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THE IMPLEMENTATION OF A DECISION-MAKING SYSTEM BASED ON FUZZY LOGIC FOR OPTIMIZING PRODUCTION SCHEDULING OF PLASTIC PARTS MANUFACTURED BY INJECTION MOLDING

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Abstract: This paper presents the development of a user interface for a fuzzy logic decision-making system designed to optimize production scheduling in the injection molding industry. The system integrates input variables such as production time, due date, the client negotiation possibility, project complexity, safety stock and profit rate, to dynamically determine order priorities. The user interface enables intuitive interaction, allowing users to provide real-time data as input and visualize the output. By using fuzzy logic, the system can overcome uncertainties, which are common in production environments, enhancing scheduling efficiency and decision-making accuracy. The interface simplifies the interpretation of complex data, ensuring better utilization of resources and adherence to deadlines, resulting in an improved operational performance.

Key words: Fuzzy Logic, User Interface, C#, Production scheduling, Injection Molding.

1. INTRODUCTION

Production scheduling has been a cornerstone of operational management for a long time, and it still is today, directly shaping a company's efficiency. In today's dynamic and unpredictable industrial landscape, the ability to systematically and flexibly organize production activities is essential in order to have success. This complex process requires not only effective resource management and optimized schedules but also close collaboration between different departments within an organization. The objective of production scheduling is to guarantee a great flow of operations, to minimize costs and to avoid resource waste. However, the complexities of modern manufacturing environments, characterized by greater demand and evolving technology, exposed the limitations of traditional scheduling methods. As a result, industries are always seeking advanced tools and technologies to enhance their scheduling process. Conventional methods, such as deterministic models or optimization algorithms, often struggle to adapt

to the uncertainty that exists in today's production systems.

A decisional procedure structured in 2 steps is presented in [1]. The first step proposes an algorithm based on fuzzy logic used to assign priorities to different types of parts that are going to be machined. In the second step, an operation-machine allocation and scheduling algorithm is presented.

The criteria used to determine the machining priorities (the input values of the fuzzy system) are: the order volume, delivery due date, processing time, and the number of tools required to machine a type of part.

The development of a hybrid decisional system used for production scheduling is detailed in paper [2]. An adaptable fuzzy logic system is upgraded by using genetic algorithms. By using fuzzy logic, the system can take multiple criteria into consideration and can determine solutions very fast. The subsequent utilization of a genetic algorithm optimizes the initial solution, obtained with fuzzy logic, by using specific methods, resulting in a more accurate result.

The integration of fuzzy logic in production planning and scheduling in the steel industry is presented in [3]. The paper analyzes the problem of assigning steel grades to customer orders. Fuzzy sets are used to reduce the variety of steel grades and to describe the characteristics of the materials by the decision factors.

Research [4] develops a hybrid method of manufacturing scheduling, based on fuzzy sets and genetic algorithms which takes into consideration the possibility that the machines involved in the manufacturing process can fail. Through modeling and simulation of discrete events, the situations caused by failures are evaluated, allowing for the possibility of finding alternative solutions for the process.

Research [5] focuses on flexible manufacturing systems (FMS) scheduling, using a fuzzy logic approach. Four input variables are defined: machine processing time, machine availability, the delivery due date and the setup time. The output variable is the order priority. The model will select the machines first, and then it will assign operations based on a multi-criteria scheduling scheme.

In the injection molding industry, it is crucial for manufacturers to meet the delivery due dates for the products ordered by the customers. In paper [6], a mathematical model is proposed for the planning problem of mold manufacturing within a decisional system.

This paper presents a decisional system based on fuzzy sets, that determines the manufacturing priorities associated with the orders, that company in the plastic injection molding industry must honor.

2. THE FUZZY LOGIC SYSTEM

2.1. The system structure

The dynamic and uncertain nature of the production environment always pushes researchers, engineers, production managers to test or to find new ways to overcome these challenges. Another important thing to mention is that very different factors come into play when scheduling the production, depending on the industry. In the injection molding industry, the authors found six important factors that should influence production scheduling, by determining the priority of each order: production time, due

date, the possibility of negotiating with the client, the project complexity, the safety stock and the profit rate.

The system is structured on 2 two layers. It uses six input variables, to determine two intermediate priorities, which also become input variables, used to determine the output variable, which is the priority of an order. The structure of the decisional system is presented in the diagram in figure1.

