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PERFORMANCE EVALUATION OF A FLOW-LINE BY IMPROVING ANFIS SUGENO WITH FIS MAMDANI

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Rezumat. *Această lucrare prezintă metoda Fuzzy Logic pentru a evalua performanța unei linii de flux reale. Linia de flux cuprinde un număr de mașini care sunt dispuse în serie, iar fluxul de produse este continuu. Obiectivul acestei lucrări constă în prognozarea ratei de producție a unui sistem de fabricație folosind metoda Fuzzy Logic prin ANFIS SUGENO și FIS MAMDANI. Datele de intrare sunt prelucrate în ANFIS SUGENO pentru a vizualiza modul de construcție al funcțiilor de apartenență de intrare, cu scopul de a realiza un model propriu FIS MAMDANI. Funcțiile de apartenență ale variabilelor de intrare sunt modificate prin eliminarea valorilor ce depășesc domeniul de reprezentare, urmând ca apoi să fie stabilite regulile de inferență și domeniul de reprezentare a variabilelor de ieșire. Formele funcțiilor de apartenență sunt foarte importante, deoarece ele influențează precizia de prognoză. Un studiu de caz este realizat pentru a demonstra performanța și flexibilitatea abordărilor propuse.*

Abstract. *This paper presents the Fuzzy Logic method in order to evaluate the performance of a real flow-line. The flow-line comprises a number of machines that are arranged in series and the flow of products is continuous. The objective of this paper consists in the production rate prediction of a manufacturing system using the Fuzzy Logic method through ANFIS SUGENO and FIS MAMDANI. Input data are processed in ANFIS SUGENO to view the construction mode of the input membership functions in order to achieve our own model of FIS MAMDANI. Input variables' membership functions are modified by removing the values which exceed the representation range, after which the inference rules and the representation range of the output variables are to be established. The forms of membership functions are very important because they influence the prediction accuracy. A case study is carried out to demonstrate the performance and flexibility of the proposed approaches.*

Keywords: estimation, flow-line, ANFIS SUGENO, FIS MAMDANI.

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1. Introduction

Nowadays, companies have to synchronize their production in conformity with market needs. For that, it is necessary to evaluate the performance of manufacturing systems. In this paper, we considered a flow-line as a manufacturing system. In order to evaluate de performance of a manufacturing system, this study aims to apply the fuzzy logic method. In the first stage, we proposed the ANFIS SUGENO method in order to view the construction mode of the input membership functions. Then, the FIS MAMDANI method is applied in order to establish the inference rules and the representation range of the output variables. For the model fuzzy implementation we used a programming language such as Matlab. The use of fuzzy logic represents a feasible method for modelling and finding a solution for the stochastic problem. The cycle time of machines in a flow line is considered as a stochastic variable and is established by a required production rate. This production rate is calculated so that the required quantity of finished products is produced within a set period of time. The scope of the applicability is to estimate the production rate of a manufacturing system using the Fuzzy logic method through ANFIS SUGENO and FIS MAMDANI.

2. Related Works

In many applications the fuzzy logic modelling is based on the engineers' knowledge. The fuzzy membership functions and the fuzzy rules are difficult to generate, thereby the experience of engineers is very important. Many methodologies for generating the membership functions and fuzzy rules from data can be found in the literature. Isomursu classified the design parameters as follows: Fuzzification, Database, Rule Base, Logic Decision Making, and Defuzzification [1]. Chen implemented an algorithm in which complicated input-output data are decomposed into simpler input-output data [2].

In the field of industrial engineering, D. Fonseca used the fuzzy logic as a feasible method for modelling and finding a solution for the stochastic problem to balance an assembly line [3]. N. Tsourveloudis et al. used a set of distributed fuzzy controllers at one level to reduce Work in Process and to coordinate the operation of the production system [4].

Also, a method to maintain the WIP and cycle time at reduced levels and the machine utilization and throughput in high level was proposed [5]. S.M. Homayouni used Genetic algorithm to adjust the membership functions of Supervisory Fuzzy controllers and to increase the performance of Genetic Supervisory Fuzzy controllers. The main objective was to synchronize the production rate in order to satisfy the demand of final products while maintaining minimum WIP and delays within the production system [6].

