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The Defects Reduction in Injection Molding by Fuzzy Logic based Machine Selection System

S. Suwannasri, and R. Sirovetnukul

Abstract**—**The effective machine-job assignment of injection molding machines is very important for industry because it is not only directly affects the quality of the product but also the performance and lifetime of the machine as well. The phase of machine selection was mostly done by professionals or experienced planners, so the possibility of matching a job with an inappropriate machine might occur when it was conducted by an inexperienced person. It could lead to an uneconomical plan and defects. This research aimed to develop a machine selection system for plastic injection machines as a tool to help in decision making of the user. This proposed system could be used both in normal times and in times of emergency. Fuzzy logic principle is applied to deal with uncertainty and mechanical factors in the selection of both quantity and quality criteria. The six criteria were obtained from a plastic manufacturer's case study to construct a system based on fuzzy logic theory using MATLAB. The results showed that the system was able to reduce the defects of Short Shot and Sink Mark to 24.0% and 8.0% and the total defects was reduced around 8.7% per month.

Keywords**—**Injection molding machine, machine selection, fuzzy logic, defects in injection molding, matlab.

I. Introduction

THE production line of plastic manufacturing is usually composed of several injection molding machines. These machines have the same function but are different in their specification, information and capacity. Therefore, the increasing number of machines may cause greater variety of products. However, the procurement of new machines should be gradually increased. The machine is added up when it causes the profitability. The injection molding machines are usually assigned to a job based on their capacity or physical properties (e.g. clamping force, dimension of tie bars). The previous job's characteristic is also considered (e.g. color, or material).

The machine selection is determined by experienced planners, but the human's decision making is not stable for application of production planning. It leads to loss of cost and time. Therefore, a decision support system is selected as a tool. The decision support system is a computer system that simulates the decision making ability of a human. The system has adequate knowledge and executes to make decision despite limitation of time and massive of information. The fuzzy logic has been applied to the proposed system to analyze all results regarding information which could not be modeled like human thinking in a short time.

This research attempts to develop the plastic injection machine selection system based on fuzzy logic as the decision support system. It also aims to reflect the product cost reduction when the proposed system is applied. After that, the comparison between the current system and the proposed system will be illustrated. This research is organized into five sections as follows. Section 2 concerns the general information and previous researches in area of injection molding machine selection. Common defects in injection molding and the basic principle of fuzzy set theory are also presented. Section 3 includes the system development. Section 4 contains the results and discussion. Finally, Section 5 deals with a conclusion.

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II. Literature Review

This section contains details of the current situation of the machine selection researches, injection molding machine selection and fuzzy logic principle.

A. The Related Researches Involving Machine Selection

A decision support system was developed by applying the Analytical Hierarchy Process (AHP) method and a rule-based technique [1]. Their purpose is to select an appropriate machine for a Flexible Manufacturing System (FMS). They used past information and machine database as the input data. One advantage of this approach is to allow users to add or deduct machines directly in the database via application of Database Management System. However, a disadvantage is that the system relies on all answers and ratings of users. This makes it require a high level of knowledge management. In addition, dealing with non-standard data makes the system take so much time. MACSEL software used by [1] is also applied to a study of [2], which aimed to select a machining center. AHP is also found to be used in many studies [3]-[5]. These studies considered rating scores based on users' experience. However, a research [6] suggested that AHP was not a best method to select the machine.

Some studies [7], [8] used fuzzy TOPSIS for deciding to buy a robot, a rapid prototype, and a machine center respectively. TOPSIS was also used in conjunction with AHP, by means of fuzzy extension [9]. Their methods are named fuzzy TOPSIS and fuzzy AHP, which allowed them to weight inexplicit criteria. Qualification of fuzzy theory can support decision makers in assessing quantities specified in intervals, which is more convenient to deal with fixed-value quantities. This method can show priority of each criteria with fuzzy number better than with precise number. Fuzzy TOPSIS was used for assessing scores of CNC machining centers rated by purchasers. Fuzzy number cooperated with an expert system in a form of Fuzzy Multiple Attribute Decision-Making (FMADM) model for selecting a batch-dryer, a machine for producing foodstuffs [10]. This kind of models is also used for selecting a machine for a production system of Flexible Manufacturing Cells (FMC) [11]. Their approach was found to be realistically and economically. These studies have shown that fuzzy theory was excellent in simulating human logic.