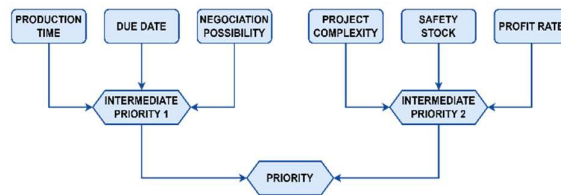


Fig. 1. The structure of the decisional system

2.2. The system description

After establishing the variables of the system, the next step is to determine the influence the input variables have on the output variables, which is presented below:

- Intermediate priorities 1 and 2 are the output variables of the first layer of the system, which turn into input variables for the second layer. These are both directly proportional to the priority, therefore the influence of the input variables on the priority is the same as that on the intermediate priorities;
- The production time is the number of hours required to finish an order. It is directly proportional to the priority, indicating that the orders with higher production time will be prioritized;
- The due date represents the moment when the parts must be delivered to the client. It is inversely proportional to the priority, meaning that the orders with a tighter deadline will take precedence;
- The client negotiation possibility is closely related to the due date, because what it refers to is the possibility to delay an order or to deliver a smaller quantity of parts. The bigger the negotiation possibility, the more urgent an order will be;
- Project complexity involves various necessary operations in order to finish a batch of parts, like the quality control, the mounting of the mold, plastic material preparation, etc;

The orders with a higher complexity will be prioritized;

- The safety stock is the number of parts of the product that will be manufactured, which are currently in stock. It is inversely proportional to the priority, meaning that products with lower safety stocks will take precedence;
- The profit rate involves different methods through which the process becomes more efficient (lower cycle times, bigger profit made from mold manufacturing, etc.). The projects with a higher profit rate will be prioritized.

For a better visualization, a summary of the relationships between the system's variables is shown in figure 2.

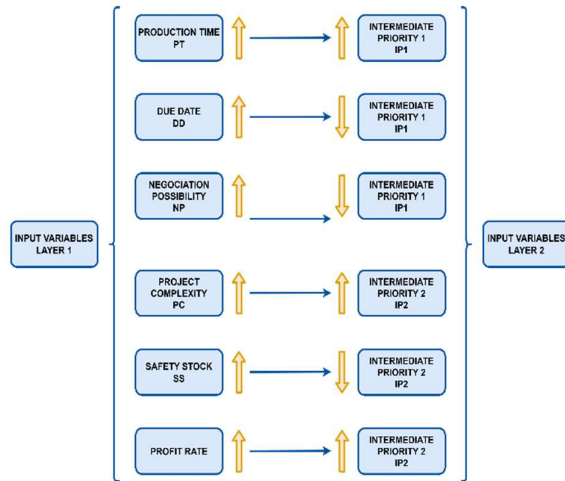


Fig. 2. The influence of the input variables on the priority

The following step is to establish the range of values for all the variables of the system.

The range of values for the production time (PT) is represented in (1).

$$PT: D_{PT} = [0, 120] \text{ [hours]} \quad (1)$$

The range of values for the due date (DD) is represented in (2).

$$DD: D_{DD} = [0, 15] \text{ [days]} \quad (2)$$

The range of values for the negotiation possibility (NP) is represented in (3).

$$NP: D_{NP} = [0, 10] \quad (3)$$

The range of values for the project complexity (PC) is represented in (4).

$$PC: D_{PC} = [0, 10] \quad (4)$$

The range of values for the safety stock (SS) is represented in (5).

$$SS: D_{SS} = [0, 200] \text{ [%]} \quad (5)$$

The range of values for the profit rate (PR) is represented in (6).

$$PR: D_{PR} = [0, 50] \text{ [%]} \quad (6)$$

The range of values for the intermediate priority 1 (IP1) and the intermediate priority 2, the output values on the first layer becoming input values on the second layer of the system (IP2) is represented in (7).

$$IP1/IP2: D_{IP1/IP2} = [0, 10] \quad (7)$$

The range of values for the output variable of the system, the priority (P), is represented in (8).

$$P: D_P = [0, 10] \quad (8)$$

Going forward, a number of linguistic degrees will be assigned to the variables, each linguistic degree having a corresponding membership function. The bigger the number of the linguistic degrees, the bigger the precision of the system. Therefore, a number of 10 linguistic degrees was assigned to each variable of the system. Because naming all of them would have been a hard and unnecessary job, each linguistic degree will be a number from 1 to 10.