3. Theoretical Framework and Research Methodology

In this research we use a fuzzy model with the following stages [7-10]:

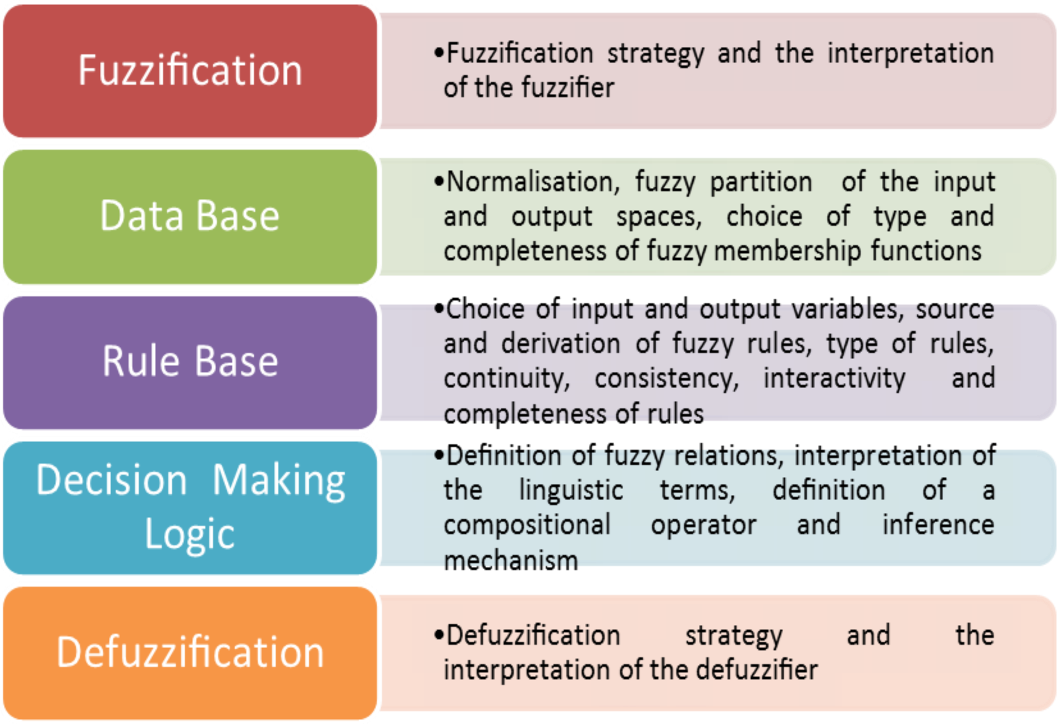

Fig. 1. Phases of Fuzzy Logic.

The membership function $\mu_F(u)$ of a fuzzy set F is defined as follow:

$$\mu_F(u): U \rightarrow L \tag{1}$$

where, L represents any set at least partially ordered (L -fuzzy set, L stands for lattice) and is considered an interval of real numbers [0, 1]. The membership function allocates to each $u \in U$ a value from the unit interval [0, 1]. The sets fuzzy represent the sets defined with generalised membership functions. F is completely defined as a set of tuples Zadeh (1965) [7]:

$$F = \{u, \mu_F(u)\} | u \in U\ . \tag{2}$$

The value of $\mu_F(u)$ is considered a single number or an interval of real numbers. Zadeh (1965) defined Fuzzy sets as an interval valued fuzzy sets, as follows [7]:

$$F = \{u, \mu_F(u)\} | u \in U \tag{3}$$

where $P(L)$ represents the set of all fuzzy subsets of L.

The most important membership functions are: Triangular, Trapezoidal, Generalized bell, Gaussian, Pi, Difference between two sigmoidal, Product of two sigmoidal, etc.

