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Risk Prioritization in the Process of Molding Plastic Materials

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Abstract
In the industry, the plastic injection process is frequently used. For this reason, establishing risks and preventing them is a permanent concern of quality management and more. To prioritize these risks, a series of models and methods established by research in the field are applied. The case study presented in the paper aims to prioritize the risks that can lead to defective parts in the injection molding process. To achieve this objective, the fuzzy ELECTRE method was used. The opinions of the decision-makers were presented using linguistic terms. As a defuzzification method, the CFCS algorithm was used to convert the fuzzy score into a crisp score. The aggregate matrix is implemented in the ELECTRE fuzzy model. The results obtained by comparing the Net superior ranking with the Net inferior ranking us to the conclusion that, through this analysis, a series of problems can be anticipated and resolved with priority before they arise.

Keywords
risk prioritization, the plastic injection process, CFCS algorithm, ELECTRE fuzzy model

1. Introduction

Plastic materials are one of the options for consumer goods manufacturers, regarding the materials used. Although, for decades metal materials were the only alternative, as technology evolved and consumers wanted better products, made in a shorter time, many manufacturers turned to plastic materials. Even industries that relied heavily on metals in the past such as: automotive, aerospace, military, have now switched to plastic parts. Even though metal will not be completely replaced, as there are still industries where it is the best material, plastic brings a number of benefits.

Comparing the process of processing plastic with that of metal, in the first case, significant savings in production time, labor, energy and costs are achieved. It is important, however, that the processing process is well done and that the potential risks are eliminated from the very beginning.

2. Process of Molding Plastic Materials

Injection molding is the most commonly used manufacturing process for the fabrication of plastic parts. A wide variety of products are manufactured using injection molding, which vary greatly in their size, complexity, and application. The method is suitable for the mass production of products with complicated shapes, and takes a large part in the area of plastic processing.

The process of injection molding is divided into 6 major: clamping, injection, dwelling, cooling, mold opening, removal of products (Figure 1).

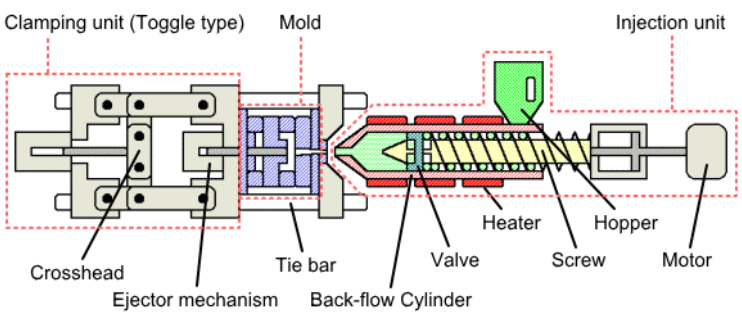

Fig. 1. Injection molding machine [1]

The injection molding process requires the use of an injection molding machine, raw plastic material, and a mold. Injection molding machine is divided into two units i.e. a clamping unit and an injection unit. The functions of the clamping unit are opening and closing a die, and the ejection of products. There are 2 types of clamping methods, namely the toggle type shown in the Figure 1 below and the straight-hydraulic type in which a mold is directly opened and closed with a hydraulic cylinder.

The functions of the injection unit are to melt plastic by heat and then to inject molten plastic into a mold. The screw is rotated to melt plastic introduced from the hopper and to accumulate molten plastic in front of the screw (to be called metering). After the required amount of molten plastic is accumulated, injection process is stared.

While molten plastic is flowing in a mold, the machine controls the moving speed of the screw, or injection speed. On the other hand, it controls dwell pressure after molten plastic fills out cavities.

The position of change from speed control to pressure control is set at the point where either screw position or injection pressure reaches a certain fixed value.

Molding condition means cylinder temperature, injection speed, mold temperature etc. set in a molding machine to obtain required moldings, and the number of combinations of conditions is innumerable. Depending on the conditions selected, the appearances, dimensions, and mechanical properties of the molded products change considerably.

Therefore, well-tried technology and experience are required to select the most suitable molding conditions. The possible defects that can occur in the parts obtained by this process are shown in Table 1.