The membership functions for the first and the last linguistic degree will be a trapezoidal function, allowing for a range of values to have the highest degree of membership, while the other membership functions will be triangular, therefore a single, crisp value will have the highest degree of membership. As an example, (9) presents the linguistic degrees of the output value, the priority. The same goes for all the other variables of the fuzzy logic system.

$$P: L_P = [1, 2, 3, 4, 5, 6, 7, 8, 9, 10] \quad (9)$$

The graphical representation of the membership functions of the priority is shown in figure 3.

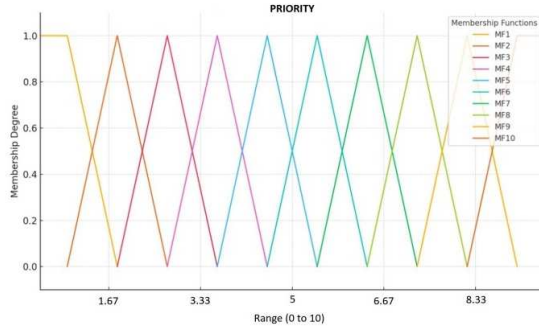


Fig. 3. The membership functions of the priority

After the membership functions are defined, the rules of the system have to be determined based on the decisional inferences. The rules of the system are a structured set of instructions that determine how the input variables influence the output variable. The decisional system is divided into three fuzzy systems. The required number of rules is based on how many input variables the system has, and how many linguistic degrees are assigned to each input variable. It is calculated with equation (10).

$$N_R = N_{LG}^{N_V} \quad (10)$$

Where:

N_R = number of rules;

N_{LG} = number of linguistic degrees;

N_V = number of variables.

Therefore, the total number of rules is 2100. Two thousand for the two systems on the first layer (a thousand each) and one hundred for the system on the second layer. More details about how the rules were generated are mentioned in section 3.

The last step in determining a fuzzy logic system is data defuzzification, which involves transforming the output variable from fuzzy values into crisp, actionable values, which can be used in production activities. Essentially, this step converts fuzzy results into practical or clear actions. The chosen method for data defuzzification is the center of gravity method, as it is one of the most widely used and it suits this particular case.

3. THE USER INTERFACE

The development of a personalized user interface (UI), specifically adapted for a fuzzy logic system provides different advantages over using standard interfaces from specialized software. The biggest advantage is the enhanced user-friendliness provided by a customized interface, which can be designed with simplified and optimized controls. This approach allows users with limited knowledge in specialized software to interact with the fuzzy logic system more intuitively, focusing only on the input variables, and not on the whole mechanism behind it.

Additionally, a dedicated UI can support a more efficient workflow by guiding the user step-by-step through data entry and result analysis. This ensures that the fuzzy logic system help the user to easily navigate through the uncertainties of the production environment, a crucial aspect in real-life applications where complex decision-making processes depend on efficient operations.

Moreover, a custom Ui can significantly reduce the learning curve for the user, by hiding the complexities of the native environment of other production scheduling software.

A very big time consumer when it comes to developing a fuzzy logic decisional system is the definition of the membership functions assigned to each linguistic degree. By developing an algorithm using the C# programming language (Fig. 4), this process can now be finished by just defining the variable and its correspondent range of values.

```

0 references
class Program
{
    0 references
    static void Main(string[] args)
    {
        string name = Console.ReadLine();
        string priorityName = Console.ReadLine();
        double min = double.Parse(Console.ReadLine());
        double max = double.Parse(Console.ReadLine());
        domeniiValori(name, priorityName, min, max);
    }

    1 reference
    static void domeniiValori(string name, string priorityName, double min, double max)
    {
        double factor = 0.9090909090909091;
        string output = "";
        string levelName = "";
        //string priorityName = "";

        // Loop to calculate and output each priority level membership function
        for (int i = 1; i <= 10; i++)
        {
            double a, b, c, d, e = 0;
            if ((double)((min - max) / 10) >= 2)
            {
                a = ((double)(max - min) / 10) * factor;
                b = (((double)(max - min) / 10) + ((double)(max - min) / 10) * i) * factor;
                c = (((double)(max - min) / 10) + ((double)(max - min) / 10) * (i - 2))) * factor;
                d = (((double)(max - min) / 10) + ((double)(max - min) / 10) * (i - 1))) * factor;
            }
        }
    }
}

```


The production time is calculated with equation (11).

$$PT = \frac{N_o P}{\frac{60}{C_t} * N_o C * 60} [hours] \quad (11)$$

Where:

PT = production time [hours];

N_oP = number of parts to be manufactured [pcs];

C_t = cycle time [s];

N_oC = number of mold cavities.

