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ESTIMATING THE PRODUCTION RATE OF A MANUFACTURING LINE USING SIMULATION-PROGRAMMING AND FUZZY-LOGIC TECHNIQUES

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Rezumat. *Lucrarea se referă la utilizarea a trei metode alternative pentru modelarea, simularea și estimarea ratei de producție. Metodele de evaluare a performanțelor analitice se bazează pe modelarea stocastică a fluxurilor sistemelor de producție. Procesele care implică fenomene aleatorii au fost în mod tradițional modelate prin utilizarea distribuțiilor statistice. Lucrarea arată că metodele Fuzzy Logic sunt capabile să producă soluții similare metodelor convenționale. Obiectivul acestei lucrări este de a implementa principalele contribuții aduse în domeniul ingineriei industriale prin modelarea, simularea și estimarea ratei de producție, într-*un studiu de caz real.

Abstract. *This paper deals with the use of three alternative methods in order to model, simulate and estimate production rate. The methods for evaluating the analytical performances are based on the stochastic modelling of production systems flows. Processes that imply random phenomena have traditionally been modelled through the use of statistical distributions. The paper shows that the Fuzzy Logic methods* are able to achieve similar solutions to conventional methods. *The objective of this work is to implement the main contributions brought in the industrial engineering field by modelling, simulating and estimating the production rate, in a real case-study.*

Keywords: mathematical model, Fuzzy method, simulation, estimation, production rate.

1. Introduction

In a competitive environment, like the automotive industry, production control policies play a key role in the success of the company. By the term of "production control policies", it is necessary to understand the researches on performance analysis based on simulation studies and queuing theory [1].

The research presented in this article tackles the evaluation of a production control policy. Indeed, simulation-programming and fuzzy-logic techniques are used in many fields such as marketing, finance and engineering.

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Therefore, the work consists in applying these methods on a manufacturing system from the automotive field.

The bibliographic study was the first stage of this work. During this phase, it was necessary to deepen the notions of statistical learning and more particularly the methods of fuzzy logic and Markov chain.

A flow line includes different machines arranged in series. The parts come from the source to the first machine, then to the second machine and so on to the last machine, and then get into the sink. The parts must be processed on each machine and the processing times on different machines are not the same.
The model developed with the Markov chain for two machines was first introduced by Buzacott [2] and was restricted to homogeneous lines. Gershwin and Schick [3] have developed an exact solution for the three-machine model, but have reached the conclusion that "it is difficult to programme the model and cannot be extended to large systems" [4]. To achieve a solution for flow lines with more than two machines, approximations are needed. Gershwin [4] has proposed an approximation method, called the decomposition method, which analyses the model of long lines.

A flow line can be viewed as a machines network. The machines can fail in a random order and at different times can be incapable to produce more parts because phenomena of starvation and/or blocking appear. The literature offers a wide range of intelligent techniques in order to schedule the production systems, like: fuzzy logic systems (FLS), artificial neural networks (ANN), genetic algorithms (GA), artificial intelligence (AI) and hybrid systems.

The fuzzy logic method provides the mathematical framework that allows simple representations of the principles of production control or planning in terms of IF-THEN rules [5].

The fuzzy logic method was introduced in 1965 by Zadeh [6] and the Fuzzy sets with linguistic variables (Zadeh, [7]) were subsequently successfully used in many engineering applications, like control problems of production systems [8, 9].

In industrial engineering, the fuzzy sets theory is used as a method for modelling an assembly line and solving the stochastic balancing problem [10].

Nikos C. Tsourveloudis proposes a method to evaluate the production rate in each processing phase in order to satisfy the demand for finished parts and to reduce the work in process (WIP) from the production system [5,11].

2. Research Methodology

In this article are presented three different methods to help the company estimate the production rate of any manufacturing line.

2.1. Discrete-events simulation

The discrete-events simulation of manufacturing lines represents a powerful tool in order to achieve the performance measures. For designing and optimizing the manufacturing systems we can use simulation software that can provide reports for monitoring the performance.