Many researchers have employed fuzzy theory as the primary tool for solving problems in selecting machines. Fuzzy logic was used for solving problems of crane selection to match construction [12]. The procedure for selecting machines was proposed by performing with 3 machine selection rules namely Lowest average cost, Least average process time, and Least aggregate cost and process time [13]. These rules are applied to machine selection by considering minimization of processing cost and time. They can support functionality of production scheduling by means of dispatching rules under production factors such as due dates, number of suitable resources to process a job operation, and machine breakdown. A paper was published regarding identifying the most suitable machine from a list of available machines for scheduling with fuzzy machine selection process [14]. They employed simple machine selection rules to enhance the performance of each of the four dispatching rules. Comparing efficiency of fuzzy machine selection approach with machine selection rules, the latter was found to be significantly superior in improving production schedules, both in terms of Mean Job Tardiness and Mean Job Cost. Thus fuzzy approach is beneficial for applying to job shop environment, where rigid rules were traditionally used, while production conditions are constantly changing. Convenience in dealing with machine selection by means of fuzzy approach was also found in selecting a 2D laser scanner [15]. In addition, the work [16] revealed that both crisp criteria and fuzzy criteria can also be applied to machine selection when only few data are available. According to all mentioned researches, comparing to other approaches, fuzzy approach was found to be the most appropriate in dealing with problems of machine selection with a reasonable time and cost of development.

B. Injection Molding Machine Selection

The injection machine is obviously a representative of complicated machine selection process. Job shop scheduling problem (FJSS) is usually indicated for this machine where a finite set of customer orders will be assigned on a finite set of machines [17]. However, some researchers proposed it by parallel machine scheduling [18]–[20]. Traditionally, any machine will be selected when it matches with the clamping force, platens and mold's shot size. Nowadays, good for the design part, materials are required to be compatible with the existing tools under quality management [21]. The criteria are different in each manufacturer followed by their priority of criteria and production resources. For example, manufacturer A has 10 operators per 8 injection molding machines. The number of operators was not used to be a selection criterion because there are enough operators. On the other hand, manufacturer B has 6 operators which are not balanced to 11 injection molding machines. Thus manufacturer B has to use number of operators as a machine selection criteria.

The relationship between products and mold is one-to-many relationship. This relationship is also found in the molds and the machines [17]. The selection criteria of clamping force are the basis of other criteria [22]. This is because clamping force is a variable that highly affects product [23]. The technical factors (e.g. tonnage, pressure, open distance, tie-bar space, mold dimension, temperature, etc.) and economic factors (e.g. shot weight size) were offered. These criteria were called the compatibility factors of mold-machine compatibility [18].

C. Effect of Machine Selection Criteria on the Defects in Injection Molding

The type of defects in plastic injection production relates to some selection criteria. For example, if a machine had operated the last batch with black color material, the brighter color product might be contaminated with black dot (black streaking) leading to waste time and resources. Otherwise, a burn mark on product caused by some particles will remain in the last batch as well.

The information of common defects in injection molding machine is shown in Table I. These defects are mainly caused by machines, molds and materials [21], [24]. The criteria are different in each manufacturer followed by their priority of criteria and production resources. For example, a company may consider using suitable material as their criteria. But another company with only few alternative machines could not avoid using harmful material for maintaining of a machine's lifetime. Besides, the machine's operating system could be indirectly influenced by unsuitable machine usage such as irregular electrical system caused by loading capacity. It affects the heating system that may become disordered or does not meet setting condition that leads to burn marks or unmelted particles of the product. Additional labor cost would be needed during overtime when the job could not be finished on regular time due to sudden failure of the machine. Therefore, effective machine selection does not only improve product quality but also reduces cost of labor during overtime work.