Table 1. Possible defects of plastic parts [2]

Defect	Causes
Flash	Injection pressure too high clamp force too low
Warping	Non-uniform cooling rate
Bubbles	Injection temperature too high Too much moisture in material Non-uniform cooling rate
Unfilled sections	Insufficient shot volume Flow rate of material too low
Sink marks	Injection pressure too low Non-uniform cooling rate
Ejector marks	Cooling time too short Ejection force too high

3. Presentation of the Methods Used

3.1. Description of the Fuzzy Set

Fuzzy set [3] was first introduced by Lotfi A. Zadeh in 1965 as an extension of the crisp set. A set whose elements have a degree of membership. If X is a universal set with element x, then a fuzzy set $\tilde{A}$ in X is a set of ordered pairs $\tilde{A} = \{(x, \mu_A(x): x \in X\}$, where $\mu_A(x)$ is a membership function. Thus, the membership function $\mu_A(x)$ is defined as $\mu_A: X \rightarrow [0, 1]$.

The *Fuzzy Number* [3] $\tilde{A}$ is a fuzzy set whose membership function must satisfy the following conditions:

(1) A fuzzy set $\tilde{A}$ of the universe of discourse, X is convex;

(2) A fuzzy set $\tilde{A}$ of the universe of discourse, X is a normal fuzzy set if $x_i \in X$ exists;

(3) $\mu_A(x)$ is piecewise continuous.

Fundamentally, the triangular membership function (Figure 2) can be defined by three parameters (l, m, n) with ($l < m < n$). All the parameters determine the coordinates of the three angles as l, m, n and *triangular fuzzy number* (TFN) [4] function is defined as

$$\mu_A(x) = \begin{cases} \dfrac{x-l}{m-l}, & l \le x \le m \\ \dfrac{n-x}{n-m}, & m \le x \le n \\ 0, & x > n \end{cases} \tag{1}$$

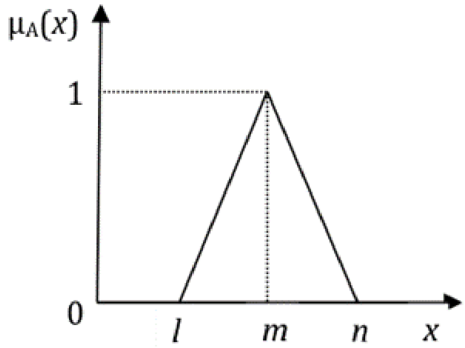

Fig. 2. Triangular fuzzy number

The *arithmetic operation*s [5] of triangular fuzzy number the four operations that can be performed on the triangular fuzzy number are as follows: Let $\bar{X}$ = (x_1, x_2, x_3) and $\bar{Y}$ = (y_1, y_2, y_3) be the triangular fuzzy number:

1. Addition $\bar{X} + \bar{Y}$ = ($x_1 + y_1$, $x_2 + y_2$, $x_3 + y_3$)
2. Subtraction $\bar{X} - \bar{Y}$ = ($x_1 - y_1$, $x_2 - y_2$, $x_3 - y_3$)
3. Multiplication $\bar{X} \times \bar{Y}$ = ($x_1 \times y_1$, $x_2 \times y_2$, $x_3 \times y_3$)
4. Division $\bar{X}/\bar{Y}$ = (x_1/y_1, x_2/y_2, x_3/y_3)

(2)

3.2. Description of the Fuzzy ELECTRE Method

The ELECTRE method (Elimination et Choix Traduisant la Realité) appeared in 1965, when a group of French researchers from SEMA (Société d'économie et de mathématiques appliquées) laid the foundations for a ranking and choice method in the presence of points of multiple vision [6-9].

Step 1: Frame the alternatives and criteria based on the risk factors

Let A = {A_1, A_2 ...A_m} be the set of alternative and C = {C_1, C_2 ...C_n} be the set of criteria and decision-markets are T = {T_1, T_2 ...T_d}.

Step 2: Construct the linguistic decision matrices using linguistic terms with aid of decision makers.

$$L_k = \begin{bmatrix} \tilde{a}_{11k} & \tilde{a}_{12k} \cdots & \tilde{a}_{1nk} \\ \tilde{a}_{21k} & \tilde{a}_{22k} \cdots & \tilde{a}_{2nk} \\ & \vdots & \vdots \\ \tilde{a}_{m1k} & \tilde{a}_{m2k} \cdots & \tilde{a}_{mnk} \end{bmatrix}; \quad W_k = [\tilde{w}_{1k,}\ \tilde{w}_{2k}, \dots, \tilde{w}_{nk}] \tag{3}$$

where $\tilde{a}_{ijk}$, i = 1,2,...,n; j =1,2...,m; k = 1,2,...,d the relation between i^{th} alternative is the j^{th} criteria by the k^{th} expert, where $\tilde{a}_{ij}$ and $\tilde{w}_{ij,}$ are linguistic variable.

