	-850
Jan-17	6.785	8.780	-1.050
Feb-17	9.745	10.540	1.995
Mar-17	11.950	9.650	2.790

Table 3. The Translation of The Steps of Fis Tsukamoto Method

Step	***FIS Tsukamoto***
Fuzzyfication	Non fuzzy to fuzzy or from numerical variable to linguistic variable
Rule 'IF-THEN"	Formation of shaped rules 'IF-THEN' is done by connecting between input variables and output variables using operators "*and"*
Inference	1. Function implication with function "min" 2. The composition between rules uses monotonic reasoning
Defuzzyfication	Calculation using the centre average defuzzifier method

3.2 Fuzzyfication

Fuzzyfication aims to turn crisp input data into fuzzy. This study used several variables in determining the amount of production. A formation of fuzzy sets is used to define crisp input values. Demand and supply as input variable and production as output variables. Universe of Discourse in this study is obtained from the lowest data and the highest data from the company. For solid concrete block product, the universe of discourse value of demand variable is [5.805, 15.675], inventory variable is [-2.578, 7.310] and production variable is [7.110, 12.625]. As for block paving products, the universe of discourse value of demand variable is [6,785, 11,950], inventory variable is [-1.050, 2,790] and production variable is [7,120, 10,540]. Each fuzzy set has domains whose values are in universe of discourse. The domains in fuzzy set obtained the lowest data, the lower quartile (Q1), the median (Q2) and the upper quartile (Q3) as well as the company highest data. Before calculating quartile and median values, it is needed to sort the data first. The fuzzy set value of each variable for solid concrete block and block paving products is presented in **Table 4** and **Table 5**. There are three fuzzy variables that will be represented in membership function i.e. demand variable with small, medium, large fuzzy set, inventory variable with small, medium, large fuzzy set and production variables with reduced, permanent and increased fuzzy set.

Table 4. The Fuzzy Set Value Of Each Variable For Solid Concrete Block Manufacturing

Function	Variable	Fuzzy Set	Universe of Discource	Domain
Input	Demand	Small	[5.805, 15.675]	[5.805, 11.200]
		Medium		[7.373, 13.975]
		Large		[11.200, 15.675]
	Stock	Small	[-2.578, 7.310]	[-2.578, 447,5]
		Medium		[-800, 5.577]
		Large		[447,5, 7.310]
Output	Production	Reduced	[7.110, 12.625]	[7.110, 10.912]
		Permanent		[7.538, 12.500]
		Increases		[10.912, 12.625]

Table 5. The Fuzzy Set Value Of Each Variable For Paving Block

Function	Variable	Fuzzy Set	Universe of Discourse	Domain
Input	Demand	Small	[6.785, 11.950]	[6.785, 9.897,5]
		Medium		[8.400, 10.850]
		Large		[9.897,5, 11.950]
	Stock	Small	[-1.050, 2.790]	[-1.050, 535]
		Medium		[-850, 1.995]
		Large		[535, 2.790]
Output	Production	Reduced	[7.120, 10,540]	[7.120, 9.725]
		Permanent		[8.780, 9.840]
		Increases		[9.725, 10.540]

3.3 Representation of Solid Concrete Block Product Demand Variable

The membership function of small fuzzy set used membership function of left curve shape of the shoulder. In solid concrete block product, the membership function is divided into three intervals, [0, 5.805], [5.805, 11.200] and [11.200, ∞]. For the membership function of medium fuzzy set, a triangular membership function was used in which this function was divided into three intervals, [0, 7.373], [7.373, 11.200], and [11.200, 13.975]. For the membership function of large fuzzy set, increased linear membership function was used in which this function was divided into three intervals, [0, 11.200], [11.200, 15.675], and [15.675, ∞]. The fuzzy set of demand variable of solid concrete block products can be seen in **Fig.2**.

3.4 Representation of Solid Concrete Block Products Inventory Variable

In solid concrete block product, the membership function was divided into three intervals, [0, -2.578], [-2.578, 447.5] and [447,5,∞], medium fuzzy set, triangular membership function was used in which this function was divided into three intervals, [0, -800], [-800, 447.5], and [447.5, 5.577], large fuzzy set, increased linear membership function was used, in which this function was divided into three intervals, [0, 447.5], [447.5, 7.310], and [7.310, ∞]. Fuzzy set of inventory variable of solid concrete block products is in **Fig.3**.

