Journal of Research and Innovation for Sustainable Society (JRISS)
Volume 6, Issue 2, 2024
ISSN: 2668-0416
Thoth Publishing House

DOI: 10.33727/JRISS.2024.2.12:109-118

Using the Ishikwa diagram for problem analysis in the laser cutting process

Alexandru-Vasile Oancea[1], Corneliu Rontescu[2], Ana-Maria Bogatu[3*], Dumitru-Titi Cicic[4]

[1]Faculty of Industrial Engineering and Robotics, National University of Science and Technology Politehnica Bucharest, ORCID: 0009-0004-3463-5458
[2]Faculty of Industrial Engineering and Robotics, National University of Science and Technology Politehnica Bucharest, ORCID: 0000-0002-4826-4131
[3]Faculty of Industrial Engineering and Robotics, National University of Science and Technology Politehnica Bucharest, ORCID: 0000-0001-6336-0095
[4]Faculty of Industrial Engineering and Robotics, National University of Science and Technology Politehnica Bucharest, ORCID: 0000-0003-4758-7235

E-mail: ana_maria.bogatu@upb.ro

Abstract: Laser cutting is a computer numerically controlled process widely used in the automotive industry for cutting metal materials needed to manufacture parts used in automobile production. The production process represents all the conscious actions of a company's employees carried out with the help of various machines, equipment, or installations on raw materials, materials, or other components to transform them into products or services with a certain market value. The Ishikawa diagram, also known as the cause-and-effect diagram, is often used in industrial process analysis, defect prevention, and product design processes. The paper presents the results of the research conducted on the use of the Ishikawa diagram in analyzing the causes that lead to negative effects in the laser cutting process of S235JRH structural steel pipes. After defining the problem, by applying the "WHO, WHAT, WHERE, WHEN, HOW MUCH, HOW, WHY" method, all possible causes were identified using the "5 Whys" method. The analysis identified 11 probable causes, and through further analysis, it was concluded that 3 of them were already present in the process, influencing the laser cutting of the pipes and generating quality problems. All the identified causes built the Ishikawa diagram consisting of 7Ms.
Keywords: *Ishikawa, cause-effect, 7Ms, Brainstorming*

Introduction

In the field of quality management, seven basic tools are used to measure and maintain quality [1]:

- Ishikawa Diagram: A frequently used tool for analyzing and graphically representing the relationships between an undesirable effect and the causes that led to its occurrence.
- Pareto Chart: Aims to prioritize the necessary actions for solving complex problems. By using it, important causes are separated from unimportant ones, thus contributing to the resolution of the analyzed problem [2].

- Control Chart: A linear graph of the measurements of a product or process over time, with defined control limits based on statistics. Its purpose is to display and manage variations during the process output, identify changes in the process, and separate special cause variations from common ones.
- Check Sheet: A data collection form used to record the number of observations or the occurrence of certain events.
- Flowchart: Helps in understanding the process flow and the interrelationships between processes.
- Histogram: A graphical representation of the distribution of numerical data.
- Scatter Diagram: A graph of one measured variable compared to another variable. Its purpose is to study possible relationships between different variables.

The histogram, or frequency distribution diagram, aims to quickly visualize the center, variation, and shape of the measurement distribution. It provides clues for reducing variation and identifying the causes of problems [3].

The Ishikawa method was first used by Kaoru Ishikawa (1915–1989) in 1960 [1,2]. The Ishikawa diagram, also known as the cause-and-effect diagram or "fishbone" diagram, is a simple graphical tool used to identify causes that lead to undesirable effects and analyze the relationship between a problem and all possible causes.

Possible causes are categorized as machines, methods, people/labor, materials, measurement, environment, and quality management (all categories start with the letter M, which is why the method is also called the 7Ms method). The Ishikawa diagram schematically illustrates the relationships between a specific result and its causes. The effect is the "fish head," and the potential causes and sub causes define the "fishbone structure" [4,5].

The Ishikawa diagram can be applied to analyze and evaluate a quality problem in various production activities as well as in the field of services provided to beneficiaries.