The profit rate is calculated with equation (12).

$$PR = \frac{OV}{PV} * 100 [\%] \quad (12)$$

Where:

PR = profit rate [%];

OV = order value [RON];

PV = project value [RON].

The second window, detailed in figure 8, with the case study results, allows the user to view the priorities associated with each mold and to assign the orders to an injection machine. The third window has the role to guide the user when it comes to assigning the molds to the injection machines. With the help of a Gantt chart, the production manager can decide on which machine each mold will run, so that the manufacturing process will be the most possibly efficient one. Therefore, the aim of the Gantt chart is to reduce idle times and allow for a better resource management, optimizing the total production time. The third window of the interface is detailed in figure 9 along with the results obtained by analyzing a case study, to demonstrate how decisional system works.

4. CASE STUDY

To validate the functionality of the fuzzy logic system, a case study will be analyzed. This particular case study involves 5 molds that need to run on a 500 KN injection machine. There are two such machines available, therefore, the priority of the orders corresponding to each mold needs to be determined. Going forward, the input data for all the orders will be presented.

1st mold:

- Production Time: 150 000 parts need to be injected, with a cycle time of 22 de seconds.

The mold has 8 cavities; therefore, the production time is 114.6 hours;

- Due date: 10 days;
- Negotiation possibility: 6;
- Project complexity: 1;
- Safety stock: 50% of a batch (75 000 parts);
- Profit rate: 30%.

2nd mold:

- Production time: 45 000 parts need to be injected, with a cycle time of 16 de seconds. The mold has 2 cavities; therefore, the production time is 100 hours;
- Due date: 7 days;
- Negotiation possibility: 10;
- Project complexity: 8;
- Safety stock: 150% of a batch (67 500 parts);
- Profit rate: 7%.

3rd mold:

- Production time: 25 000 parts need to be injected, with a cycle time of 23 de seconds. The mold has 4 cavities; therefore, the production time is 39.9 hours;
- Due date: 4 days;
- Negotiation possibility: 6;
- Project complexity: 6;
- Safety stock: 100% of a batch (25 000 parts);
- Profit rate: 22%.

4th mold:

- Production time: 500 parts need to be injected, with a cycle time of 19 de seconds. The mold has 1 cavity; therefore, the production time is 2.6 hours;
- Due date: 1 days;
- Negotiation possibility: 2;
- Project complexity: 4;
- Safety stock: 0% of a batch (0 parts);
- Profit rate: 50%.

5th mold:

- Production time: 32 000 parts need to be injected, with a cycle time of 27 de seconds. The mold has 4 cavities; therefore, the production time is 60 hours;
- Due date: 8 days;
- Negotiation possibility: 4;
- Project complexity: 7;

- Safety stock: 25% of a batch (8 000 parts);
- Profit rate: 18%.

The input data associated with each mold will be consecutively introduced in the decisional system, which, based on the set of rules, will

automatically calculate the priority assigned to each mold. Figure 8 shows the calculated priority of each mold, as it is presented in the second window of the UI, the result viewing window.