On the market there is a great variety of dedicated discrete-events simulation software suitable to evaluate manufacturing systems: Delmia Quest, Arena, Tecnomatix Plant Simulation.

The software Delmia QUEST is a Discrete-Event Simulation system which has integrated 3D CAD geometry: sources, buffers, machines, sinks, etc. The software includes real production variables within a plant layout, such as the machine cycle time, labourers' movement and/or operating speeds [12-14].

2.2. Markov chains and decomposition method

The general phases of the decomposition method are [13, 14]:

Phase 1: Initialization

- $\tau_i^u = \tau_i$, i= 1, 2, 3, …, k-1
- $\tau_i^d = \tau_{i+1}$, i = 1, 2, 3, …, k-1 (1)

Phase 2: Starvation and blocking

- $\tau_i^u = \frac{1}{\frac{1}{X_{i-1}} + \frac{1}{\tau_i} - \frac{1}{\tau_{i-1}^d}}$ I = 1, 2, 3, …, k-1
- $\tau_i^d = \frac{1}{\frac{1}{X_{i+1}} + \frac{1}{\tau_{i+1}} - \frac{1}{\tau_{i+1}^u}}$ i=k-2, k-3, …., 1 (2)

Phase 3: Iteration

$$|X_i - X_1| < \varepsilon,\ i = 2, 3, \ldots, k\text{-}1, \quad (3)$$

where

τ_i is the production rate of each machine
τ_i^u is the production rate when the machine is up
τ_i^d is the production rate when the machine is down
X_i is the production rate calculate for two machine using the Markov chain
ε is a very small positive real number = 0.0001.

To estimate production rate for two machines using the Markov chain X_i, we need to find the states, the Markov chain and the normalization and balance equations. There are three states:

- x_1: M_1 and M_2 are working,
- x_2: M_1 working and M_2 is waiting (idle),
- x_3: M_1 blocked and M_2 is working.

These situations are indeed states because of the assumption of exponential distribution for the machining times.
The graph of the Markov chain is the following:

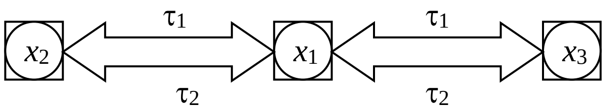


Fig. 1. Markov model.

The stationary probabilities π_1, π_2, π_3 are obtained by writing the balance equations relative to the cuts between x_1 and x_2 and between x_1 and x_3:

$$\begin{aligned} \pi_1 . \tau_2 &= \pi_2 . \tau_1, \\ \pi_1 . \tau_1 &= \pi_3 . \tau_2. \end{aligned} \tag{4}$$

Using, also, the normalising equation

$$\pi_1 + \pi_2 + \pi_3 = 1 \tag{5}$$

finally we obtain the production rate of the system X_i, which is the production rate of one of the machines, in this case the machine M_2, which delivers the finished parts [13, 14].

2.3. Fuzzy production scheduling

Fuzzy logic systems include fuzzy sets and rules. A fuzzy logic is characterised by four modules: fuzzifier; rule base; inference engine and defuzzifier.

The fuzzifier operation is performed to identify if the input data are the member of the set fuzzy or not. Fuzzification refers to the process of transforming a crisp set into linguistic terms.

A rule (IF-part) presents the conditions where the rule is applicable and provides the input data. The next part (THEN-part) offers the answer or conclusion that should be drawn under these conditions. A two-input rule of the Mamdani type has the syntax [7]:

IF *X* is *A* AND *Y* is *B* THEN *Z* is *C*,

where,

- *X*, *Y* are the input
- *Z* is the output variable,
- *A*, *B* and *C* are the linguistic variations.