D. Fuzzy Logic Principle

Fuzzy logic is a principle of mapping classical sets and fuzzy sets to the functions. A fuzzy set is defined as a set with degree of memberships. Thus, it provides means to model the uncertainty (e.g. vagueness, imprecision) and the lack of information. Fuzzy logic is applied as a suitable role in figuring a rule-based and linguistic control strategy of industrial process control. Fuzzy logic theory is adaptably and wide-spread used in Industrial Engineering [25].

Fuzzy sets are the function that maps universe X onto the range [0, 1]. The fuzzy set A of universe X is represented by the membership function of set A (μ_A). For example, the fuzzy set T is the function μ_T that carries X into [0, 1] [26]. The mapping is explained by equation (1).

$$\mu_T(x) \in [0, 1], \quad (1)$$

$\mu_T(x)$ is represented the degree of membership of element x in fuzzy set T or $\mu_T(x)$ = degree to which $\mu_T(x) \in A$.

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 the range 0 to 1. It can be called a degree of membership or membership value, but less sharp from the set in classical theory.

The membership functions are designed based on two conditions of each membership function. These functions overlaps with the closest membership functions and its membership values in fuzzy sets should have a sum of 1. This research designed all membership functions in triangular fuzzy number because it is more general and adaptable than other approaches.

The fuzzy sets and fuzzy operators exhibit as the subjects and verbs of fuzzy logic. The if-then rules make fuzzy logic useful. The structure of a single IF-THEN rule is as follows:

If x is A then y is B

Where x and b are fuzzy variables, 'A' represents a condition and is called the antecedent, 'y' represents a conclusion and is called the consequent. Both antecedent and consequent can have more than one part.

Fuzzy inference system was proposed in two methods: Mamdani-style and Sugeno-style inferences. This research uses Mamdani-style as the solution method because the output is the form that suitable for this study. Meanwhile, Sugeno style is more appropriate for a problem that functioning or a mathematical output is employed.

The process of Mamdani-style inference system includes fuzzification, rule evaluation, aggregation of rule outputs and defuzzification. The inputs of fuzzy inference system are the crisp numbers. Later, they will be in forms of normalization or fuzzification to be the appropriate linguistic fuzzy sets. Then, these fuzzy sets will be applied to antecedents. If the fuzzy rules are constructed, the fuzzy operators (AND or OR) will be integrated into those rules. Later, all rule consequents are taken into membership functions and combined with a single fuzzy set. The output of the aggregation process is one fuzzy set for each output variable. Finally, defuzzification is performed the last step. The output of this process is turned to the crisp number (single number). There are two major defuzzification techniques: the Mean of Maximum (MOM) and the centre of gravity (COG) or centroid technique.

Fuzzy logic is able to enhance planning performance by decreasing the human's bias in general organization. The advantages of fuzzy logic implementing are as follows:

1) User-friendly
2) Realistic process
3) Understandable for inexpert decision makers
4) Minimization of programming and development time
5) Lower computational time than other AI techniques
6) Adaptable with another system.

III. Methodology

This section contributes an idea of research. The contents are data collection, designing framework and building a system, encoding with MATLAB, system testing, Results, conclusion and discussion.

A. Collecting Data

This research observed all data and machine selection criteria from a plastic manufacturer. The eleven machines are selected to develop the proposed system as in Table I.