1) Triangular membership function

The syntax of the function is: *y* = trimf(*x*, [*a b c*]).
The triangular curve is a function of a vector, *x*, and is conditioned by three scalar parameters *a*, *b*, and *c*, as follows:

$$f(x;a,b,c)=\begin{cases} 0, & x\le a \\ \dfrac{x-a}{b-a}, & a\le x\le b \\ \dfrac{c-x}{c-b}, & b\le x\le c \\ 0, & c\le x \end{cases} \qquad (4)$$

2) Trapezoidal membership function

The syntax of the function is: *y* = trapmf(*x*, [*a b c d*]).

The trapezoidal curve is a function of a vector, *x*, and is conditioned by four scalar parameters *a*, *b*, *c*, and *d*, as follows:

$$f(x;a,b,c,d)=\begin{cases} 0, & x\le a \\ \dfrac{x-a}{b-a}, & a\le x\le b \\ 1, & b\le x\le c \\ \dfrac{d-x}{d-c}, & c\le x\le d \\ 0, & d\le x \end{cases} \qquad (5)$$

In this paper a model is proposed which has the following steps:

1. Establishing input data.
2. Processing input data in ANFIS SUGENO to view the construction mode of input membership functions.
3. Construction of the FIS MAMDANI model for estimating the production rate:

   3.1 The ANFIS SUGENO triangular membership functions are preserved for the input variables with the modification of the intervals.

   3.2 Establishing inference rules.

   3.3 The Sugeno output function is replaced with the Mamdani type.

4. Results Achieved in a Real-case Study

4.1 Data collection

We proposed to evaluate it by the fuzzy logic method, a real case study, a flow-line consisting of 8 machines [11-13].

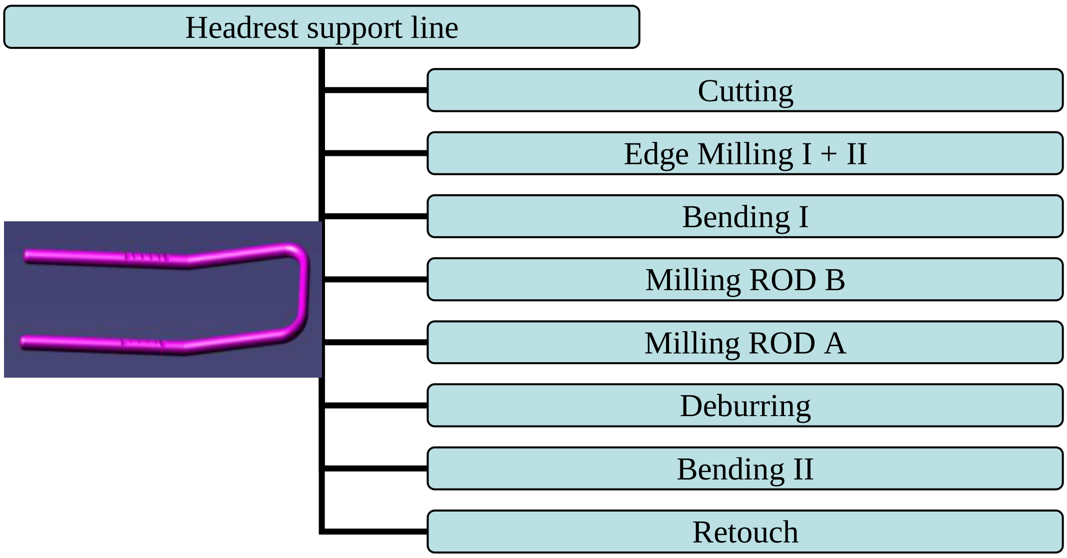

Fig. 2. Machines of the Headrest support line.

The M_1-M_8 machines with the time cycle (T_c) shown in Table 1, are considered.