The Mamdani method uses the *min* operator for the implication and the *min-max* operator for composing:

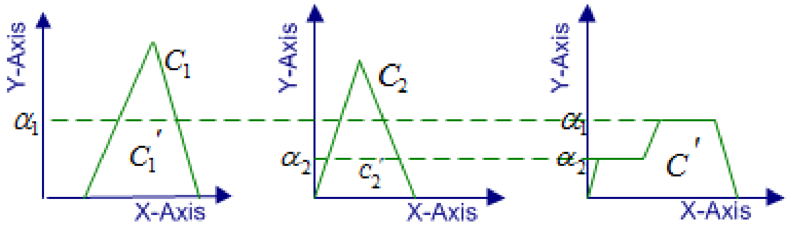


Fig. 2. Mamdani method.

The output data are defined by the output sets according to rule base and inference engine.

The fuzzified functions are converted into numeric values in the defuzzifier unit through the fuzzy inference engine.

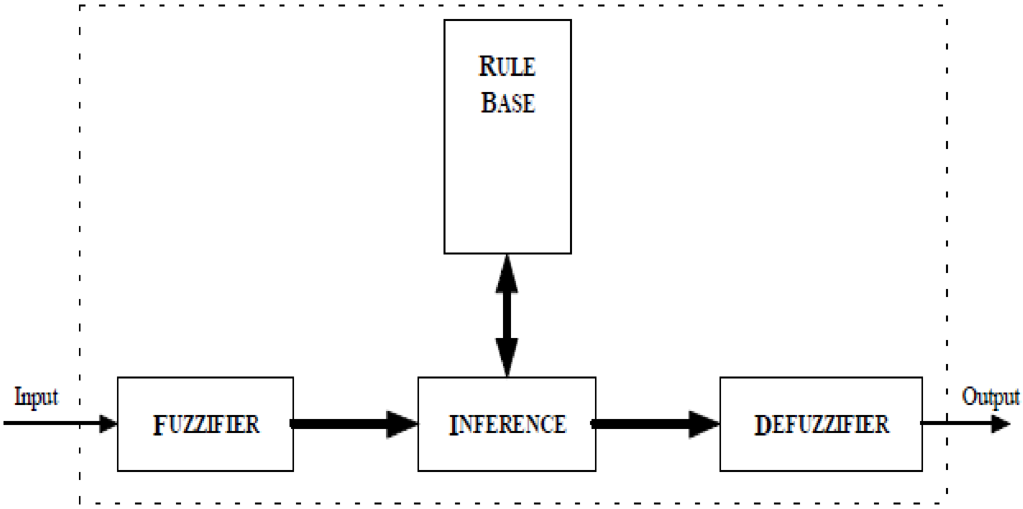


Fig. 3. Structure of a fuzzy logic system.

In fuzzy logic, the membership function represents the degree of truth as an extension of valuation: Generalized bell-shaped membership function, Gaussian membership function, Gaussian combination membership function, Triangular membership function, Trapezoidal membership function, Sigmoidal membership function, Difference between two sigmoidal membership functions, Product of two sigmoidal membership functions, Z-shaped membership function, Pi-shaped membership function, S-shaped membership function, etc.

3. Case Study. Simulation Results and Comparisons

It is meant to experiment a real case study from the automotive field, a manufacturing line which makes the Free-sprocket for the 5th gear (Fig. a).

The Free-sprocket for the 5th gear is a TLx gearbox component (Fig. b).

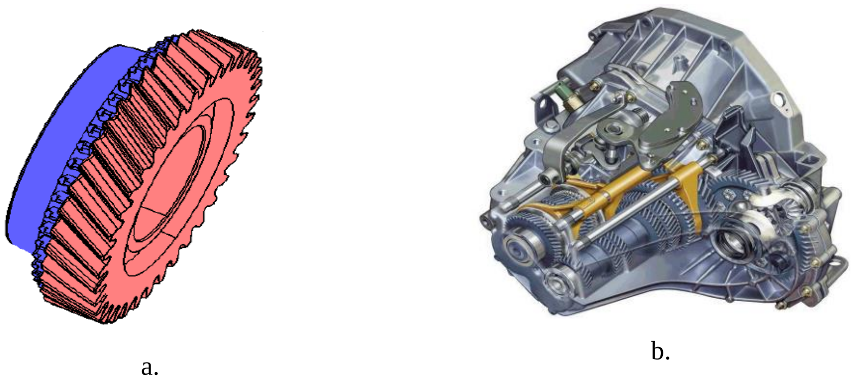


Fig. 4. Description:
a. Free-sprocket for 5th gear b. Gearbox

The assembly of the Free-sprocket for the 5th gear is shown in the figure below:

