An Automated Plastic Injection Molding Machine Selection System based on Fuzzy Logic Using MATLAB

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***Abstract*— In the phase of production planning, machine selection play important role in planning. At present, the majority of the machine selection process of plastic injection molding industry is conducted manually by an experienced planner. Therefore, the production plan depends on the skills and the experiences of the planner. However if a plan is conducted by an inexperienced planner it could lead to an uneconomical plan and delivery failure. Therefore, this study aims to develop a decision support tool for the plastic injection machine selection for the flexible production planning in dynamic planning and to enhance the irregular of operation flow by human's decision making. The machine selection system is developed by using six selection criteria from a plastic manufacturer's case study to construct a system based on fuzzy logic theory using MATLAB. The proposed system is designed to reduce decision making time and maintain similar results for both experienced and inexperienced planners.**

***Keywords*—Fuzzy logic, Machine selection, Injection molding machine, MATLAB, Planning**

I. Introduction

Over the last decade, a machine-job assignment problem has been integrating in harmony with job-shop scheduling theory. However, it is not feasible in practice due to lacking of sequencing procedure by considering of cost, processing time, knowledge, experience from planner and etc. This is because a huge number of machine, machine specifications, other environmental factors which are complex decision to be selected with the machine performance trading off. In fact, all injection molding machines are assigned to a job based on their capacity or physical properties such as clamping force, dimension of tie bars and blending with other previous job histories of their last batches, e.g. part color or material. In dynamic planning, human's decision making alone will not be sufficient to the flexible production planning that leads to undesirable cost and time. This causes an irregular operational flow as opposed to an automatic computational scheduler.

To fill this incomplete process, an expert system is selected. The expert system is a computer system that simulates the decision making ability of a human that has expert knowledge and experiences. It is able to manage the uncertainties with higher potential processes significantly as an accurate expert within a limitation of time and massive of information. Due to the outstanding properties of the fuzzy logic theory in dealing with instinct input. It gains possibility to invent an efficient production planning system concerning uncertain information to solve the problem which could not be done with mathematical modeling similar to human thinking in a short time period. The system cause to reduce unnecessary cost and obviously increases competitive competency to other manufacturers. Therefore, this research aims to develop the automated plastic injection machine selection system based on fuzzy logic theory using MATLAB with product consideration. After that, a comparison between the old system and the proposed system will be illustrated in the following section.

II. Literature Review

A. *Machine selection in the shop floor*

In real-world case of machine selection, the injection machine is obviously the representative of complexity machine selection process. Their scheduling is an instance of the class of flexible job shop scheduling problem (FJSS) where a finite set of customers' orders will be assigned on a finite set of machines [1]. But other number of researches had judged in parallel machine scheduling [2][3][4]. The assignment of jobs to an injection molding machine is one-to-many relationships between the goods and the molds as well as between the molds and the machines [1]. Some researches refer clamping force as the rule of injection machine selection decision to process a product. It is an internal control variable that affects product quality. In fact, the selection criteria from a plastic manufacturer are shown in Fig. 1.

Fig. 1 shows how to select a machine by judgment with machine's specification, capacity and structural, and product requirements from a plastic injection molding industry. The following details are:

1) Step 1: To select a machine having clamping force consistent with a required product.

2) Step 2: To select a machine having comprehensive distance of tie bars with injection mold size of product's specification. This distance of injection mold must not longer than in machine tie bars.

3) Step 3: To select a machine having comprehensive shot weight with product's weight but less than maximum shot weight of machine to avoid material overflows.

4) Step 4: To select a machine that worked the last job with a color similar to a required product if possible.

5) Step 5: To select a machine that worked the last job with the best material grade for the easiest cleaning.

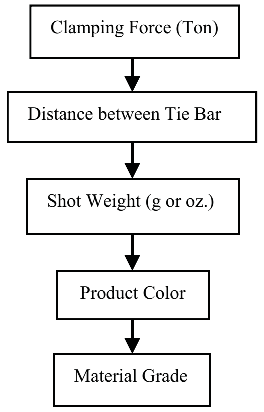

Fig. 1 Injection molding machine selection criteria

Even higher computer technology revolutions were introduced but rather many industries keep employing an expert or an experienced planner to handle until this day because of the following reasons.