Based on T_c, the production rate (R_p) per machine, the manufacturing time for a part (T_{f1}), the number of parts made (P_r) in 8 hours (480 [min]), are calculated.

$$R_p = \frac{1}{T_c} \tag{6}$$

$$T_{f1} = \frac{60}{R_p} \tag{7}$$

$$P_r = R_p \cdot 480 \tag{8}$$

Table 1. Production characteristics of the manufacturing flow

	Symbol	Unit	M1	M2	M3	M4	M5	M6	M7	M8
Cycle time	Tc	[min]	0.08	0.14	0.2	0.17	0.17	0.3	0.22	0.19
Production rate per machine	Rp	[parts/min]	12.5	7.01	5	5.83	5.83	3.33	4.55	5.26
Production time for 1 part	Tf1	[sec]	4.80	8.56	12.00	10.29	10.29	18.02	13.19	11.41
Parts made in 480 [min]	Pr	[parts]	6000	3365	2400	2798	2798	1597	2184	2525

Based on T_{f1}, the idle time of the part for the entry in manufacturing (T_{AF}), the busy time for the part manufacture (T_{OF}), the blocking time of the part for entry into production to the next machine (T_{BF}) and the finish time of the part (T_{FP}) are calculated, having as initial reference the M_1 cycle (the idle time for the first part is 0.1 [sec]) for the production flow represented by the M_1-M_8 machines, with the following conditions:

- the part instantly passes from one machine to another, so there is no intermediate storage;
- the idle time for M_1 to receive the first part is considered a negligible time;

The calculation of production times for the M_1-M_8 machines is shown in Table 2.

Table 2. Calculation of the manufacturing time according to cycle time for M_1-M_8 machines

Machine	M1		M2		M3		M4		M5		M6		M7		M8		Cycle Time
	Tf1	Rp	Tf1	Rp	Tf1	Rp	Tf1	Rp	Tf1	Rp	Tf1	Rp	Tf1	Rp	Tf1	Rp	
	4.80	12.5	8.56	7.01	12.00	5.00	10.29	5.83	10.29	5.83	18.02	3.33	13.19	4.55	11.41	5.26	
No. of parts	TAF	TFP	TAF	TFP	TAF	TFP	TAF	TFP	TAF	TFP	TAF	TFP	TAF	TFP	TAF	TFP	
1	6	10.80	10.80	19.36	19.36	31.36	31.36	41.65	41.65	51.94	51.94	69.96	69.96	83.15	83.15	94.55	1.5759
2	0	15.60	3.76	27.92	3.44	43.36	1.71	53.65	1.71	63.94	6.02	87.98	4.83	101.17	6.61	112.57	1.8762
3	0	20.40	7.52	36.48	6.88	55.36	1.71	65.65	1.71	75.94	12.04	106.00	4.83	119.18	6.61	130.59	2.1765
4	0	25.20	11.28	45.04	10.32	67.36	1.71	77.65	1.71	87.94	18.05	124.01	4.83	137.20	6.61	148.61	2.4768
5	0	30.00	15.04	53.60	13.76	79.36	1.71	89.65	1.71	99.94	24.07	142.03	4.83	155.22	6.61	166.63	2.7771
6	0	34.80	18.80	62.16	17.20	91.36	1.71	101.65	1.71	111.94	30.09	160.05	4.83	173.24	6.61	184.64	3.0774
7	0	39.60	22.56	70.71	20.64	103.36	1.71	113.65	1.71	123.94	36.11	178.07	4.83	191.26	6.61	202.66	3.3777
8	0	44.40	26.31	79.27	24.09	115.36	1.71	125.65	1.71	135.94	42.13	196.09	4.83	209.27	6.61	220.68	3.6780
9	0	49.20	30.07	87.83	27.53	127.36	1.71	137.65	1.71	147.94	48.14	214.10	4.83	227.29	6.61	238.70	3.9783
10	0	54.00	33.83	96.39	30.97	139.36	1.71	149.65	1.71	159.94	54.16	232.12	4.83	245.31	6.61	256.72	4.2786
11	0	58.80	37.59	104.95	34.41	151.36	1.71	161.65	1.71	171.94	60.18	250.14	4.83	263.33	6.61	274.73	4.5789
12	0	63.60	41.35	113.51	37.85	163.36	1.71	173.65	1.71	183.94	66.20	268.16	4.83	281.35	6.61	292.75	4.8792