TABLE I
MACHINE SPECIFICATION OF SAMPLE INJECTION MOLDING MACHINE

Machine Number	Clamping Force (Ton)	Distance between Tie bar X (mm)	Distance between Tie bar Y (mm)	Shot weight (g)
M1	30	260	260	28
M2	30	260	260	28
M6	50	300	300	45
M7	50	300	300	45
M8	50	300	300	45
M3	50	310	310	56
M5	50	310	310	56
M4	50	310	300	60
M9	55	310	310	23
M10	75	350	380	100
M11	75	350	380	100

Because, these machines can show the overlapping specification. And all 6 criteria can be utilized by one or more machines in each machine group. The machine specification was collected to use as antecedents of rules and create fuzzy inference system and an additional subsystem. This subsystem was used to avoid excessive information and complicated system.

Table II shows machine selection criteria of the plastic manufacturer case study. A machine will be selected by the judgment with machine's specification, capacity and structural, and product requirements from a plastic injection molding industry. Details of the selection are:

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

2nd Step: To select a machine having a comprehensive distance of tie bars with the injection mold size of the product specification. This distance of injection mold must not be longer than machine tie bars.

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

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

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

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TABLE II
INJECTION MOLDING MACHINE SELECTION CRITERIA FROM A CASE STUDY

Injection Molding Machine Selection Process	Descriptions
Clamping Force	The force between both sides of injection mold (moving platen and stationary platen). If an injection mold has adequate clamping force, two sides of injection mold will be jointed completely without leakage.
Distance between Tie Bars	Any injection mold can be installed if mold dimension does not exceed that machine's distance between tie bars. This length refers to both horizontal and vertical axes.
Shot Weight	The capacity of melted plastic weight is injected directly into the injection mold at once feeding. The target product should have weight equal or lower than the maximum shot weight of machine in order to avoid material overflow
Product Color	For producing a product with a specified color, the job should be matched with the machine that has been used for producing products with the same color or the most similar one.
Material Grade	The selected machine should be one that has been operated with best material grade for ease of cleaning like the last batch.

B. Design Framework and Develop the System

Regarding the integration of the proposed system with current planning process, the new business workflow and overall system diagram is designed. This system is function of mapping a job to a machine number. The machine sizes for this system are 30 - 75 tons. The proposed system was composed with one fuzzy inference system and one subsystem. The overall system is shown in Fig. 1. The proposed system, name IMM Selection System, cooperates with the existing business process. The performance of planning officer will be enhanced in the machine selection phase. The compositions of our proposed system are as follows:

1) Fuzzy Inference System: This system is operated based on fuzzy logic theory.

i. Inputs: Clamping force, distance between tie bar X, distance between tie bar Y and shot weight.

ii. Output: Machine Group (MGr) when MGr = n group (n= 1,2,3,...,6). These groups were classified by the similar machine specification.

2) Subsystem: This system is an indicator for evaluation of the best machine in a machine group. The judgment of the machine's previous jobs against product specifications will be done.

i. Inputs: Machine Group, Product color, Material grade, that will be generated by the fuzzy inference system.

ii. Output: Machine Number (M) by M = 1,2,3,...,11.

Table III shows all data in a fuzzy inference system which consists of four membership functions of input variables and one membership function of an output variable. The data of input variables for the fuzzy inference system are considered step by step. For example, if clamping force is 30, then the linguistic term is 'Very very low' and the degree of membership range is 1.0; and if the clamping force change 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.

All variables are transformed to fuzzy sets and linguistic values. The 480 rules were constructed and added into this system. The detail is followed;

The number of rules

= No. of clamping force's fuzzy sets × No. of distance between tie bar X's fuzzy sets × No. of distance between tie bar Y's fuzzy sets × No. of shot weight's fuzzy sets

= 4 × 4 × 5 × 6 = 480 rules

In this problem, the 'AND' operator was applied to construct all fuzzy rules. It provided the corrected results. These fuzzy rules will have multiple antecedents, for example:

IF ClampingForce is Verylow
AND TiebarX is Verylow
AND TiebarY is Verylow
AND Shotwt is Veryverylow
THEN MCgroup is G1