- The realization of outstanding selection process's property that must deal with uncertainty and imprecision,
- The difficulty forms with a mathematical model or programming,
- Human logic could learn knowledge and then problem solving reacts along with unsharpness information and for the problem that could not be modeled to solve also,
- Conventional machine scheduling theory had not concern in machine selection process before assigning jobs to each machine.

The selecting of processing parameters in plastic injection molding manufacturing is more similar with logical machine selection than currently scheduling solution. This process has to analyze what process parameters are the most suitable for a product characteristic after the information of product specification has entered. Thus, there was a possibility to adapt the knowledge of injection molding machine's process parameter selection in view of machine selection by using the fuzzy logic.

B. Fuzzy logic

Fuzzy logic is chosen as an alternative to classical logic in application areas of industrial process control through consumer product, aerospace and bioengineering. Each of these applications, fuzzy logic plays a similar role in shaping a suitable rule-based and linguistic control strategy. There have been successful applications and implementations of fuzzy set theory in Industrial Engineering [5].

A fuzzy set can be simply defined as a set with fuzzy boundaries, which provides means to model the uncertainty associated with vagueness, imprecision, and lack of information. It is a principle of mapping of Classical Sets and Fuzzy Sets to the functions. In the fuzzy theory, fuzzy set A of universe X is defined by function $\mu_A(x)$ called the membership function of set A.

$$\mu_A(x) : X \rightarrow [0,1], \quad (1)$$

where

$$\mu_A(x) = 1 \text{ if } x \text{ is total in } A;$$

$$\mu_A(x) = 0 \text{ if } x \text{ is not in } A;$$

$$0 < \mu_A < 1 \text{ if } x \text{ is partly in } A.$$

The membership value is "1" if it belongs to the set or "0" if it is not a member of the set. The degree of membership is the value in range 0 to 1, can be called degree of membership or membership value, but less sharp from the set in classical theory. The feature of the membership function is defined by three properties. They are Core, Support and Boundary. To design membership functions we should perform in a way which satisfies the following 2 conditions: 1) Each membership function overlaps only with the closest membership functions. 2) For any possible input data, its membership values in all relavant fuzzy sets should sum of 1. One of the most practical approaches for forming fuzzy set relies on the knowledge of single or multiple experts. Later, a new technique to form fuzzy sets was recently introduced and based on artificial neural networks, which learn available system operation data and then derive the fuzzy sets automatically.

The fuzzy sets and fuzzy operators act as the subjects and verbs of fuzzy logic. Conditional statements, if-then rules, make fuzzy logic useful, lead to the complete sentence. The structure of a single IF-THEN rule is as follows:

If x is A then y is B

where x is A' is called the antecedent and describes a condition, 'y is B' is called the consequent and describes a conclusion. Both antecedent and consequent can have multiple parts.

Fuzzy inference can be defined as a process of mapping from given input to an output, using the theory of fuzzy sets. Fuzzy inference techniques were proposed in two methods; Mamdani-style and Sugeno-style inferences [6]. Sugeno style is more appropriate for a problem with functioning or a mathematical output is employed but this is not related to our automated machine selection system within this research and is not suitable for our objective. Therefore, Mamdani-style inference system will be raised to be the solution method. The process of Mamdani-style inference system is following,

1) Fuzzification of the input variables: When the crisp inputs are obtained, they are fuzzified against the appropriate linguistic fuzzy sets.

2) Rule evaluation: To take the fuzzified inputs and apply them to the antecedents of the fuzzy rules, If a given fuzzy rule has multiple antecedents, the fuzzy operator (AND or OR) is used to obtain a single number that represents the result of the antecedent evaluation. It is note that different methods might cause dissimilar results. However, the customization of AND and OR operations allowed for user in many fuzzy packages.

3) Aggregation of the rule outputs: To take the membership functions of all rule consequents and combine them into a single fuzzy set. The output of the aggregation process is one fuzzy set for each output variable.