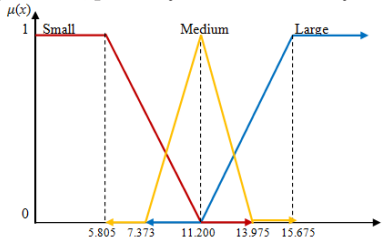

Fig.2. The fuzzy set of solid concrete block demand variable

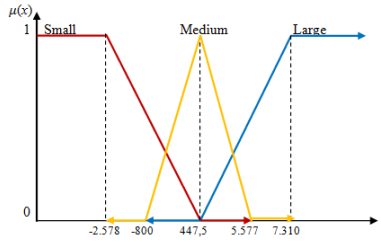

Fig.3. The fuzzy set of solid concrete block stock variable

3.5 Representation of Solid Concrete Block Products Production Variable

In Table 4, the membership function of decreased fuzzy set used membership function of left curve shape of the shoulder. In solid concrete block product, the membership function was divided into three intervals, [0, 7.110], [7.110, 10.912] and [10.912, ∞], permanent fuzzy, triangular membership function was used in which this function was divided into three intervals, [0, 7.538], [7.538, 10.912], and [10.912, 12.500], increased fuzzy, increased linear membership function was used in which this function was divided into three

intervals, [0, 10.912], [10.912, 12.625], and [12.625, ∞]. The fuzzy set of production variable for solid concrete block products can be seen in **Fig.4**.

3.6 Representation of Block Paving Product Demand Variable

From **Table 5**, the membership function of small fuzzy set used membership function of left curve shape of the shoulder. In solid concrete block product, the membership function was divided into three intervals, [0, 6.785], [6.785, 9897.5] and [9.897,5, ∞], medium fuzzy, triangular membership function was used in which this function was divided into three intervals, [0, 8.400], [8.400, 9.897,5], and [9.897,5, 10.850], large fuzzy, increased linear membership functions was used in which this function was divided into three intervals, [0, 9.897,5], [9.897,5, 11.950], and [11.950, ∞]. The fuzzy set of demand variable for block paving is in **Fig.5**.

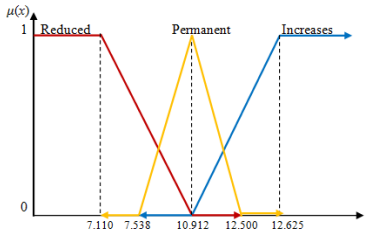

Fig. 4. The fuzzy set of solid concrete block production variable

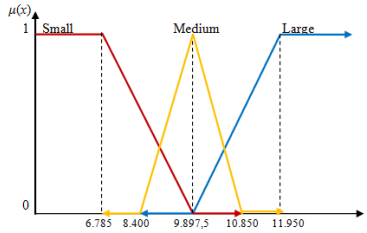

Fig.5. The fuzzy set of paving block demand variable

3.7 Representation of Block Paving Products Inventory Variable

In solid concrete block product, the membership function was divided into three intervals, [0, -1.050], [-1.050, 535] and [535, ∞], for the membership function of medium fuzzy set, triangular membership function was used in which this function was divided into three intervals, [0, -850], [-850, 535], and [535, 1.995], large fuzzy, decreased linear membership was used in which this function was divided into three intervals, [0, 535], [535, 2.790], and [2,790,∞]. The fuzzy set of paving block stock variable in **Fig.6**.

3.8 Representation of Block Paving Products Production Variable

In **Table 5**, decreased fuzzy set used left curve shape of the shoulder membership function. In solid concrete block product, the membership function was divided into three intervals, [0, 7.120], [7.120, 9.725] and [9.725, ∞], crisp fuzzy set, triangular membership function was used in which this function was divided into three intervals, [0, 8.780], [8.780, 9.725], and [9.725, 9.840], increased fuzzy set, increased linear membership function was used in which this function was divided into three intervals, [0, 9.725], [9.725, 10.540], and [10.540, ∞]. Fuzzy set of production variables for block paving is in **Fig.7**.