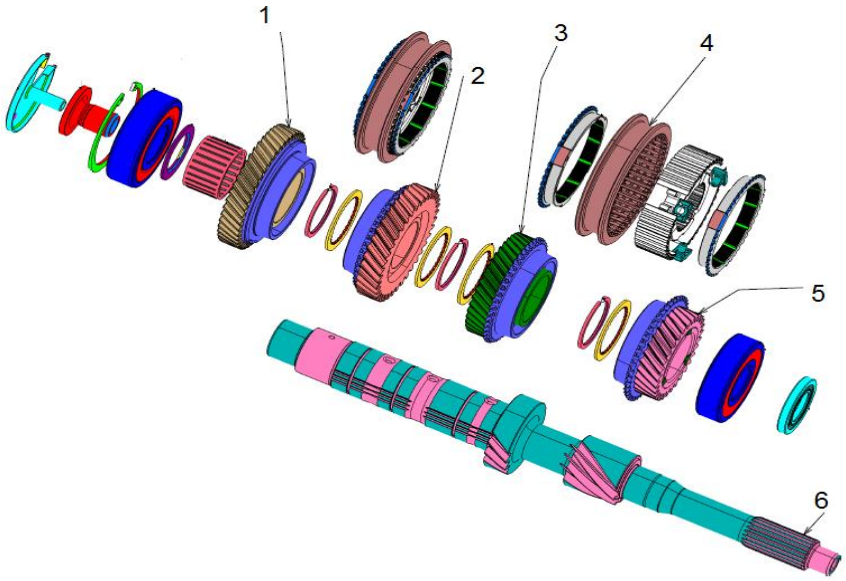


Fig. 5. Description:
1. Free-sprocket for the 6th gear. 3. Free-sprocket for the 4th gear. 5. Free-sprocket for the 3rd gear
2. ***Free-sprocket for the 5th gear.*** 4. Balador 3-4. 6. Spindle.

Table 1. The machines on which the Free-sprocket is made

No of operation	*Name of operation*	*No of machines*	*Equipment*
Op. 110+120	Faces turning 1 + 2	1	FAMAR
Op. 130	Milling teeth	1	LIEBHERR
Op. 140	Chamfering teeth	1	WERA ZEM 300
Op. 150	Shaving teeth	1	SICMAT
Op. 160	Washing before pressing	1	MAL CINETIC
Op. 170+180	Pressing + welding	1	SOUDURE CINETIC

Table 2. Production rate for each machine

Machines	*Production rate [products/min]*	*Tcy [min]*
M_1	1.667	0.600
M_2	1.821	0.549
M_3	3.125	0.320
M_4	1.923	0.520
M_5	4.464	0.224
M_6	4.608	0.217

3.1.Discrete-events simulation using DELMIA Quest software

Using simulation with the Delmia Quest software on the case study, a production of 0.983333 products/minute (see Fig. 6) is obtained.