4) Defuzzification: Defuzzification is the last step in the fuzzy inference process. In order to express the crisp number (single number) in the final output of a fuzzy system, the defuzzification is required. There are two major defuzzification techniques: the Mean of Maximum (MOM) and the centre of gravity (COG) or centroid technique.

We could synthesize beneficial properties of taking on fuzzy logic to be the solution for injection molding machine selection via previous researches as following issues,

- Broad applicable and practicable in selection problems
- Flexibility to modify by a user without high knowledge background
- Realistic
- Handle imprecision and vagueness in dynamic environment of industry
- Lower computational time than other AI techniques

Although, this term does not represent the best answer when an organization has to confront with unsteady decision making in every manufacturing type but fuzzy logic implementing is foundation of user-friendly, realistic process, understandable for inexpert decision makers and minimization of programming and computation time, enhance planning performance by decreasing human's bias in general organization [7] [8] and adaptable with another system.

III. System development

This research used injection molding machine's information of a medium-size plastic manufacturer which is handling more than 300 products that need a planner's decision to allocate among 35 machines every month depending on 50 customer orders above. An interview with production planners was conducted in order to comprehend the selection logic idea of each resource allocation cycle. Furthermore, in order to avoid large volume of information and high consuming of computational time. The 11 machines were used for development of system prototype. These machines have the same and different specification of each by covering 30-75 tons of machine size. The data of input variables for the fuzzy inference system are considered step by step as follows:

1) Clamping force: This is the force between both sides of injection mold in the unit of ton. If an injection mold is provided with adequate clamping force, two sides of injection mold will be jointed completely without leakage. Thus the expected machine must not have clamping force lower than the product requirement.

2) Distance between tie bars: The length between tie bars both vertical and horizontal axis. Any injection mold can be installed into a machine if it does not exceed that machine's distance between tie bars. In this research, te variale can be separated this variable to be 2 membership functions as follows:

2.1) *Distance between tie bar X*: The length between of two tie bars in horizontal axis.

2.2) Distance between tie bar Y: The length between of two tie bars in vertical axis.

3) Shot weight: The maximum weight of plastic is injected directly into injection mold at once feeding. The target product should have weight equal or lower than maximum shot weight of machine to avoid material overflow.

All variables were classified in range by representing with linguistic term and then were transformed to the degree of membership by data changing phenomena. For example, if clamping force is 30, then the linguistic term is 'Very very low' then the degree of membership range is 1.0; and if the clamping force changed to be 31, then the degree of membership range in 'Very very low' is 0. As a result, the degree of membership range in 'Very low' will be 1.0.

Fig. 2 shows membership function of all variables in fuzzy inference system which consists of four membership functions for input variables and one membership function for an output variable. After membership function of input variables had illustrated, then the 480 rules were constructed and added into this system. The output of the fuzzy inference system in this problem is machine group (MGr). There are n groups of machine, but in this study group of machine can be classified to six machine group corresponded to machine specifications (n=6), these was classified by the similar machine specification. The fuzzy inference system diagram is illustatrated in Fig. 3.

In according to indentify which machine is the most suitable for a job, the output of fuzzy inference system (machine group) has to be completely evaluated by other criterions that are *Product color* and *Material grade*.

4) Product color: This attribute is color of product that we want to produce. It will be matched with any machine that used to produce the same color in the latest batch. For example, if product color is white, the product color of the latest batch of selected machine should be white also or nearly clear (colorless) color. If a machine group processes in the same color in more than one machine, the material grade will be considered in the next step.

5) Material grade: This attribute refers to the complication of cleaning process and raises more risk of contamination from material burning of each material grade. If the material grade of a job is A, the last batch of a suitable machine should have produced in the same grade or nearly.