Step 3: Transform the linguistic matrices into triangular fuzzy matrices. Then, construct the aggregated triangular decision matrix T (Table 2) and the weighted matrix W (Table 3).

Table 2. Triangular fuzzy matrices T

	C_1	C_2	...	C_n
A_1	$(l_{11,}\ m_{11,}n_{11})$	$(l_{12,}\ m_{12,}n_{12})$	⋯	$(l_{1n,}\ m_{1n,}n_{1n})$
A_2	$(l_{21,}\ m_{21,}n_{21})$	$(l_{22,}\ m_{22,}n_{22})$	⋯	$(l_{2n,}\ m_{2n,}n_{2n})$
⋮	⋮	⋮	⋯	⋮
A_m	$(l_{m1,}\ m_{m1,}n_{m1})$	$(l_{m2,}\ m_{m2,}n_{m2})$	⋯	$(l_{mn,}\ m_{mn,}n_{mn})$

Table 3. Weighted matrix W

T_1	$(w_{11,}\ w_{12,}w_{13})$
T_2	$(w_{21,}\ w_{22,}w_{23})$
...	...
T_n	$(w_{n1,}\ w_{n2,}w_{n3})$

$$l_{mn} = \min_d\{l_{mn}\};\quad m_{mn} = 1/d\ \Sigma m_{mn};\quad n_{mn} = \max_d\{n_{mn}\}$$
$$w_1 = \min_d\{w_{dn}\};\quad w_2 = 1/d\ \Sigma w_{dn};\quad w_3 = \max_d\{w_{dn}\} \tag{4}$$

Step 4: The triangular fuzzy matrix T is converted into crisp value matrix to get the defuzzied matrix by the CFCS algorithm [10, 11]:

a) Normalization

$$xa_{ij}^{n} = \frac{a_{ij}^{n} - mina_{ij}^{n}}{\Delta_{min}^{max}}$$
$$xb_{ij}^{n} = \frac{b_{ij}^{n} - mina_{ij}^{n}}{\Delta_{min}^{max}} \tag{5}$$
$$xc_{ij}^{n} = \frac{c_{ij}^{n} - mina_{ij}^{n}}{\Delta_{min}^{max}}$$

where $\Delta_{min}^{max} = max\ c_{ij}^{n} - min\ a_{ij}^{n}$

b) Evaluate the right score and left the score

$$xas_{ij}^{n} = \frac{xb_{ij}^{n}}{1 + xb_{ij}^{n} - xa_{ij}^{n}}$$
$$xcs_{ij}^{n} = \frac{xc_{ij}^{n}}{1 + xc_{ij}^{n} - xb_{ij}^{n}} \tag{6}$$

c) Total normalized values

$$x_{ij}^{n} = \frac{xas_{ij}^{n}\left(1 - xas_{ij}^{n}\right) + \left(xcs_{ij}^{n} * xcs_{ij}^{n}\right)}{1 - xas_{ij}^{n} + xcs_{ij}^{n}} \tag{7}$$

d) Calculation of separated value

$$z_{ij}^{n} = min\ a_{ij}^{n} + x_{ij}^{n} * \Delta_{min}^{max} \tag{8}$$

Step 5: Normalize the defuzzied matrix

$$\mathrm{D} = \begin{bmatrix} u_{11} & u_{12} \cdots & u_{1n} \\ u_{21} & u_{22} \cdots & u_{2n} \\ & \vdots & \vdots \\ u_{m1} & u_{m2} \cdots & u_{mn} \end{bmatrix} \tag{9}$$

The defuzzied matrix D is normalized by

$$r_{ij} = \frac{u_{ij}}{\sqrt{\sum_{i=1}^{n} u_{ij}^{2}}} \tag{10}$$

to get the normal

$$\mathrm{U} = \begin{bmatrix} r_{11} & r_{12} \cdots & r_{1n} \\ r_{21} & r_{22} \cdots & r_{2n} \\ & \vdots & \vdots \\ r_{m1} & r_{m2} \cdots & r_{mn} \end{bmatrix} \tag{11}$$

Step 6: Construct the weighted normalized matrix W.

