Use of the Ishikawa diagram in the investigation of some industrial processes

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Abstract. The use of the Ishikawa diagram was proposed by Japanese professor Kaoru Ishikawa in the 1960s. The diagram must highlight the possible causes of a certain effect. In the research presented in this paper, the analysis method based on the design of the Ishikawa diagram was used to identify the factors able to ensure the adequate development of some investigations concerning certain industrial processes. It was found that various criteria could be used to evaluate the effect. Versions of Ishikawa diagrams were proposed in the cases of chemical engraving process, cast iron milling process, 3D printing process and the reliability of computer subsystems, respectively. A comparison of the Ishikawa diagram method with the systemic analysis method highlighted some particular aspects that could be considered when the problem of investigating the influence of certain process input factors on the process output parameters is formulated.

1. Introduction

The main groups of theoretical research methods are the analysis methods, synthesis method, modeling and/or simulation methods, optimizing methods. One of the theoretical analysis methods is the analysis through the cause-effect method. This method was proposed by the Japanese professor Kaoru Ishikawa, in the 1960s, when he worked at Tokyo University. Sometimes, the application of the method is finalized by the elaboration of the so-called Ishikawa diagram or diagram in the fishbone or herringbone diagram.

Practically, the Ishikawa diagram is a graphical representation of the connection between a result and the factors able to exert influence on the result. In this way, for example, the diagram offers a general image concerning the causes that generate a certain effect. The main stages in the elaboration of the Ishikawa diagram are the following: 1. Problem definition; 2. Elaboration of the graphical representation; 3. Analysis of the information offered by the diagram and that highlights the main factors or the factors whose values could be changed; 4. Developing a plan to act by considering the remarks from the previous stage.

As benefits of using the Ishikawa diagram, the following could be mentioned: a better understanding of a process or equipment, initiation of an innovation process, facilitating the learning process and the ideas change, better manage of the factors able to generate less convenient effects, eventual establishing of the necessity of technical norms elaboration etc.

Over the years, the Ishikawa diagram was analyzed or used in solving many scientific research problems.
Thus, Ilie and Ciocoiu took into consideration the risk of an event with multiple causes in the elaboration of the fishbone diagram [1]. They considered that the inclusion of the risk score for each category of causes could extend the Ishikawa diagram applicability.

Romo et al. showed how the Ishikawa diagram could be used to identify the possible causes of a problem [2]. They highlighted the importance of using subsequently the question “why does this happen” in problem-solving. The importance of considering the correct evaluation of the probability that corresponds to various causes and their impact was mentioned.

Magdum and Gore investigated a manufacturing process to identify the root causes of parts rejection and found that various factors generate a certain ovality of the part [3]. The analysis facilitated the elaboration of an Ishikawa diagram, used then as a guideline for solving the problem. They appreciated that other methods could be applied to prioritize the causes that generate the part rejection and to apply a certain solution.

Luca developed research concerning the errors that appear in the evaluation of the precision of the parts. He took into consideration the influence of various factors on the dimensional accuracy, on the shape and position accuracy and the surface roughness, respectively [4]. On the other hand, five groups of factors were identified as able to affect the parts precision evaluation: man, method, machines, materials, and environment. The author proposed the use of an improved model of Ishikawa diagram, obtained as a combination of three skeletons that correspond to considered ways of parts precision evaluation.

Luo et al. highlighted the possibility of using the fishbone diagram and risk analysis method in the safety evaluation of a natural spherical gas tank [5]. They proposed the use of a modified classical risk matrix in a combination with an improved version of the fishbone diagram. As the main results, they mentioned the elaboration of specific measures to eliminate or to diminish the risk of accidents.

The objective of the research presented in this paper was to highlight the possibilities of using the Ishikawa diagram in initiating some doctoral research activities that correspond to certain processes or equipment from the industrial engineering field. The connection between these processes is that having some input factors, starting from a raw part, and needed some output factors, generally shaping the finished part, using the Ishikawa diagram, someone can see some common lines to guide within the direction of solving the problems occurring during the technological processes.