To finish the first part on the M_1-M_8 flow, the manufacturing time is given by the relation:

$$T_{FP1} = T_{AF\_M1} + \sum_{n=1}^{8} T_{f1\_n} = 1.5759 \qquad (9)$$

The calculation of production rate and times to finish the parts x = 2-12 for M_1-M_8 machines is given by the relations:

$$\begin{aligned} T_{FP\_x} &= T_{FP\_x-1\_n} + T_{f1\_n} \quad if \quad T_{FP\_x\_n} > T_{FP\_x-1\_n-1} \\ T_{FP\_2} &= 13.46 + 8.56 = 22.02[\text{sec}] \quad if \quad 13.46 > 9.7 \end{aligned} \qquad (10)$$

so M_1 is blocked 3.76 [sec] by M_2 until this finishes the first part and

$$T_{FP\_x} = T_{FP\_x-1\_n-1} + T_{f1\_n} \quad if \quad T_{FP\_n} < T_{FP\_n-1}$$
$$T_{FP\_x} = 37.48 + 10.29 = 47.75[\text{sec}] \quad if \quad 35.75 < 37.46 \tag{11}$$

so, M_4 waits for 1.71 [sec] until M_3 finishes the part.

The production cycle rate (R_P) is set by the machine with the largest time cycle (M_6) with a capacity of 1597 [parts/day] and is calculated with the relation:

$$R_P = \frac{\sum_{x=1}^{4} T_{cx}}{4} = \frac{1.5759 + 1.8762 + 2.1765 + 2.4768}{4} = 2.064[\text{sec}] \tag{12}$$

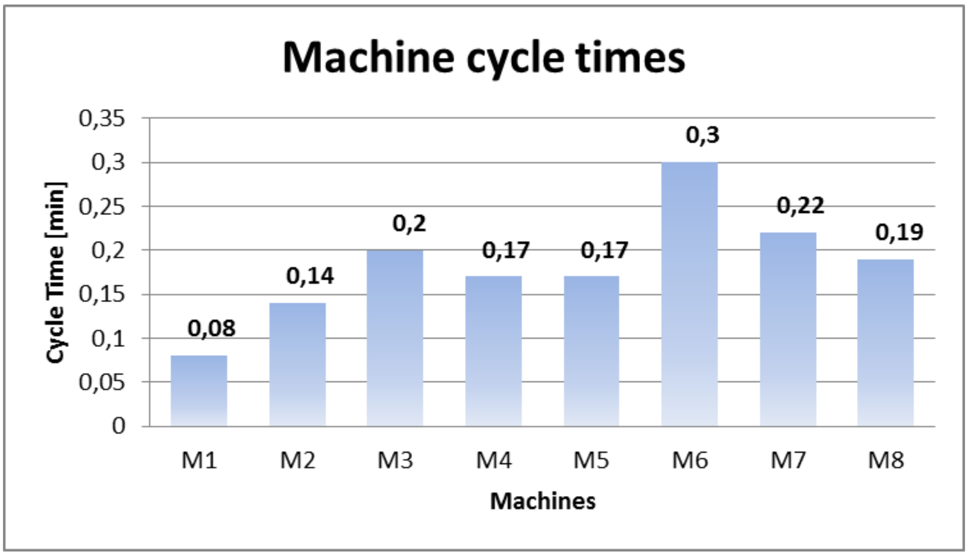

Fig. 3. Machine cycle times.

It is noticed that M_6 machine has the worst performance (0.3) and M_1 has the best one (0.08). The relationships between cycle times are highlighted in relation (1.8).

$$T_{CM1} < T_{CM2} < T_{CM3} > T_{CM4} = T_{CM5} < T_{CM6} > T_{CM7} > T_{CM8}$$
$$0.08 < 0.14 < 0.2 > 0.17 = 0.17 < 0.3 > 0.22 > 0.19 \tag{13}$$

Based on the obtained data, in Table 2 are determined the idle, busy and blocked times, for a work schedule of 480 [min] for the M_1-M_8 machines, thus obtaining Table 3.