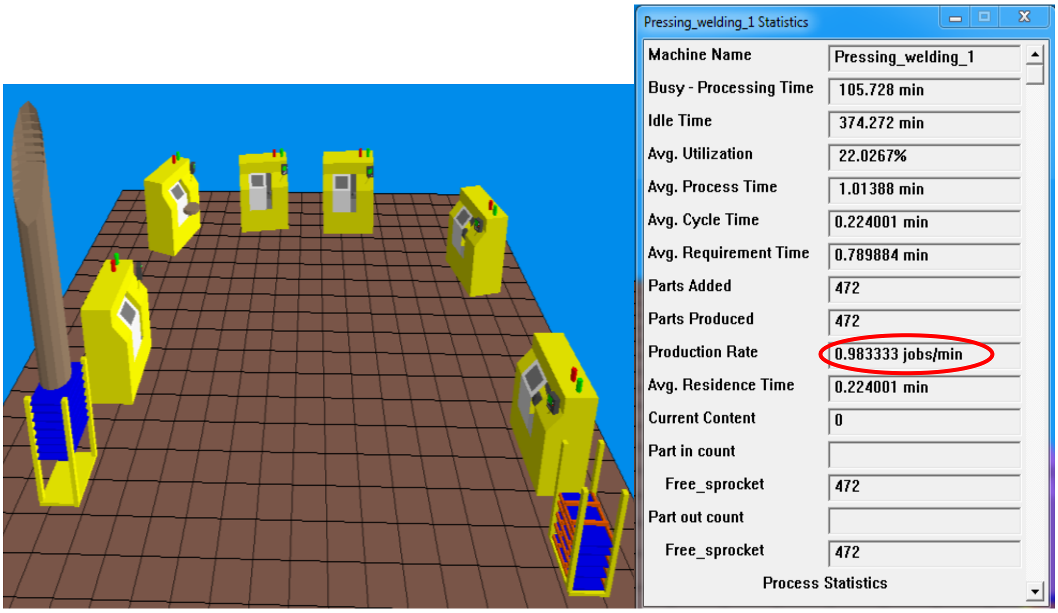
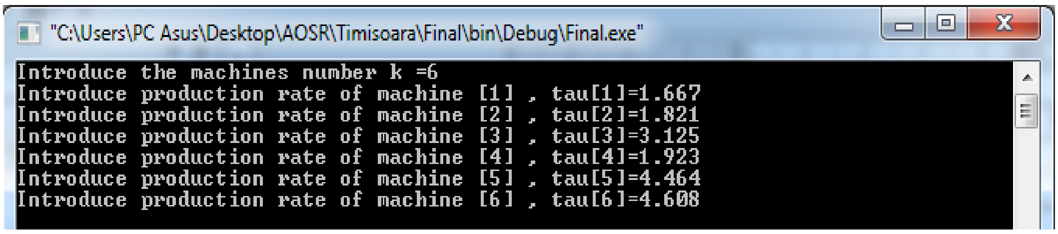


Fig. 6. Simulation results obtained in Delmia Quest software

3.2.Markov chains and decomposition method using C++ programming

Using C++ programming a production rate of 0.9617 products/minute is obtained (see Fig. 7).