General Steps for Applying the Analysis Method

- Problem Definition
  - Defining the effect
- Developing the Analysis Methodology
  - Precisely defining the effect
  - Conducting a brainstorming session to identify causes
  - Defining the family of causes
- Building the Diagram
- Exploiting the Diagram

This paper presents the method of identifying causes using one of the seven quality tools, specifically the Ishikawa diagram. The causes of a quality problem identified in the laser cutting process of arc-shaped pipe parts made from structural steel, used for manufacturing the support of refrigeration units needed for truck refrigeration trailers, are analyzed.

1. Materials and Methods Used

1.1 Analyzed Part

The analyzed part is made from rectangular pipe, 60x40x4, manufactured from S235JRH structural steel (Figure 1). This is a structural steel whose chemical composition is indicated in Table 1.

Table 1. Chemical composition of S235JRH material according to EN10219-1

Material: S235JRH										
C[%]	Si[%]	Mn[%]	P[%]	S[%]	Al[%]	Ni[%]	Mo[%]	Cu[%]	V[%]	Ti[%]
0.064	0.017	0.34	0.012	0.01	0.039	0.02	0.002	0.02	0.003	0.001

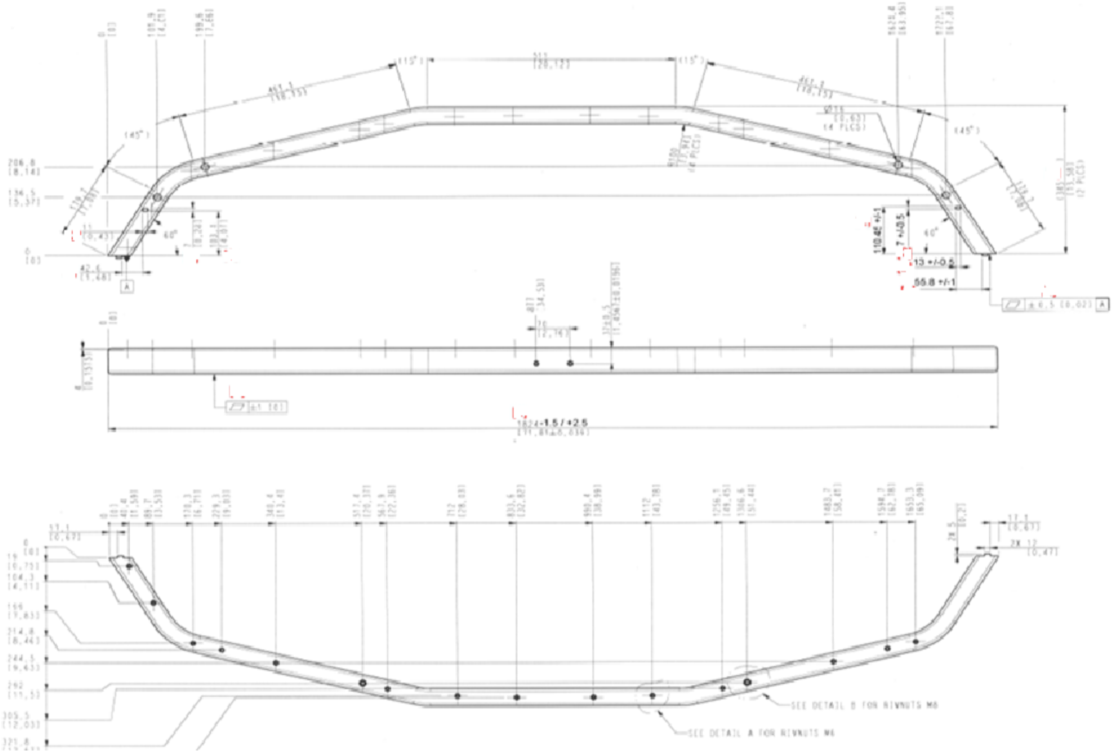


Figure 1. Execution drawing of the accessory

The analyzed part is used in the assembly of the refrigeration unit support for truck trailers (Figure 2).