Table 3. Idle, busy and blocked times (480 [min]) for flow-line M_1-M_8

Machine	M1	M2	M3	M4	M5	M6	M7	M8
Idle	0.1	0.18	0.323	7.22	7.39	0.87	26.03	26.85
Busy	127.87	228.02	319.68	274.17	274.17	479.13	351.3	303.88
Blocked	352.03	251.8	160	198.61	198.44	0	0	0

4.2 Research assumptions

We will assume that the following characteristics hold [11-13]:

1) The Machine M_1 processes parts arriving from an infinite input flow and sends the processed parts to the Machine M_2. The Machine M_2 takes the parts from the Machine M_1 and sends the processed parts to the Machine M_3, and so... Machine M_n takes the parts from Machine M_{n-1} and sends the processed parts to an always available output.
2) The production system treats a single part type.
3) The processing times of machines M_1, M_2 ..., M_n are constant.

4.3 Data analysis

In this paper, we evaluate a real flow-line using the Matlab software.

4.3.1 Processing input data in ANFIS SUGENO to view the construction mode of input membership functions.

Table 4. The range of the input data

	Range	Left	Center	Right
input_1	[0.1 26.85]	[-13.28 0.2929 13.23]	[0.3599 13.66 26.85]	[13.47 26.85 40.23]
input_2	[127.9 479.1]	[-47.76 127.9 303.5]	[127.9 303.5 479.1]	[303.5 479.1 654.8]
input_3	[0 352]	[-176 0.002869 176]	[0.0002878 176 352]	[178 354 530]
input_4	[4.8 18.02]	[-1.81 4.871 11.25]	[4.891 11.24 17.99]	[10.3 17.8 24.63]

4.3.2 Construction of the FIS MAMDANI model for estimating the production rate:

1) The ANFIS SUGENO triangle-type membership functions are preserved for the input variables with the modification of the intervals as follows [14]:
   - to the left triangle membership functions are changed the field by removing the negative number, the centre, i.e. 0 and the right delimitation values are retained;
   - to the triangular membership functions from centre are fully preserved the numerical values;
   - to the right triangle membership functions are retained the left and the centre delimitation values and the right field is changed by eliminating the positive number that exceeds the value of the representation range;

Table 5. The modified range of the input data

	Range	Left	Center	Right
input_1	[0.1 26.85]	[0 0 13.23]	[0.3599 13.66 26.85]	[13.47 26.85 26.85]
input_2	[127.9 479.1]	[0 0 303.5]	[127.9 303.5 479.1]	[303.5 479.1 479.1]
input_3	[0 352]	[0 0 176]	[0.0002878 176 352]	[178 352 352]
input_4	[4.8 18.02]	[0 0 11.25]	[4.891 11.24 17.99]	[10.3 18.02 18.02]