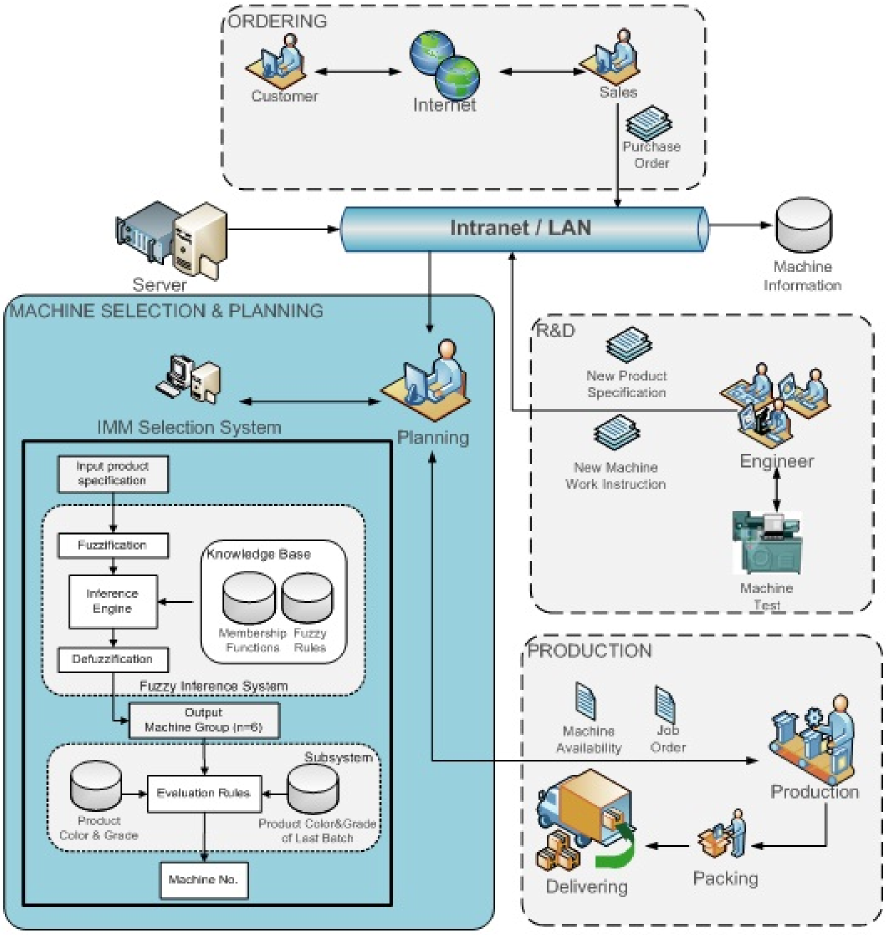

Fig. 1 The overall system diagram included injection molding machine selection system

The sample of fuzzy rules in the proposed system

1. If (ClampingForce is Verylow) and (TiebarX is Verylow) and (TiebarY is Verylow) and (Shotwt is Veryverylow) then (MCgroup is G1).

2. If (ClampingForce is Verylow) and (TiebarX is Verylow) and (TiebarY is Verylow) and (Shotwt is Verylow) then (MCgroup is G1).

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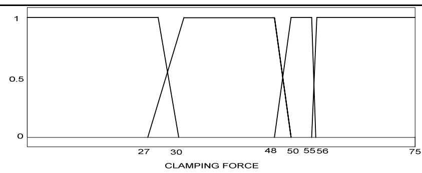
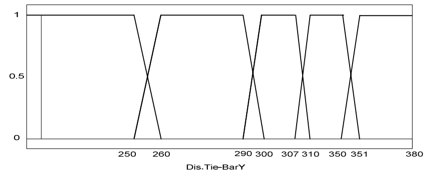
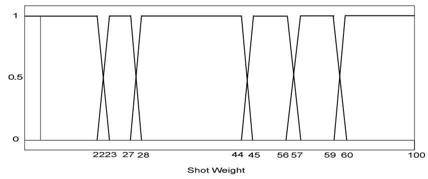
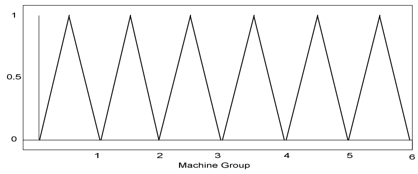
479. If (ClampingForce is High) and (TiebarX is High) and (TiebarY is Veryhigh) and (Shotwt is High) then (MCgroup is G6) (1) 480. If (ClampingForce is High) and (TiebarX is High) and (TiebarY is Veryhigh) and (Shotwt is Veryhigh) then (MCgroup is G6).