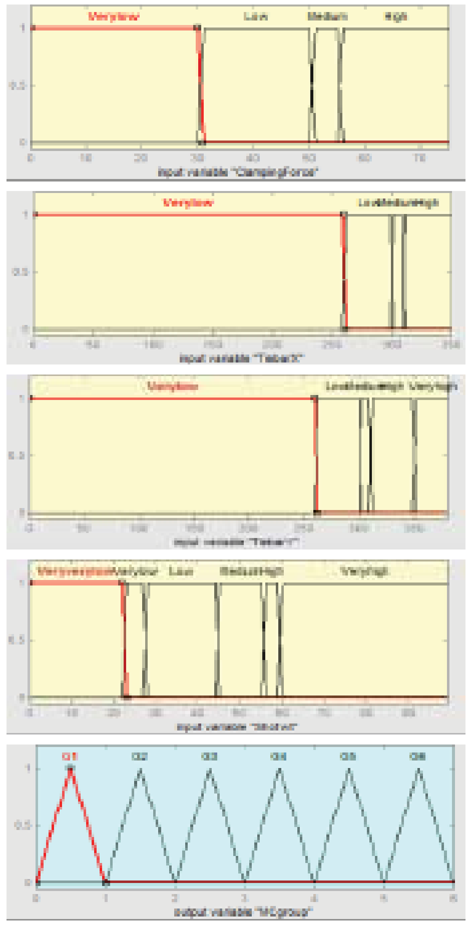

Fig. 2 Membersip function of input variables.

The reason why two attributes of product color and material grade were not added to the fuzzy inference system in this paper is that it is necessary to reduce the complexity of the system and to avoid computational time consuming in program development and analysis phases. The decision flowchart of product color and material grade decision process are shown for more understandable in Fig. 4.

IV. Result and discussion

To evaluate the suitable machine, ten examples of orders have been executed to the proposed system. The computation time of the system was three to five seconds; on the contrary, a human planner requires five minutes to execute the plan. Meanwhile if we double the size of sample data, the proposed system still maintains the same computational time. On the other hand, a human planner requires much more time and risk the chance of making mistake during planning. Therefore, the proposed system provided the efficient of computational time, user-friendly and easy to customize.

In fact, there are another two variables which are product color and material grade. These variables can be applied into the fuzzy inference system. However, there are excluded in this proposed system since an extremely longer computational time due to the huge number of rules. It is found that in practice a manufacturer uses clamping force and distance between tie bars as their selections as well as other criteria are required individually. Although, clamping force has been reporting to be a highly effective factor for injection molding machine selection during the production planning phase, the less of significant criteria, distance between tie bars and material color or grade are also commonly used in industries.

V. Conclusions

From the study, the existing machine-job assignment problem principle would not be impacted to the plastic injection industry. All injection molding machine are assigned to a job based on their capacity or physical properties such as the highest clamping force, dimension of tie bars and blending with another previous job history of their last batches, part colour and material. The majority of machine selection process is conducted manually by an experienced planner. Human's decision does not support to the flexible production planning in dynamic planning and leads to undesirable cost, which increases revising time of a production plan after uncertain information has come. This research aims to study concerned criteria for selecting the injection molding machine in production planning process and applying for development of the automated plastic injection machine selection system based on fuzzy logic theory using MATLAB. The benefits of applying fuzzy logic are broad, applicable, practical, flexible, easy to modify without knowledge background, realization, imprecision and vagueness in dynamic environment of industry and lower computational time. After testing a prototype system with real order data, the system has shown almost similar correctness with human's decision. Moreover, an efficient computational time consuming could be obtained when the realistic and user-friendly system was running.