2) The inference rules are established

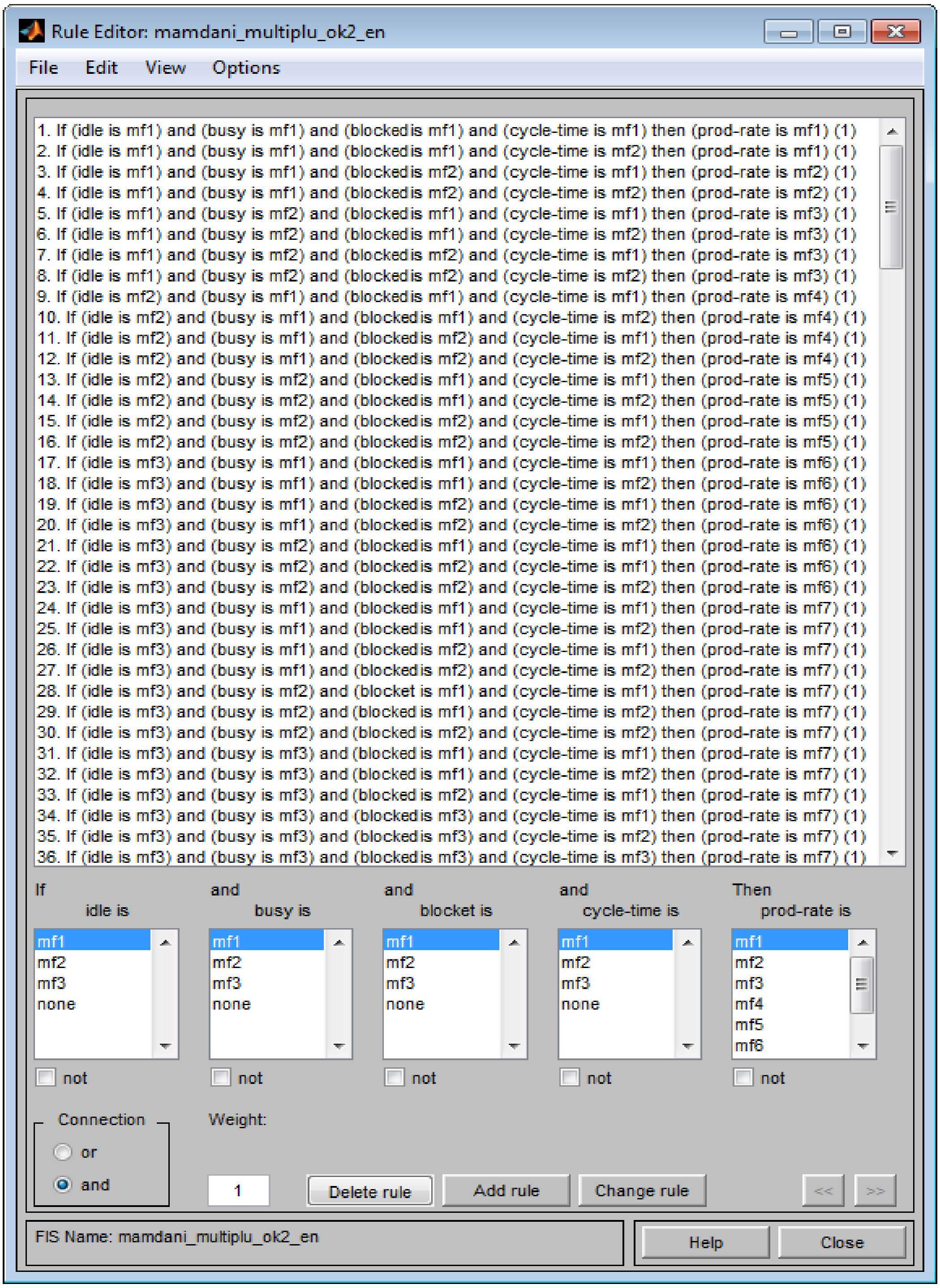

Fig. 4. Inference rules.

3) The production rate of the production line is estimated using the Mamdani output function.