Evaluated the weighted normalized decision matrix where weights are defined by the decision-maker with the help of expert in the field knowledge.

$$W = (\mathrm{W1, W2, ..., Wn})$$
$$W = \begin{bmatrix} w_1\, r_{11} & w_2\, r_{12} \cdots & w_n\, r_{1n} \\ w_1\, r_{21} & w_2\, r_{22} \ldots & w_n\, r_{2n} \\ & & \vdots \\ w_1\, r_{m1} & w_2\, r_{m2} \cdots & w_n\, r_{mn} \end{bmatrix} = \begin{bmatrix} m_{11} & m_{12} \cdots & m_{1n} \\ m_{21} & m_{22} \cdots & m_{2n} \\ & \vdots & \vdots \\ m_{m1} & m_{m2} \cdots & m_{mn} \end{bmatrix} \tag{12}$$

Step 7: Determine the concordance and discordance index in:

$$c_{mn} = \sum_{j\ c_w} W_j, \quad \text{where } c_{mn} = \left\{j, m_{mj}\ \geq m_{nj}\right\}, \text{for } j=1, 2, \ldots\ n \tag{13}$$

$$d_{mn} = \frac{\max|m_{mj}-m_{nj}|}{\min|m_{mj}-m_{nj}|}, \quad \text{where } d_{mn} = \{j, m_{mj} < m_{nj}\}, \text{ for } j=1, 2, \dots n \tag{14}$$

The initial function for concordance index C_{mn} measures whether a is at least as good as b. Thus the matrix CM is calculated as follows

$$CM = \begin{bmatrix} - & c_{12} & \cdots & c_{1n} \\ c_{21} & - & \cdots & c_{2n} \\ & & & \vdots \\ c_{m1} & c_{m2} & \cdots & - \end{bmatrix} \tag{15}$$

The discordance index d_{mn} is strictly measured for b with compared to a. The matrix DM is calculated as follows

$$DM = \begin{bmatrix} - & d_{12} & \cdots & d_{1n} \\ d_{21} & - & \cdots & d_{2n} \\ & & & \vdots \\ d_{m1} & d_{m2} & \cdots & - \end{bmatrix} \tag{16}$$

Step 8. Determine the net superior and inferior value C_a is used to determine the number of superior rankings of alternatives.

$$C_a = \sum_{b=1}^{n} c_{ab} - \sum_{b=1}^{n} c_{ba} \tag{17}$$

On the contrary, D_a is used to determine the number of inferiors ranking of the alternatives.

$$D_a = \sum_{b=1}^{n} d_{ab} - \sum_{b=1}^{n} d_{ba} \tag{18}$$

4. Establishing the Critical Failure Variant. Case Study for Injection Molding Process

- **Step 1**: The selection criteria considered are the risk factors:

  C_1: severity (S);
  C_2: occurrence (O);
  C_3: detection (D).

Potential risk factors are presented in Table 4 and linguistic variables in Table 5.

Table 4. Potential risk factors for the plastic injection process

Risk factors	Notation	Risk factors	Notation
Temperature of mould too low	R_1	Clamping force too low - failure in the hydraulic system	R_5
Temperature of cylinder too low	R_2	Clamping force too low – incorrect adjustment	R_6
Pressure of cylinder too low	R_3	Clamping plan damaged /used	R_7
Insufficient quantity of material injected –incorrect adjustment	R_4	Temperature of mould too high	R_8

Table 5. Linguistic variables

Linguistic variables	Triangular Membership Function
Very Low Risk (VLR)	(0; 0; 0.25)
Low Risk (LR)	(0; 0.25; 0.5)
Medium Risk (MR)	(0.25; 0.5; 0.75)
High Risk (HR)	(0.5; 0.75; 1)
Very High Risk (VHR)	(0.75; 1; 1)

- **Step 2**: Establishing matrices of direct linguistic relationship

The three decision-makers' views are taken for this analysis. The fuzzy linguistic values are utilized to provide the relationship between alternatives and criteria with the opinion of the decision-maker (Table 6, Table7, Table 8).

Table 6. First decision opinion maker

	C_1	C_2	C_3		C_1	C_2	C_3
R_1	MR	LR	MR	R_5	LR	MR	HR
R_2	MR	VLR	MR	R_6	LR	LR	LR
R_3	LR	LR	MR	R_7	LR	LR	VLR
R_4	LR	MR	HR	R_8	MR	VLR	LR

Table 7. Second decision opinion maker

	C_1	C_2	C_3		C_1	C_2	C_3
R_1	MR	LR	MR	R_5	LR	MR	HR
R_2	HR	VLR	HR	R_6	HR	LR	MR
R_3	LR	MR	MR	R_7	LR	LR	VLR
R_4	MR	MR	VHR	R_8	HR	VLR	MR

Table 8. Third decision opinion maker

	C_1	C_2	C_3		C_1	C_2	C_3
R_1	HR	MR	LR	R_5	MR	MR	HR
R_2	MR	VLR	MR	R_6	LR	LR	VLR
R_3	MR	LR	LR	R_7	R	MR	VLR
R_4	LR	HR	HR	R_8	MR	VLR	VLR

The criteria are also evaluated by the decision factors (Table 9).