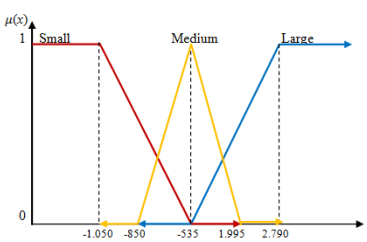

Fig.6. The fuzzy set of paving block stock variable

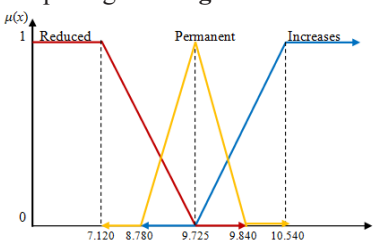

Fig.7. The fuzzy set of paving block production variable

3.9 Formation of Rule'IF-THEN'

After fuzzyfication process, then the next step is to form fuzzy rule by connecting input variable and output variable. Each rule has two antecedents and one consequent. The operator used in rules formation is operator and. Each product has 27 rules. This is due to each product has three fuzzy sets for each fuzzy variable. The forming of fuzzy rule for solid concrete block and block paving product is in **Tables 6** and **Table 7**.

Table 6. Fuzzy Rule Of Solid Concrete Block Product

Rule	Antecedents	Demand	Operation	Stock	Consequent	Production
R1	*IF*	Large	*and*	Small	*THEN*	Increases
R2	*IF*	Large	*and*	Small	*THEN*	Permanent
R3	*IF*	Large	*and*	Small	*THEN*	Reduced
R4	*IF*	Large	*and*	Medium	*THEN*	Increases
R5	*IF*	Large	*and*	Medium	*THEN*	Permanent
R6	*IF*	Large	*and*	Medium	*THEN*	Reduced
R7	*IF*	Large	*and*	Large	*THEN*	Increases
R8	*IF*	Large	*and*	Large	*THEN*	Permanent
R9	*IF*	Large	*and*	Large	*THEN*	Reduced
R10	*IF*	Medium	*and*	Small	*THEN*	Increases
R11	*IF*	Medium	*and*	Small	*THEN*	Permanent
R12	*IF*	Medium	*and*	Small	*THEN*	Reduced
R13	*IF*	Medium	*and*	Medium	*THEN*	Increases
R14	*IF*	Medium	*and*	Medium	*THEN*	Permanent
R15	*IF*	Medium	*and*	Medium	*THEN*	Reduced
R16	*IF*	Medium	*and*	Large	*THEN*	Increases
R17	*IF*	Medium	*and*	Large	*THEN*	Permanent
R18	*IF*	Medium	*and*	Large	*THEN*	Reduced
R19	*IF*	Small	*and*	Small	*THEN*	Increases
R20	*IF*	Small	*and*	Small	*THEN*	Permanent
R21	*IF*	Small	*and*	Small	*THEN*	Reduced
R22	*IF*	Small	*and*	Medium	*THEN*	Increases
R23	*IF*	Small	*and*	Medium	*THEN*	Permanent
R24	*IF*	Small	*and*	Medium	*THEN*	Reduced
R25	*IF*	Small	*and*	Large	*THEN*	Increases
R26	*IF*	Small	*and*	Large	*THEN*	Permanent
R27	*IF*	Small	*and*	Large	*THEN*	Reduced

After calculating the number of solid concrete block production in the period of October 2016 - March 2017, the output can be seen in **Table 8**. Similarly to solid concrete block product, optimal is the best, the highest, the most profitable, the best or the highest. The output result of production quantity of block paving by using Tsukamoto's FIS can be seen in **Table 9**. After obtaining the optimal production result with Tsukamoto's FIS, the next step is to predict the production for the future period. The prediction method used is constant method and linear method. From the calculation of SEE (Standard Error Estimate) for both methods of predicting, then the best method is used to determine the amount of production based on demand data for the next six months period which is the linear method

with the smallest SEE value.