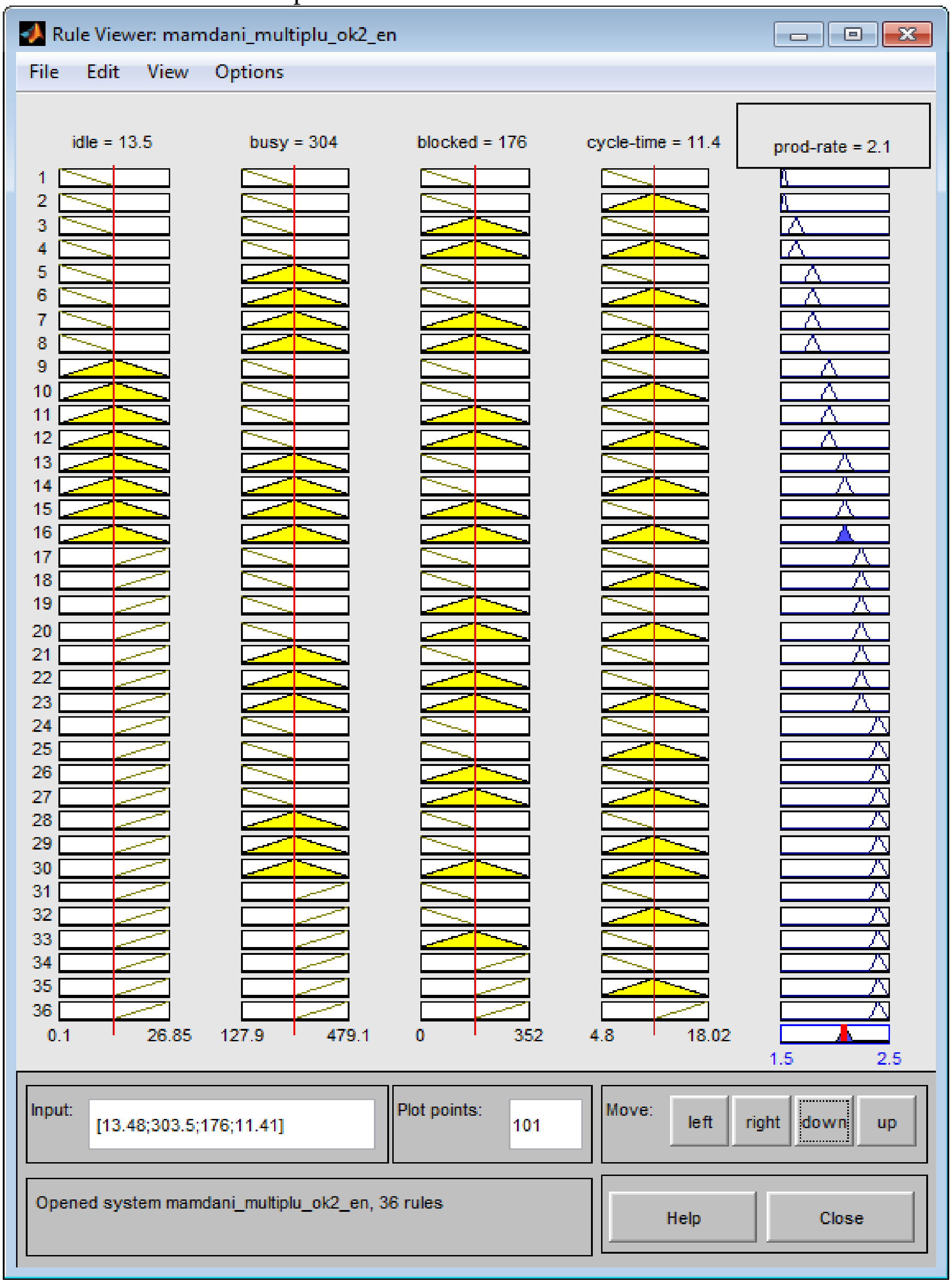

Fig. 5. Output data.

5. Conclusions and Directions for Further Research

In this paper we have analysed the performance of a flow-line using ANFIS SUGENO and FIS MAMDANI.

The ANFIS SUGENO method helps us to establish the input membership functions and then to construct the model FIS MAMDANI in order to estimate the production rate.

From the ANFIS membership functions, we eliminate the negative variables and positive variables that exceed the value of the representation range.

This type of construction achieves a reduction in the number of rules from 81 to 36 with a 5% error. It is noted that for all the two models analysed (ANFIS SUGENO vs. FIS MAMDANI) the optimal forecasting solution is found approximately in the middle of the rules, respectively, 41 out of 81 and 16 out of 36.

Once matched membership functions and inference rules, the Matlab software can estimate the production rate of the manufacturing system.

In our case study, the production rate was estimated at 2.1 parts/minute.

The methodology applied in this case study was validated in another studies conducted by us with other parameters, and the results were framed in the same percentage error.

Future studies will focus on applying the approach to diverse real flow-line that can be illustrated as machine-buffer-machine-buffer-...-machine.

The machines in a flow-line are usually decoupled with the help of buffers.

The production rate can be increased by buffers reallocation.

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