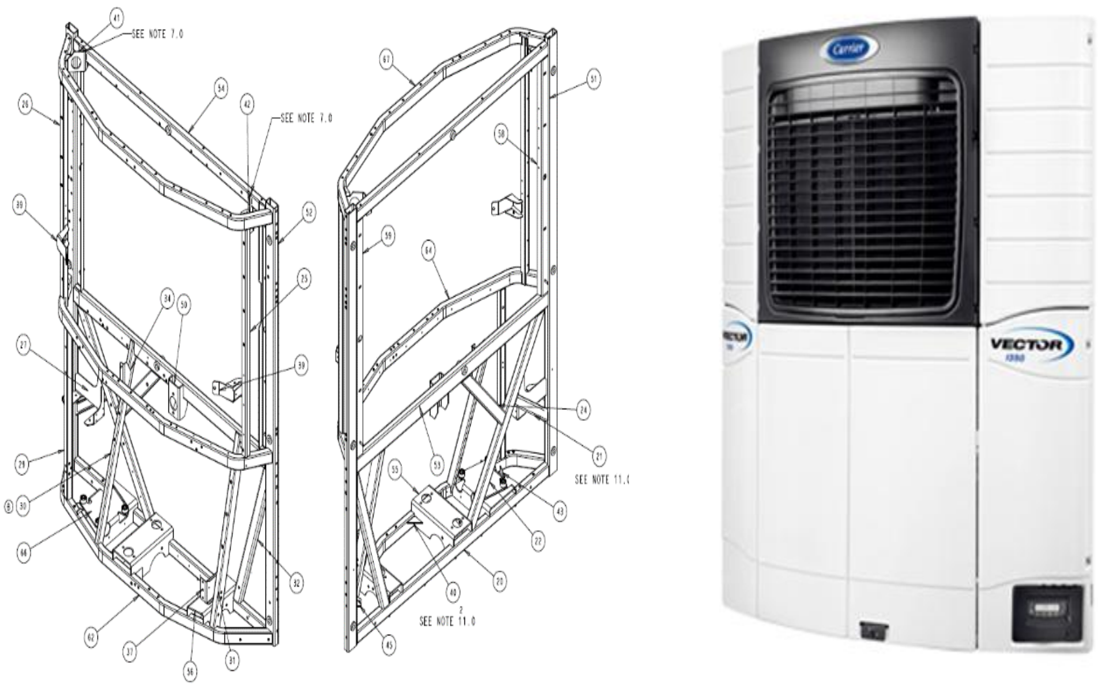
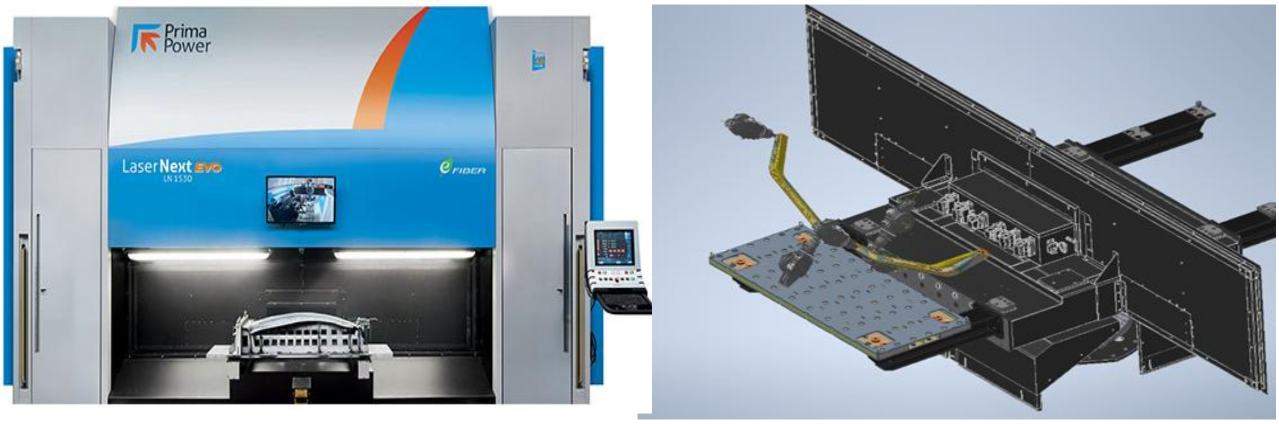