The mechanism of the subsystem is as follows:

- Product color: This attribute is color of product that we want to produce. In order to avoid the color contamination, the product will be matched with the machine that has been used to produce the same color or the most similar one. In this study, there are four product colors (i.e. clear, white, grey and black). If more than one machine in a machine group has processed the same color, the material grade will be considered.
- Material grade: This attribute refers to the complication in cleaning process. In this study, there are four product colors, i.e. clear, white, grey and black. 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. The four grades of material were A, B, C and D. If material grades are sorted by the ability of cleaning, the A > B > C > D is achieved. That means A is the easiest cleaning material and D is the hardest one.

TABLE III
THE LINGUISTIC VARIABLES AND THEIR RANGES FOR MEMBERSHIP FUNCTION CONSTRUCTION

	Variables	Range	Linguistic value	Membership functions
Input	Clamping force (Ton)	0 -30	Very low	
		31 - 50	Low	
		51- 55	Medium	
		56 - 80	High	
	Distance between tie bar X (mm)	0 – 260	Very low	
		261- 300	Low	
		301 – 310	Medium	
		311 - 350	High	
	Distance between tie bars Y (mm)	0 – 260	Very low	
		261- 300	Low	
		301 – 310	Medium	
		311 – 350	High	
		350 - 380	Very high	
	Shot weight	0 – 22	Very very low	
		23-27	Very low	
		28-44	Low	
		45 – 55	Medium	
		56 - 59	High	
		60 - 105	Very high	
Output	Machine group	0 - 1	G1	
		1 - 2	G2	
		2 - 3	G3	
		3 - 4	G4	
		4 - 5	G5	
		5 - 6	G6	

The reason why those two attributes were not added to the fuzzy inference system is that it is necessary to reduce the complexity of the system and to avoid computational time consuming in program development and analysis phases.

C. System Development and Testing

The designed system has encoded the fuzzy sets, fuzzy rules and procedures to perform fuzzy inference using MATLAB. Within this system, interval variables will be normalized to being in range of [0,1] and then will be carried on the inference process with Mamdani-style. The Graphic User Interface (GUIs) was developed by GUIDE (the MATLAB Graphical User Interface Development Environment). Then, FIG-file and M-file were generated. For the subsystem, the scripts were coded into that M-file. The testing will perform by running the proposed system for selecting the only most appropriate machine. The crisp values of clamping force, mold dimension X and Y (compare with distance between tie bars X and Y criteria) and shot weight were entered into the system.

Defects from that machine will then be monitored. Since the system has not been really implemented, defect data of July 2012 will be used for calculating defects from the machine. Number of defects from machines other than the selected one will be calculated for total defects and categorized by defect types. The result will be multiplied with probability value of that defect type, and then the reducing percentage (%) can be calculated.

Total number of defectives (Proposed system) of short shot

= Number of defectives from the proposed system + Number of potential defectives produced by the machines have not reassigned

= Number of defectives from the machines have not reassigned + (Total defectives from the machines have not reassigned × Probability of having defect from the machines have not reassigned)

= $1571 + [1571 \times (1571/3110)] = 2364.6 \approx 2365$

Thus, the total number of Short Shot defectives is 2365 pieces and the proposed system can reduced Short Shot defectives to 24.0%.