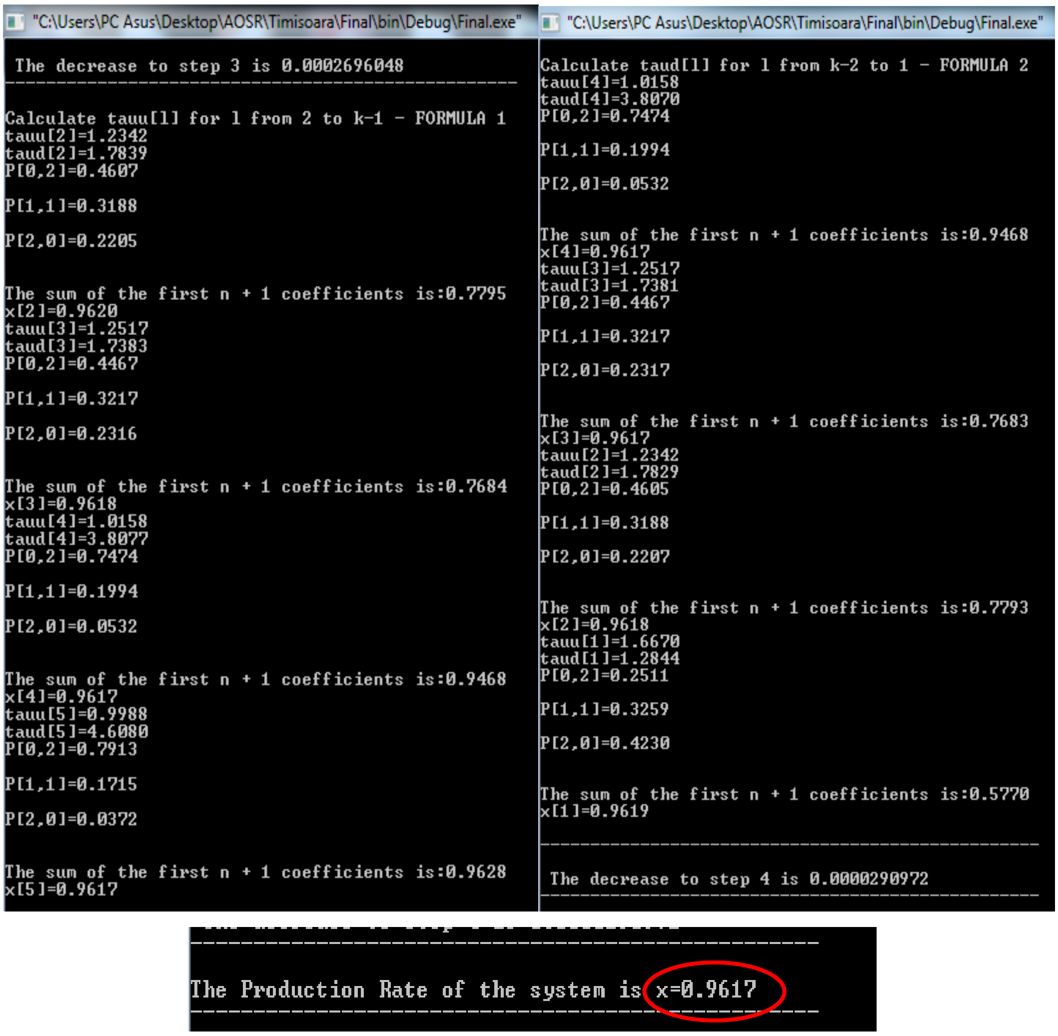


Fig. 7. Results obtained with C++ programming.

3.3. Fuzzy production scheduling using Matlab software

- Input data: the production rate for each machine and the states of the machines S_i
- The base rule is:

IF M_i is S_i , THEN production rate is R_i

Where

- i is the number of machine,
- S_i denotes the state of machine i and the linguistic value of the variable is the set = {Idle, Busy, Blocked},
- The production rate R takes linguistic values from the set ={Low, High}.