2. Use of Ishikawa diagram in defining the conditions for experimental research of chemical engraving process

The chemical machining can be defined as a non-traditional machining method based on the developing of the chemical reaction between a chemically active liquid and the workpiece material, in the workpiece zones where a process of material removal is necessary. One of the proper applications of the chemical machining method is the chemical engraving [6]. The last decades showed an extension of using the chemical engraving to perform inscriptions of drawings on the metallic or nonmetallic parts. As a chemical machining method, the chemical engraving needs to know and adequately use a set of material conditions and process characteristics. With such an aim in view and taking into consideration the facilities offered by the Ishikawa diagram and the research activity intended to be developed on the chemical engraving process, the decision to elaborate such a graphical representation was formulated.

As engraving process output results, the material removal rate, the surface roughness, the thickness of the layer affected by the machining process and the change of the chemical composition and physical properties of the chemically active liquid were considered.

The information found in the specialty literature and the analysis of the factors that are able to affect the process results (the values of the process input factors could be included in the following main groups: specimen characteristics, chemical engraving scheme, characteristics of the chemical engraving equipment, human factor involved in the investigated process) were considered. The deeper analysis of the chemical engraving process led to the identification of proper factors included in the above-mentioned groups and their consideration within an Ishikawa diagram (figure 1).
3. Use of Ishikawa diagram to identify the factors able to affect the reliability of the computer

At present, the computers can not only perform complicated calculations, but they can be embedded in systems capable of solving complex problems, with or without human help. Current computers include many components whose operation can significantly affect the good functioning of the whole ensemble in which these components are incorporated. There are many known incidents caused by the malfunctioning of some components of computers. To highlight the factors able to exert influence on the reliability of the computers, the method of the Ishikawa diagram was used (figure 2). The main groups of factors affecting the good functioning of the computers could be the following: a) Power supply; b) Component reliability; c) Environment conditions; d) Human factor; e) Operating conditions. The proper factors that act on the computer’s reliability and that determine their good functionality were emphasized in the Ishikawa diagram presented in figure 2.

![Ishikawa diagram](image)

**Figure 1.** Ishikawa diagram elaborated to highlight the factors able to affect the results of the chemical engraving process.

**Figure 2.** Ishikawa diagram that illustrates the factors able to determine the failure or malfunction of the computer system.
4. Use of Ishikawa diagram in evaluating the results of the cast iron end milling process

The milling is a machining method based on the use of a rotating cutting tool that has many cutting edges. The feed movement is performed along a direction perpendicular to the cutting tool rotation axis. The milling is applied especially in obtaining flat surfaces, but it could be also applied to obtain cylindrical, conical, spiral or more complex profiled surfaces.

![Ishikawa diagram for cast iron milling](image)

**Figure 3.** Ishikawa diagram that highlights the factors able to affect the roughness of the surfaces obtained by milling on cast iron workpieces.

The problem taken into consideration within a doctoral research program was to find solutions for improving the milling process of flat surfaces in the case of workpieces made of iron surfaces. As the main objective of the research, the improving of the surface roughness parameters was considered, aiming at finding the factors that could lead to the diminishing of the asperity’s heights of the machined surface. With this aim in view, the Ishikawa diagram presented in figure 3 was elaborated.

5. Use of Ishikawa diagram in the evaluation of the 3D printing process

The 3D printing process seems to conquer more interest based on multiple utilization in the industry. The fused filament fabrication and selective laser sintering are only some of the well-known methods used for prototyping that uses the layer by layer deposition. The idea of obtaining parts of plastic materials with properties comparable with those specific to the metallic materials and made by 3D printing continues to be investigated and developed.

As far as 3D filament printing is concerned, complex shapes of the piece and no special tooling are considerable advantages to be preferred for the parts manufacturing. Also, the process is quite simple, consisting of designing the piece and transferring the 3D model to the software of the equipment, preparing and melting the material that is subsequently pushed through a nozzle, layer by layer, to gradually generate the desired part.
The process is influenced by some general factors, including equipment, the part to be obtained, printing conditions, the method with all the necessary steps to be followed, but also the operator. These factors were included in the Ishikawa diagram presented in figure 4, considering the highlighting of the factors able to affect the 3D printing process as a problem to be investigated and fulfilling thus the stage of the problem definition when using the Ishikawa diagram.