Figure 2. Refrigeration unit assembly

Journal of Research and Innovation for Sustainable Society (JRISS)
Volume 6, Issue 2, 2024
ISSN: 2668-0416
Thoth Publishing House

The analyzed part is obtained from a rectangular pipe cut using the Prima Power Laser Next cutting equipment, presented in Figure 3. The Prima Power Laser Next is a laser cutting machine used in the industrial sector, designed for the mass production of automotive steel components. Laser Next is currently considered the fastest 3D laser cutting equipment in the world.



a) b)

Figure 3. Prima Power Next laser cutting equipment: a – front view; b – workpiece orientation and fixation device

1.2 *Defining the Problem*

The problem analyzed refers to identifying the causes of obtaining workpieces that do not meet dimensional specifications. The main deviations that occurred during the laser cutting process of the analyzed workpiece are presented in Figure 4:

- Deviations from the established dimensions were highlighted in the case of the 3 references measured on the X and Z axes;
- The deviations were highlighted only on one side of the reference, never on both sides simultaneously;
- There are maximum deviations greater than 1. For example, 1.621 in the case of reference 2 at the dimension of **1722.1 ±0.8.**

Figure 4. 3D Projection of dimensions out of tolerance

To determine the dimensional values, an inspection was performed on the three references using the 3D Arm equipment. The resulting values are presented, centralized, in Table 2.

Table 2. Centralization of data taken by measurements

DIMENSION				R1		R2		R3		
AXIS	NOMINAL	LOWER TOLERANCE	SUPERIOR TOLERANCE	MEASURED	DEV	MESURED	DEV	MESURED	DEV	DEV MAXIMUM
dx	1722.1	-0.8	'+0.8	1720.479	-2.421	1720.89	-2.010	1720.973	-1.927	-1.927
dz	136.335	-0.8	'+0.8	136.335	-0.800	136.358	-0.777	136.346	-0.789	-0.777
dx	1624.4	-0.8	'+0.8	1622.794	-2.406	1623.16	-2.040	1623.285	-1.915	-1.915
dz	206.8	-0.8	'+0.8	206.669	-0.931	206.363	-1.237	206.692	-0.908	-0.908
dx	199.6	-0.8	'+0.8	198.222	-2.178	198.594	-1.806	198.733	-1.667	-1.667
dz	206.8	-0.8	'+0.8	206.8	-0.800	206.621	-0.979	206.668	-0.932	-0.800
dx	101.9	-0.8	'+0.8	100.567	-2.133	100.914	-1.786	101.062	-1.638	-1.638
dz	136.5	-0.8	'+0.8	136.41	-0.890	136.306	-0.994	136.362	-0.938	-0.890
dx	55.8	-1	+1	56.882	0.082	55.902	-0.898	56.96	0.160	0.160
dx	567.9	-0.8	+0.8	567.457	-1.243	567.756	-0.944	568.157	-0.543	-0.543
dz	305.5	-0.8	+0.8	304.678	-1.622	304.645	-1.655	304.965	-1.335	-1.335
dx	712	-0.8	+0.8	711.431	-1.369	711.958	-0.842	712.035	-0.765	-0.765
dz	321.8	-0.8	+0.8	320.9	-1.700	321.184	-1.416	321.135	-1.465	-1.416
dx	833.6	-0.8	+0.8	833.172	-1.228	833.874	-0.526	833.455	-0.945	-0.526
dz	350	-0.8	+0.8	324.232	-26.568	324.466	-26.334	323.994	-26.806	-26.334
dz	325	-0.8	+0.8	324.475	-1.325	323.96	-1.840	323.994	-1.806	-1.325
dx	1653.3	-0.8	+0.8	1652.786	-1.314	1635.18	-18.920	1653.135	-0.965	-0.965
dz	199	-0.8	+0.8	198.503	-1.297	197.575	-2.225	197.714	-2.086	-1.297
dx	1594.7	-0.8	+0.8	1594.29	-1.210	1594.42	-1.080	1594.6	-0.900	-0.900
dz	214.8	-0.8	+0.8	213.884	-1.716	213.343	-2.257	213.447	-2.153	-1.716
dx	1483.7	-0.8	+0.8	1482.973	-1.527	1483.44	-1.060	1483.506	-0.994	-0.994
dz	244.5	-0.8	+0.8	243.876	-1.424	243.165	-2.135	243.345	-1.955	-1.424
dx	1306.6	-0.8	+0.8	1306.053	-1.347	1306.6	-0.800	1306.418	-0.982	-0.800
dz	292	-0.8	+0.8	291.238	-1.562	290.91	-1.890	290.82	-1.980	-1.562
dx	1112	-0.8	+0.8	1111.483	-1.317	1111.75	-1.050	1111.871	-0.929	-0.929
dz	321	-0.8	+0.8	321.003	-0.797	320.492	-1.308	320.678	-1.122	-0.797
dx	1256.1	-0.8	+0.8	1255.515	-1.385	1256.06	-0.840	1256.009	-0.891	-0.840
dz	305	-0.8	+0.8	304.813	-0.987	304.342	-1.458	304.453	-1.347	-0.987
dz	17.1	-1	+1	17.196	-0.814	18.167	0.157	16.989	-1.021	0.157