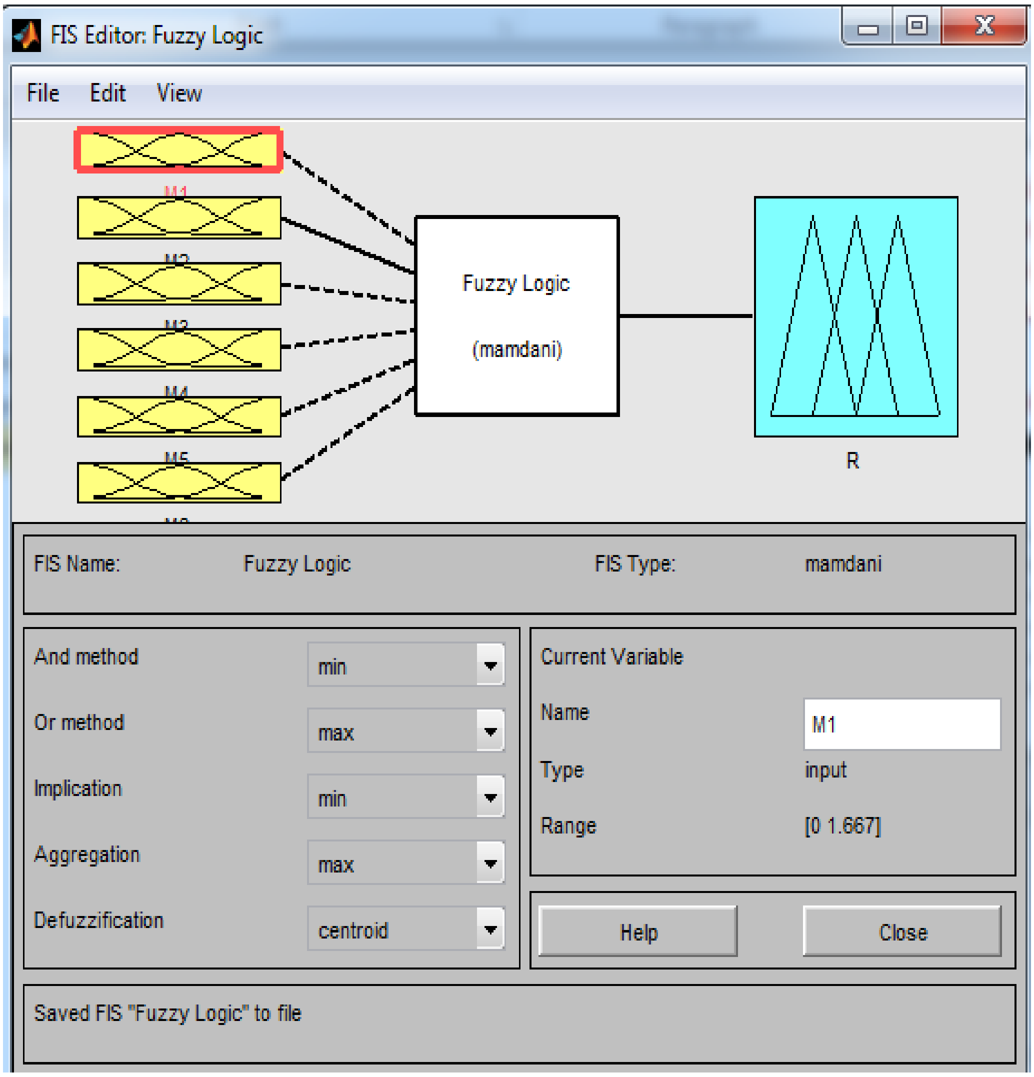


Fig. 8. Fuzzy Logic Editor.

Example:
For two machines the fuzzy rules are:

- IF M_1 and M_2 are working, THEN the production rate is high;
- IF M_1 is working and M_2 is waiting (idle), THEN the production rate is low;
- IF M_1 is blocked and M_2 is working, THEN the production rate is low.

Using Fuzzy Logic method a production rate of 0.957 products/minute is obtained (see Fig. 10).

Making a comparison among the three methods implemented in our case study, it can be noted that the results are much closer than expected (see Table 3).