Table 9. Opinion of the decision-makers on criteria

	C_1	C_2	C_3
Decision maker 1	VHR	HR	MR
Decision maker 2	HR	LR	HR
Decision maker 3	MR	MR	VHR

➢ **Step 3:** Transform the linguistic matrices into triangular fuzzy matrices. Then, construct the aggregated triangular decision matrix T and weighted matrix W.

The relation (4) is used for the calculation, and the results are listed in Table 10 and Table 11.

Table 10. Aggregated triangular fuzzy matrix (T)

	C_1	C_2	C_3
R_1	(0.25; 0.58; 1)	(0; 0.33; 0.75)	(0; 0.42; 0.75)
R_2	(0.25; 0.58; 1)	(0; 0; 0.25)	(0.25; 0.58; 1)
R_3	(0; 0.33; 0.75)	(0; 0.33; 0.75)	(0; 0.42; 0.75)
R_4	(0; 0.33; 0.75)	(0.25; 0.58; 1)	(0.25; 0.75; 1)
R_5	(0; 0.33; 0.75)	(0.25; 0.5; 0.75)	(0.5; 0.75; 1)
R_6	(0; 0.42; 1)	(0; 0.25; 0.5)	(0; 0.33; 0.75)
R_7	(0; 0.42; 1)	(0; 0.33; 0.75)	(0; 0.08; 0.5)
R_8	(0.25; 0.58; 1)	(0; 0; 0.25)	(0; 0.42; 0.75)

Table 11. Weighted matrix (W)

	C_1	C_2	C_3
Decision-maker	(0.25; 0.75; 1)	(0; 0.58; 1)	(0.25; 0.67; 1)

➢ **Step 4**: Convert triangular fuzzy values into crisp values using the CFCS algorithm (relations 5…8). Set up the usual normalize the defuzzied matrix D (Table 12).

Table 12. The defuzzied matrix D

	C_1	C_2	C_3
R_1	0.585	0.364	0.415
R_2	0.585	0.033	0.585
R_3	0.364	0.364	0.415
R_4	0.364	0.585	0.685
R_5	0.364	0.5	0.733
R_6	0.455	0.267	0.364
R_7	0.455	0.364	0.151
R_8	0.585	0.033	0.415

➢ **Step 5**: The defuzzied matrix D is normalized, using relations (10) and (11). The normalized matrix U is presented in Table 13.

➢ **Step 6**: Construct the weighted normalized matrix *W* (Table 14), using relation (12) and the decision-makers *W* (0.633; 0.503; 0.590).

Table 13. The normalized decision matrix U

	C_1	C_2	C_3
R_1	0.727	0.452	0.516
R_2	0.706	0.040	0.707
R_3	0.550	0.550	0.628
R_4	0.374	0.602	0.705
R_5	0.379	0.521	0.765
R_6	0.711	0.416	0.567
R_7	0.757	0.604	0.250
R_8	0.815	0.046	0.578

Table 14. The weighted normalized matrix *W*

	C_1	C_2	C_3
R_1	0.460	0.228	0.304
R_2	0.447	0.020	0.416
R_3	0.348	0.277	0.369
R_4	0.237	0.304	0.416
R_5	0.240	0.262	0.450
R_6	0.450	0.209	0.334
R_7	0.479	0.304	0.147
R_8	0.516	0.023	0.340

➢ **Step 7**: Calculate the concordance index C_{mn} and discordance index D_{nm}, using the relations (13) and (14). The results are presented in the matrix CM (Table 15) and matrix DM (Table 16).