IV. RESULTS AND DISCUSSION

The proposed system was tested based on daily production reports which were collected in July 2012. These data include utilization of eleven machines that were used for the proposed system, product specifications, and defective

TABLE IV
THE FAULTY PRODUCT VOLUME RECORDED FROM 11 INJECTION MOLDING MACHINES AS THE PROPOSED SYSTEM

	Short Shot	Silver	Sink Mark	Other	Black Dot	Scratch	Oily	Over Cut	Oil Mark	Discolor	Weld Line	Dakon	Burn Mark	Bubble	Flashing	Broken	Warp	Flow Mark	Crack	Gate NG
No. of defectives (%)	21.69	18.97	14.59	9.68	9.20	4.41	4.34	3.58	3.40	2.44	2.27	1.75	1.62	0.77	0.52	0.35	0.25	0.14	0.03	0.00
Cumulative (%)	21.69	40.65	55.25	64.93	74.12	78.54	82.88	86.46	89.85	92.29	94.56	96.31	97.94	98.71	99.23	99.58	99.83	99.97	100.00	100.00

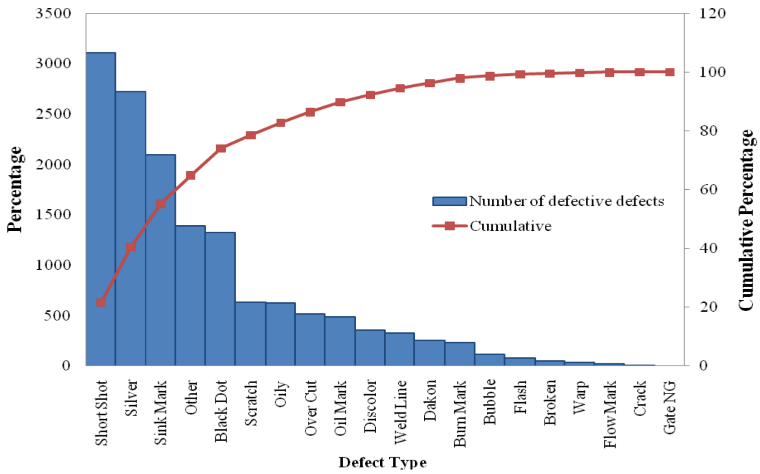


Fig. 2 The pareto graph of amount of defectives separated by types on July 2012

TABLE V
THE DEFECTS IN INJECTION MOLDING INFLUENCED BY MACHINE SELECTION CRITERIA IN THE CASE STUDY

Defects	Common Causes	Point of Troubleshooting			Reference
		Mold	Machine	Material	
Black streaking	Contaminated plastication system Improper drying	-	-	✓	[21]
Sink marks	Underpacking Mold malfunction Poor part design	✓	-	-	[21]
Discoloration	Process temperatures too high Improperly sized cylinder Contamination	-	✓	✓	[21],[24]
Scratch	Surface damage under scratch condition	✓	-	✓	[27]
Flashing (on parting line)	Over-pressurization of cavity Melt temperature too high Mold malfunction	✓	✓	-	[21],[24]
Silver streaking	Moisture trapped in material Melt temperature too high Condensation in mold Poor pressurization Water leak in mold	✓	✓	✓	[21],[24]
Oily	Contamination of oil in mold Excess use of mold release	✓	✓	-	[24]
Short shots	Cavity not filling properly Insufficient melt volume Moisture in material Mold release agent used High - pressure drop in mold Poor mold design	-	✓	✓	[21],[24]
Burn marks (on part)	Injection rate too high Lack of mold venting Clamp pressure too high	✓	✓	-	[21],[24]

products in each job. In order to compare how the proposed system improved the defects, this research made a comparison of the defect volumes with the current system. As in Table IV and Fig. 2, only the top five defect types that were produced based on 11 examined machines had been investigated because they were accounted for 82.88% of all defect types. In order to the unidentified the defect type of 'Other', all jobs that have had the defects of Short Shot, Silver, Sink Mark, Black Dot, Scratch and Oily were evaluated again by the proposed system except the 'Other' type.