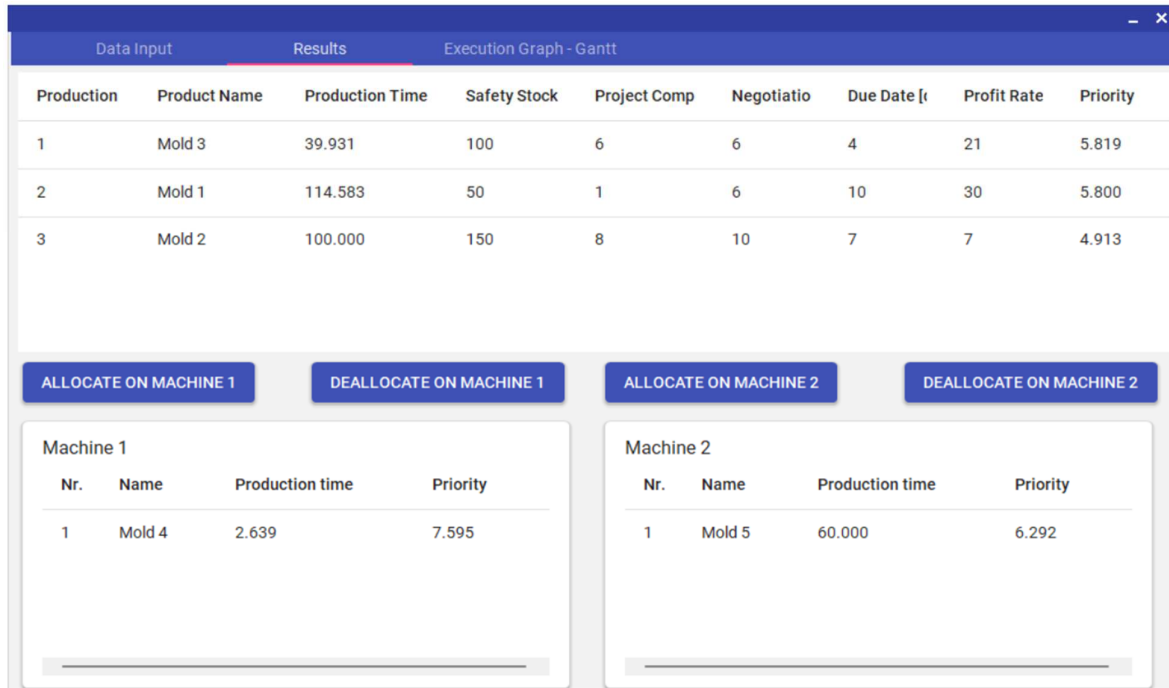


Fig. 8. Case study results

- The priority of the 1st mold: 5.80;
- The priority of the 2nd mold: 4.91;
- The priority of the 3rd mold: 5.82;
- The priority of the 4th mold: 7.59;
- The priority of the 5th mold: 6.29.

Therefore, the mold with the highest priority is the 4th mold. Once the priorities were calculated, the orders can be assigned to an injection machine, using a Gantt chart. The assignment of the molds is represented in figure 9. The orders marked with yellow will run the first injection machine, while the green ones will run on the second injection machine.

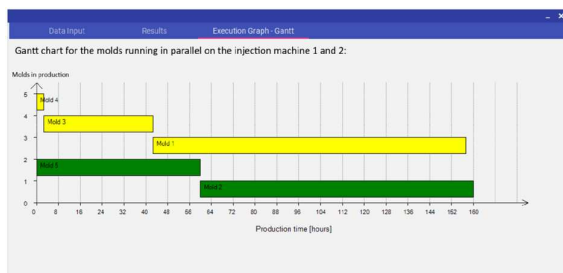


Fig. 9. The Gantt chart for the case study

5. CONCLUSION

In conclusion, the fuzzy logic-based system developed for production scheduling proved to be very efficient when it comes to determining the priority and managing the resources in the manufacturing process of plastic injection molding. By adjusting the priorities in real time, based on the input variables, the production time, the safety stock, the delivery due date, etc. and with the help of the Gantt chart, the system allows for a better resource management like time, energy and workers. This approach reduces idle times, optimizes resource utilization and increases productivity, proposing a flexible scheduling solution, capable of adapting to the dynamic conditions of the production process.

The addition of a user-friendly interface makes the system become more practical for users, allowing for an easier monitoring and faster adjustments. By simplifying the user experience, improving visualization and offering a customized experience, the user

interface makes the fuzzy logic system more accessible and more efficient across a wide range of applications.

Future work will focus on extending and optimizing this model by adding more input variables or other input variables, in order to find the most efficient combination of factors and to determine the priority even more accurately. Another idea is to make the system more modular, so that it improves its utility and broaden its adaptability capabilities, so that it can be used in other industries, that take into consideration different factors.

6. REFERENCES

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Implementarea unui sistem decizional bazat pe logică fuzzy pentru optimizarea programării producției reperelor obținute prin injecție de mase plastice.

Această lucrare prezintă dezvoltarea unei interfețe utilizator pentru un sistem decizional fuzzy, dezvoltat pentru a optimiza programarea producției în industria injectării maselor plastice. Sistemul integrează variabile de intrare precum timpul de producție, termenul limită, posibilitatea de negociere cu clientul, complexitatea proiectului, stocul de siguranță și rata profitului, pentru a determina prioritatea comenzilor de producție. Interfața utilizator permite o interacțiune intuitivă, permițând utilizatorilor să introducă date de intrare în timp real și să vizualizeze datele de ieșire. Utilizând logica fuzzy, sistemul poate combate incertitudinile, care sunt des întâlnite în mediile de producție, îmbunătățind eficiența programării și precizia luării deciziilor. Interfața simplifică interpretarea datelor complexe, asigurând o mai bună utilizare a resurselor și respectarea termenelor de livrare, ceea ce îmbunătățește performanța operațională.

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