Table 15. The matrix concordance, CM

R_a \ R_b	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8
R_1	-	1.136	0.633	0.633	0.633	1.136	0.590	0.503
R_2	0.590	-	1.223	1.223	0.633	0.590	0.590	0.590
R_3	1.093	0.503	-	0.633	1.136	1.093	0.590	1.093
R_4	1.093	0.503	1.093	-	0.503	1.093	0.590	1.093
R_5	1.093	1.093	0.590	1.223	-	1.093	0.590	1.093
R_6	0.590	1.136	0.633	0.633	0.633	-	0.590	0.503
R_7	1.136	1.136	1.136	1.136	1.136	1.136	-	0.503
R_8	1.223	1.136	0.633	0.633	0.633	1.223	1.223	-

Table 16. The matrix discordance, DM

R_b \ R_a	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8
R_1	-	16	1	1	1	1.9	1	1
R_2	1	-	2.106	1	1	1	1	1
R_3	1.326	1	-	1	7.200	1.943	1	8.759
R_4	1.493	1	1.769	-	1	1.173	1	3.747
R_5	4.294	7.117	1	11.39	-	2.119	1	2.173
R_6	1	63	1	1	1	-	1	1
R_7	4	8.875	4.852	1	5.690	3.276	-	1
R_8	1.556	23	1	1	1	1	5.216	-

➤ **Step 8**: Determine the Net superior (Table 17) and Net inferior (Table 18) values, using the concordance and discordance matrix, the sum of the value will be calculated, relations (17) and (18). These are represented in Figures 3 and 4.

Table 17. Net superior value, C_a

	C_a	Rank
R_1	-1.554	2
R_2	-1.204	3
R_3	0.200	5
R_4	-0.146	4
R_5	1.468	7
R_6	-2.646	1
R_7	2.556	8
R_8	1.326	6

Table 18. Net inferior value, D_a

	D_a	Rank
R_1	8.231	3
R_2	-111.886	1
R_3	9.501	4
R_4	-6.208	2
R_5	11.203	5
R_6	46.589	8
R_7	17.477	6
R_8	25.093	7

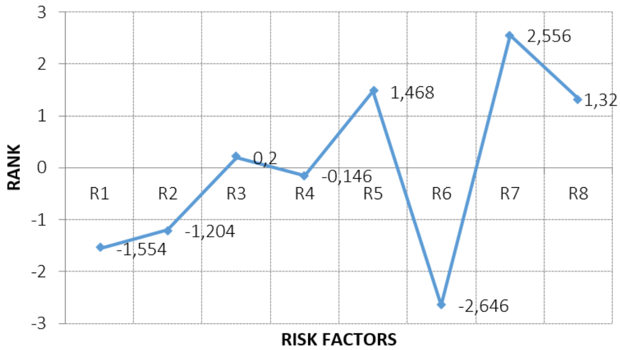

Fig. 3. Net Superior ranking values

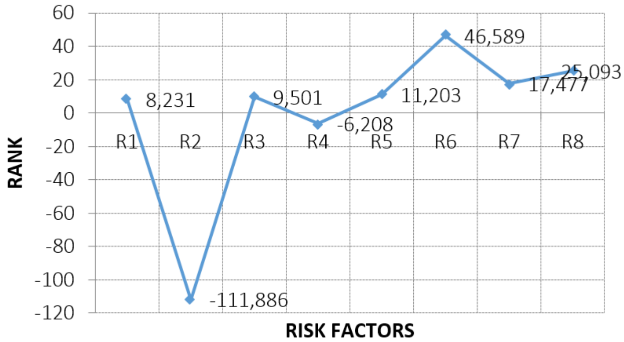

Fig. 4. Net Inferior ranking values

5. Conclusions

A comparative analysis of the obtained results (Table 19) leads us to the following conclusions:

- ✓ The Net superior ranking is generally used as the optimal ranking method. In these conditions, the risk factor that must be given special attention is R_6, *Clamping force too low*. In 2nd and 3nd place in the ranking are R_1 and R_2;
- ✓ It is observed that R_1 and R_2 appear in the first three places and in the Net inferior ranking, so these must also be considered as a priority, that is, *Temperature of mould too low* and *Temperature of cylinder too low*.

Table 19. Comparative analysis of the results

Rank	Order of priority by Net superior ranking	Order of priority by Net inferior ranking
1	R_6	R_2
2	R_1	R_4
3	R_2	R_1
4	R_4	R_3
5	R_3	R_5
6	R_8	R_7
7	R_5	R_8
8	R_7	R_6

For each of the risks established with a high degree of importance, preventive safety measures are necessary, to prevent errors, respectively the appearance of non-conforming parts.

In order to obtain even more conclusive results, it is necessary to apply other methods such as: FMEA, VIKOR, TOPSIS method. A sensitivity analysis of the results obtained is also necessary. This constitutes a future research direction.

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