Table 7. Fuzzy Rule Of Paving Block Product

Rule	Antecedents	Demand	Operation	Stock	Consequent	Production
R1	*IF*	Large	*and*	Small	*THEN*	Increases
R2	*IF*	Large	*and*	Small	*THEN*	Permanent
R3	*IF*	Large	*and*	Small	*THEN*	Reduced
R4	*IF*	Large	*and*	Medium	*THEN*	Increases
R5	*IF*	Large	*and*	Medium	*THEN*	Permanent
R6	*IF*	Large	*and*	Medium	*THEN*	Reduced
R7	*IF*	Large	*and*	Large	*THEN*	Increases
R8	*IF*	Large	*and*	Large	*THEN*	Permanent
R9	*IF*	Large	*and*	Large	*THEN*	Reduced
R10	*IF*	Medium	*and*	Small	*THEN*	Increases
R11	*IF*	Medium	*and*	Small	*THEN*	Permanent
R12	*IF*	Medium	*and*	Small	*THEN*	Reduced
R13	*IF*	Medium	*and*	Medium	*THEN*	Increases
R14	*IF*	Medium	*and*	Medium	*THEN*	Permanent
R15	*IF*	Medium	*and*	Medium	*THEN*	Reduced
R16	*IF*	Medium	*and*	Large	*THEN*	Increases
R17	*IF*	Medium	*and*	Large	*THEN*	Permanent
R18	*IF*	Medium	*and*	Large	*THEN*	Reduced
R19	*IF*	Small	*and*	Small	*THEN*	Increases
R20	*IF*	Small	*and*	Small	*THEN*	Permanent
R21	*IF*	Small	*and*	Small	*THEN*	Reduced
R22	*IF*	Small	*and*	Medium	*THEN*	Increases
R23	*IF*	Small	*and*	Medium	*THEN*	Permanent
R24	*IF*	Small	*and*	Medium	*THEN*	Reduced
R25	*IF*	Small	*and*	Large	*THEN*	Increases
R26	*IF*	Small	*and*	Large	*THEN*	Permanent
R27	*IF*	Small	*and*	Large	*THEN*	Reduced

Table 8. Output Of Production Quantities Of Solid Concrete Block With *Fis Tsukamoto* Method

Period	Demand (units)	Stock (units)	Company production (units)	*FIS Tsukamoto* Production (units)
Okt-16	7.373	450	12.500	9.937
Nov-16	5.805	5.577	7.538	8.061
Des-16	13.975	7.310	7.110	9.562
Jan-17	15.675	445	12.652	11.072
Feb-17	10.500	-2.578	9.700	12.087
Mar-17	11.900	-800	12.124	11.708

Table 9. Output Of Production Quantities Of Paving Block With *Fis Tsukamoto* Method

Period	Demand (units)	Stock (units)	Company production (units)	*FIS Tsukamoto* Production (units)
Oct-16	10.050	640	9.840	9.571
Nov-16	8.400	430	7.120	9.116
Des-16	10.850	-850	9.800	10.113
Jan-17	6.785	-1.050	8.780	7.120

Feb-17	9.745	1.995	10.540	10.540
Mar-17	11.950	2.790	9.650	9.725

4 Conclusion

The number of solid concrete blocks produced by the company in the period of October 2016, December 2016 and February 2017 according to Tsukamoto's FIS method was not optimal, while in the period of November 2016 and March 2017 was optimal according to Tsukamoto's FIS. For the period of January 2017 the company was only able to produce 12.652 solid concrete blocks. Based on Tsukamoto's FIS method, the optimal number of solid concrete block production in the three non-optimal periods is 9.973, 9.562 and 12.087 solid concrete blocks. After calculation to predict production amount of six months ahead, the best method that can be used is linier method with smallest SEE value.

The number of block paving produced by the company in the period of October 2016 based on Tsukamoto's FIS method was optimal, while the number of company production that was not been optimal was in November 2016, December 2016 and January 2017. For the period of March 2017, according to Tsukamoto's FIS, the company was only able to produce 9.725 blocks. According to Tsukamoto's FIS method, the optimal amount of production for the three non-optimal periods is 9.116, 10.113, 7.120 block paving. After calculation to predict production amount of six months ahead, the best method that can be used is linear method with smallest SEE value.

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