Table V is the type of defect and common causes. The information infers that defect types are affected by our selection criteria that are Short Shot, Sink Mark and Black Dot. Therefore, the defects of Silver, Scratch and Oily have not improved by the proposed system. And this results indicate that the proposed system did not reduced the amount of Black Dot as in Table VI.

TABLE VI
THE DEFECTIVE VOLUME RECORDED FROM 11 INJECTION MOLDING MACHINES AS THE PROPOSED SYSTEM

Faults	Defectives (pieces.)		Reducing Percentage (%)
	Current System	Proposed System	
Short Shot	3110	2365	24.0
Sink Mark	1714	1577	8.0
Black Dot	1319	1319	0.0

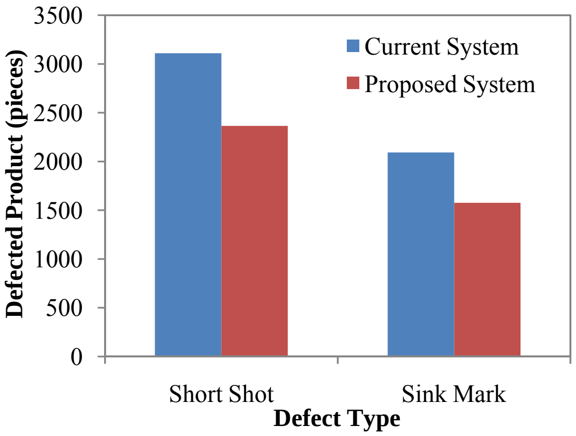


Fig. 3 The Amount of Defectives of Short Shot and Sink Mark between the current system and the proposed system

From Table VI and Fig. 3, Short Shot and Sink Mark were reduced to 24.0% and 8.0% respectively. Therefore, the total of defectives was decreased to 8.7% per month. These results indicate that if the proposed system was used, not only defective products will be reduced but costs of reprocessing, waste treatment, and inventory can also be reduced.

The results mentioned above are caused by the following:

- Short Shot and Sink Mark are affected by selecting the machines that have maximum clamping force lower than required force for products and low shot size. There is unconformity of mold closing, low density of melted material and leads to Sink Mark (Shrinkage)
- The criteria in proposed system obviously relate to the whole operating system of the machine instead of Scratch and Silver. The uncontrollable condition may occur. That cause to the other defects.
- Other defects (i.e. Silver, Black dot, Scratch and Oily) are required to be improved by another method.
- In fact, the criteria also have influence on Black Dot. However, the planner could maintain the same product color using on the machine.

V. CONCLUSION

This research aimed to develop a machine selection system for plastic injection machines as a tool to help users in making decisions. Because the using of injection molding machines directly affects the quality of the product and also performance and lifetime of the machine. However, there is possibility of matching a job with an inappropriate machine when this process is done by inexperienced planners. This research proposed the decision support system, named IMM Selection System, by applying the fuzzy logic principle to deal with uncertainty and mechanical factors in the selection of both quantity and quality criteria. The six criteria of clamping force, distance between tie bar X, distance between tie bar Y, shot weight, product color and material grade were obtained from a plastic manufacturer's case study to construct a system based on fuzzy logic theory using MATLAB. The system had tested by the comparison of defectives from the proposed system and current system. This study used data of job orders and defectives were recorded within July to August 2012, categorized by defect types. The results showed that the system was able to reduce the faults of Short Shot and Sink Mark for 49.5% and 22.6% respectively. Moreover, Flashing was decreased for 45.3%, while other defect types did not change. Therefore, in total, ratio of defective products could be decreased to 14.3% per month.

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