TNI Journal of Engineering and Technology
Vol.2 No.1 January - June 2014

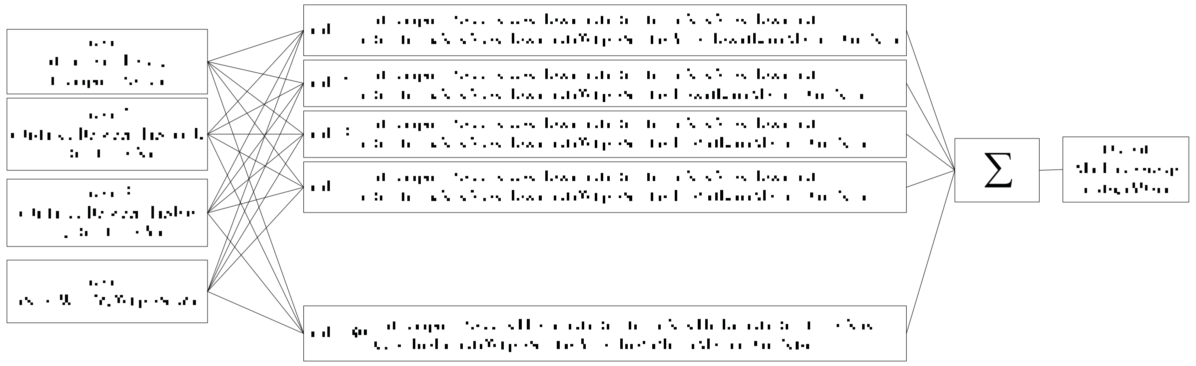

Fig. 3 Fuzzy inference system diagram

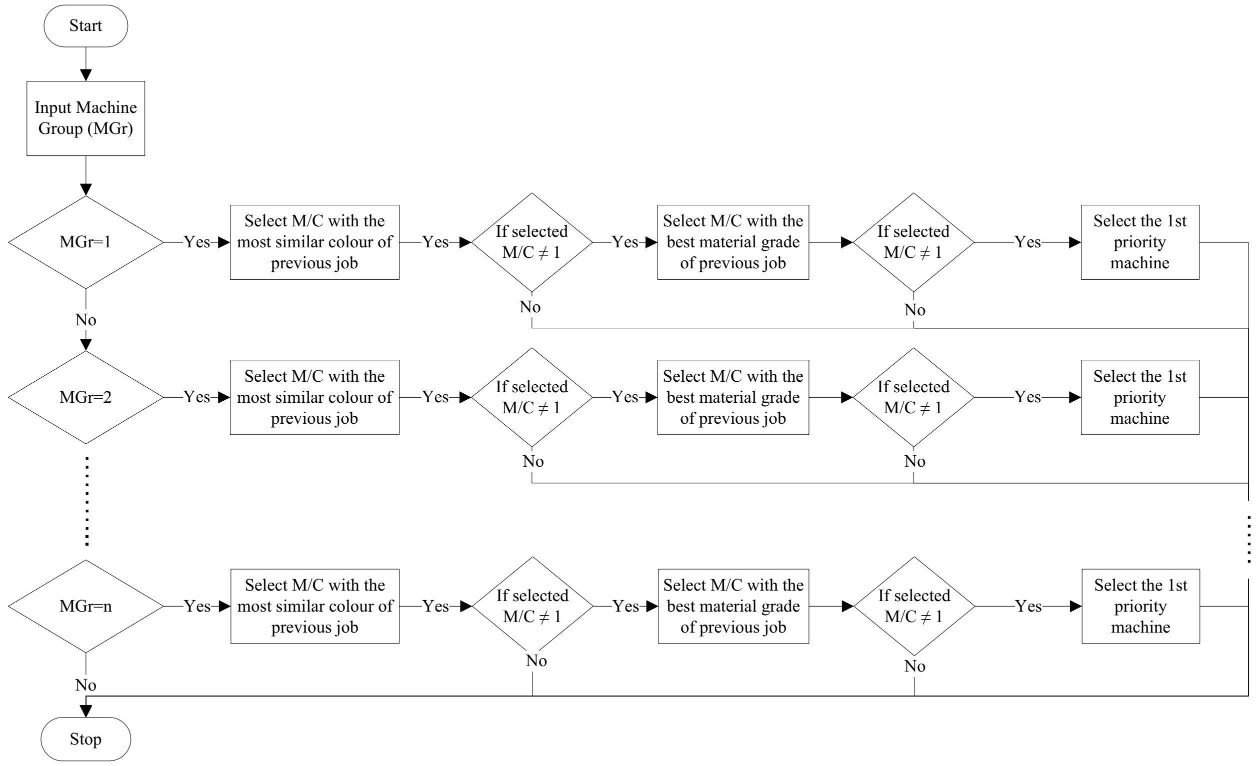

Fig. 4 Decision flowchart of Product color and Material grade variables (n = 6)

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