6. Comparison of the Ishikawa diagram method with the systemic analysis method

There were many preoccupations to apply and improve the use of the Ishikawa diagram method in solving a large set of technical and/or managerial problems and the fishbone type tool proved its utility in various situations.

The above-mentioned reasons led to the use of the Ishikawa diagram methods inclusively in solving problems from the industrial processes. The users were frequently interested in using adequate methods to identify the factors able to exert influence on the product and processes quality.

When using an industrial process, certain methods could be applied to investigate the influence exerted by distinct factors on the values of the process output parameters and the correlations between the two categories of factors. Such an investigation method could be a systemic analysis [7]. In principle, the systemic analysis considers the equipment or process investigated as a system, to which are assigned input factors, output parameters and possibly disturbing factors [8]. In the case of a process, such as the industrial processes previously addressed by using the Ishikawa diagram, as input factors, the groups of factors and the actual factors identified when the graphical representation corresponding to the Ishikawa diagram has been developed can be mentioned. As the output parameters of the investigated process, in the case of systemic analysis, several sizes of technological interest may be considered. In more complex representations, the actual connections between certain input factors and certain output parameters of the investigated process can be highlighted. The last two aspects may constitute the advantages of using systemic analysis comparing to the use of the Ishikawa diagram method.

To develop a comparison of the Ishikawa diagram method and a systemic analysis method, the following criteria could be taken into consideration:

- Method simplicity;
- Use of multiple output parameters;
- Inclusion of correlations among the input factors and output parameters;
- The necessity of using yet other methods (combination or association of the investigated analysis method with other methods);
- Suggestibility.

A weighting of the evaluation criteria could be made using the so-called matrix with double entries (or pairwise comparison matrix) (table 1) [8, 9], in which the results of comparing the identified criteria each other were included. The criteria were highlighted both along the first horizontal line and the first vertical column, but the comparisons were made firstly taking into consideration the vertical columns. Marks of 1 and 0 were inscribed when the criterion placed in the vertical column is appreciated as being more important than the criterion included in the horizontal line, and 0-1 when the situation was inverse. Marks of 0.5-0.5 were used when the two considered criteria were appreciated as of equal importance. In the penultimate horizontal line of the table, the sum of marks that correspond to each criterion mentioned in a certain vertical column was mentioned. In the last horizontal line of the table, the calculated values of the coefficients of relative importance were included. The coefficient of relative importance was determined as a ratio of the sum of marks to the number of comparisons applied to the criterion considered along the vertical column (there were such 4 comparisons).

Table 1. The weighting of evaluation criteria used to compare two distinct analysis methods.

|                  | Simplicity | Multiple output parameters | Highlighting the correlations | Association with other methods | Suggestibility |
|------------------|------------|-----------------------------|-------------------------------|-------------------------------|----------------|
| Simplicity       | X          | 1.0                         | 0.5                           | 0.5                           | 0.5            |
| Multiple output parameters | 0          | X                           | 1.0                           | 0                             | 0              |
| Highlighting the correlations | 0.5        | 0                           | X                             | 0                             | 0              |
| Association with other methods | 0.5        | 1.0                         | 1.0                           | X                             | 0.5            |
| Suggestibility   | 0.5        | 1.0                         | 1.0                           | 0.5                           | X              |
| Sum of marks     | 1.5        | 2.0                         | 3.0                           | 1.0                           | 1.0            |
| Importance relative coefficient | 0.37        | 0.5                         | 0.75                          | 0.25                          | 0.25           |

In the second stage, comparisons of each analysis method using each of the comparison criteria were made. The results of these comparisons were presented in table 2.