*Red color indicates the identified values that differ from the predetermined values.

From the analysis of the results presented in Table 2, one can observe that most of the deviations from the tolerated dimensions, 24 each, are in the R2 and R3 directions. Additionally, in the dx direction, out of a total of 14 measurements, R1 recorded 12 deviations from the established values, R2 – 12 deviations and R3 - 14 deviations.

After obtaining the measurement results, the next step is to appoint the analysis team. The team consists of a process engineer, a quality engineer, a project manager, a workshop supervisor, and a maintenance engineer. After stating the problem precisely and concisely, the real extent of the problem is established based on verified facts: the answers to the following questions "What?", "Who?", "Where?", "When?", "How?" and "Why?" (WWWWHW Method) are highlighted, as shown in table 3.

Table 3. Description of the problem

Problem Description		
W	**What?** *What is the problem?*	***Hole positioning deviations on the X and Z axes***
W	**Who?** *Who detected the problem?*	Metrology Analyst
W	**Where?** *Where was the problem detected?*	Metrology Laboratory
W	**When?** *When was the problem detected?*	January
H	**How?** *How was the problem detected?*	Following dimensional control
W	**Why?** Why is this a problem?	**Risk in the customer's assembly line (assembling impossibility)*

Following the WWWWHW analysis, the problem was correctly identified and defined: Positioning deviations of holes on the X and Z axes, allowing the transition to the next step.

1.3 *Defining the effect*

After the problem was defined, "Positioning deviations of holes on the X and Z axes," using the WWWWHW method, the effect of the problem under consideration was clearly defined. The identified effect (Figure 5) is "Risk in the client's assembly line (assembling impossibility)