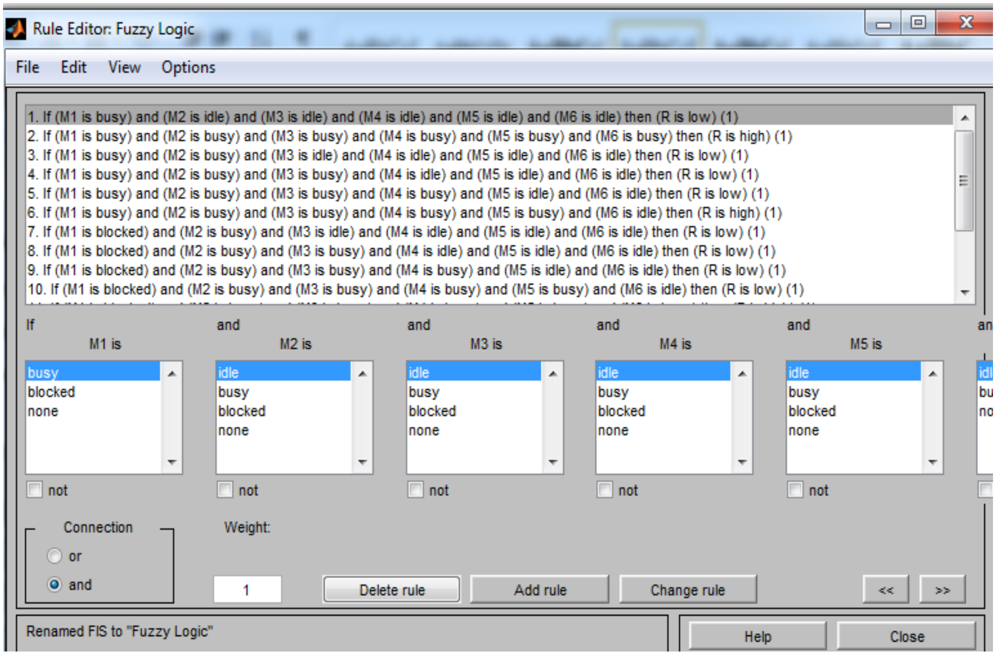


Fig. 9. Rules implemented in Matlab software.

- Output data: the production rate of the manufacturing line *R*

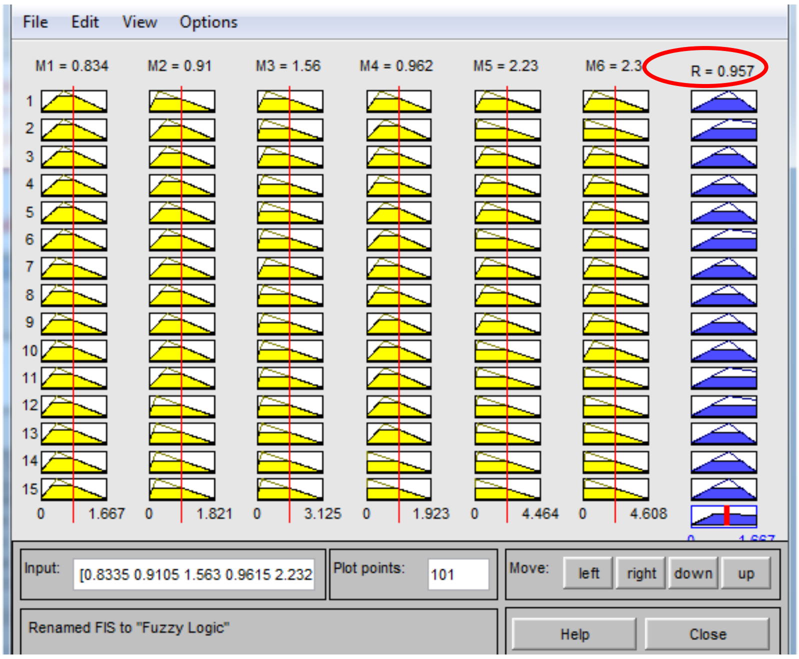


Fig. 10. Fuzzy Logic results.

Table 3. Comparison among Delmia Quest / C++ / Matlab

	Simulation using Delmia Quest	*Analytical model using C++*	*Fuzzy Logic using Matlab*
Production rate of the manufacturing line [products/min]	0.98333	0.9617	0.957

Conclusions

In this study, three simulation methods in order to estimate the production rate of a real case study have been evaluated: the discrete-event simulation using Delmia Quest software, the analytical modelling using C++ programming and the fuzzy logic simulation using Matlab software.

The discrete-event simulation results show that using a dedicate software, we can find the production rate, but the simulation model needs a lot of time, because many alternative configurations should be considered.

The results obtained with C++ programming show that the users need to know a detailed approach of the mathematical modelling.

The fuzzy logic method provides the mathematical framework that allows simple representations of the principles of production control or planning in terms of linguistic "IF…THEN…" rules. These rules are very important in the mathematical representation of the model and describe the relationship between input and output data.

The main contribution of this study was to compare the three methods in order to estimate the production rate of a real manufacturing line. It can be seen that the Fuzzy Logic method is able to achieve similar solutions to conventional methods. The Fuzzy logic results have been found to be quite close to those obtained by the simulation and the analytical model.

An interesting extension to be considered in the future would be to examine a manufacturing line by introducing the buffer between two machines in order to decouple the flow production system. A fuzzy controller could be developed to keep production close to demand and the work in process (WIP) as low as possible. WIP shows the number of parts present in the system.

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