Table 2. Comparison of two analysis methods.

| Analysis method               | Simplicity | Multiple output parameters | Highlighting the correlations | Association with other methods | Suggestibility |
|-------------------------------|------------|-----------------------------|-------------------------------|-------------------------------|----------------|
| Ishikawa diagram method       | 1          | 0                           | 0                             | 1                             | 1              |
| Systemic analysis             | 0          | 1                           | 1                             | 0                             | 0              |

Taking into consideration the information included in tables 1 and 2, the coefficient of importance \( N_i \) for each of the two methods could be calculated [9, 10]. The value of this coefficient is given by the relation:

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where \( i \) is the number of compared methods, \( j \) – the comparison criterion, \( K_{ij} \) is the values of the coefficients of importance associated with each of the methods \( i \) and for each of the comparison criterion \( j \).

In this way, the following values of the coefficients of importance are determined:

- In the case of the Ishikawa diagram method:
  \[
  N_{v1} = 0.37 \cdot 1 + 0.5 \cdot 0 + 0.75 \cdot 0 + 0.25 \cdot 1 + 0.25 \cdot 1 = 0.87
  \]

- In the case of the systemic analysis method:
  \[
  N_{v2} = 0.37 \cdot 0 + 0.5 \cdot 1 + 0.75 \cdot 1 + 0.25 \cdot 0 + 0.25 \cdot 0 = 1.25.
  \]

The above relations show that the Ishikawa diagram has a coefficient of importance of 0.87, while the systemic analysis method seems to be of 1.25 importance coefficient.

On the determined values of the coefficient of importance, as a global aspect, the systemic analysis could be considered as more advantageous, when the above-mentioned comparison criteria are considered. If particular criteria are taken into consideration, the Ishikawa diagram method could be appreciated as more convenient (for example, for the simplicity, of the possibility of association the results with other research methods or of the suggestibility).

7. Conclusions
One of the analysis methods used to suggestively illustrate the causes able to generate a certain effect is the Ishikawa diagram method. In the research whose results were presented in this paper, the Ishikawa diagram method was used to highlight the factors able to affect the results of a chemical engraving process, end milling process, the 3D printing process and the factors able to determine the failure or malfunction of the computer system. Taking into consideration the industrial processes, the analysis could be made both by using the Ishikawa diagram method and the systemic analysis method. A comparison of the two analysis methods based on the use of some distinct evaluation criteria was developed using the pairwise comparison matrix and the determination of the coefficients of importance. In this way, as a global image, the systemic analysis could be preferred, but if particular criteria are applied, the Ishikawa diagram method could be appreciated as more convenient. In the future, the idea is to develop some detailed research for each process and to practically analyze how the issues during the manufacturing process can be solved and also to improve the process on the base of the theoretical premises.

8. References
[1] Ilie G, Ciocoiu CN 2010 Management Research and Practice 2 1 1-20
[2] Ronso T, Vick N, Quilizapa L 2013 Fishbone Diagram & The 5 Whys Available at http://publichealth.lacounty.gov/qiap/docs/Topic3-Fishbone.pdf Accessed: 13.09.2019
[3] Magdum RS, Gore PN 2015 JSRD 3 765-768
[4] Luca L 2016 20th Innovative Manufacturing Engineering and Energy Conference (IManEE 2016) A reference. IOP Conf. Series: Materials Science and Engineering 161 012099
[5] Luo T, Wu C, Duan L 2018 J. Clean. Prod. 174 296-304
[6] Slătineanu L, Nagiț G, Dodun O, Coteață M, Chineșta F, Gonçalves-Coelho A, Pamies Teixeira J, San Juan M, Santo L, Santos F 2004 Non-traditional manufacturing processes (Chișinău: Publishing House Tehnica.Info)
[7] Băloiu LM, Frăsineteanu I 2001 Management of innovation (in Romanian) (Bucharest: Editura Economică)
[8] Creativity methods and techniques, 2017. Available at http://www.stiucum.com/management/managementul-cercetarii-si-dezvoltarii/Metode-si-tehnici-de-creativitate18688.php Accessed: 10.08.2019
[9] Slătineanu L 2019 Fundamentals of scientific research (in Romanian) (Iași: Publishing House PIM)
[10] Belous V 1992 Inventics (in Romanian) (Iași: Publishing House Asachi)