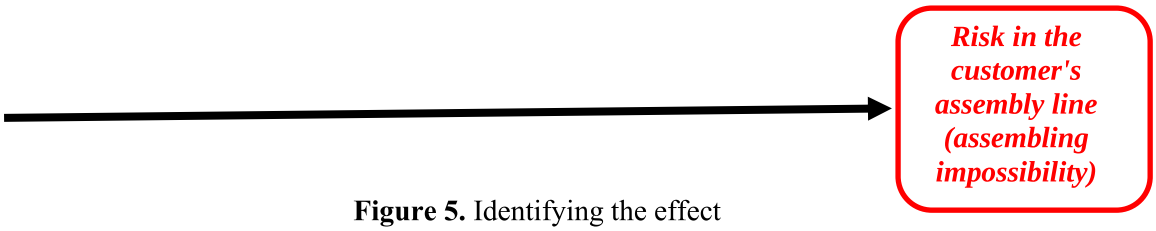


Figure 5. Identifying the effect

2. Developing the Analysis Methodology

The diagram has a common trunk (the body of the fish), at the end of which is (d) the effect (Figure 6). On the trunk, there are seven branches representing seven families of possible causes: measurement means, method, machine, material, surrounding environment, management, and labor.

At theoretical level, the method involves:

- Precisely defining the effect

The effect is defined clearly, concisely, and measurably. Often, an effect is just one of the manifestations of a more complex problem; in this case, the problem is broken down into several well-defined elementary subproblems.

➢ Conducting a brainstorming session to identify causes

Brainstorming is recommended to collect a maximum number of ideas and avoid quickly falling into a stereotypical classification that contributes little to the progress of solving the problem. The main causes (not corrective actions) are identified, with each participant actively contributing to the discussion.

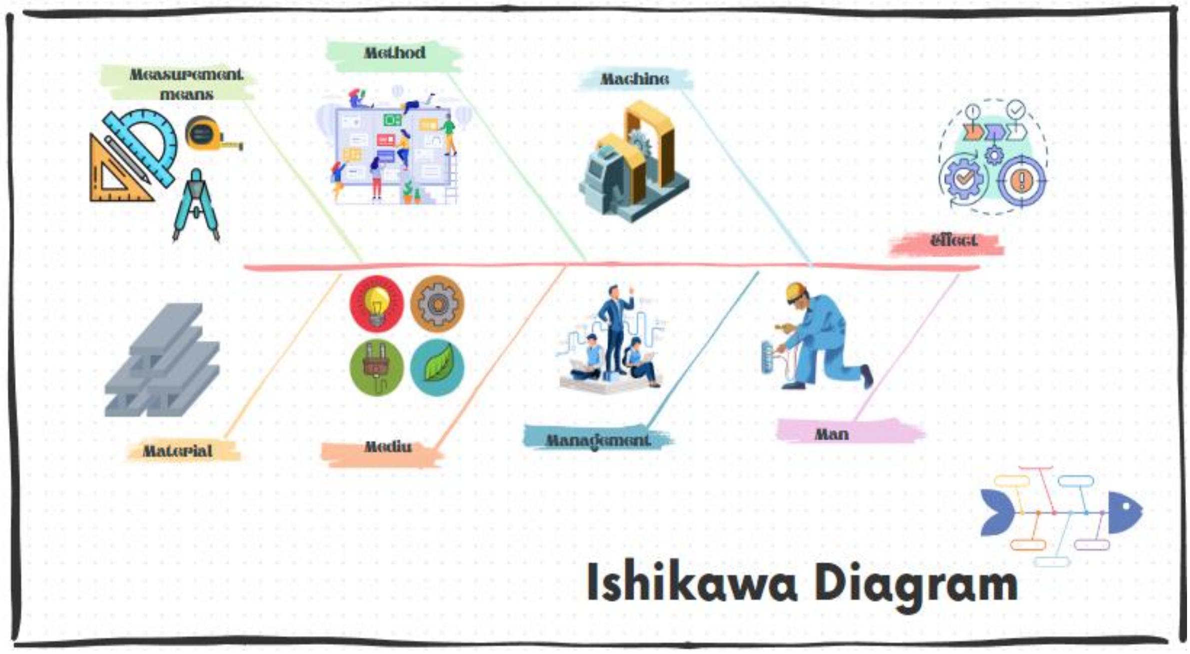


Figure 6. Graphical representation of the Ishikawa Diagram

It is verified whether each cause is "real" or "apparent" using the "5 Whys" method (Figure 7); a "real" cause generally allows the direct and unambiguous identification of the corresponding corrective action.

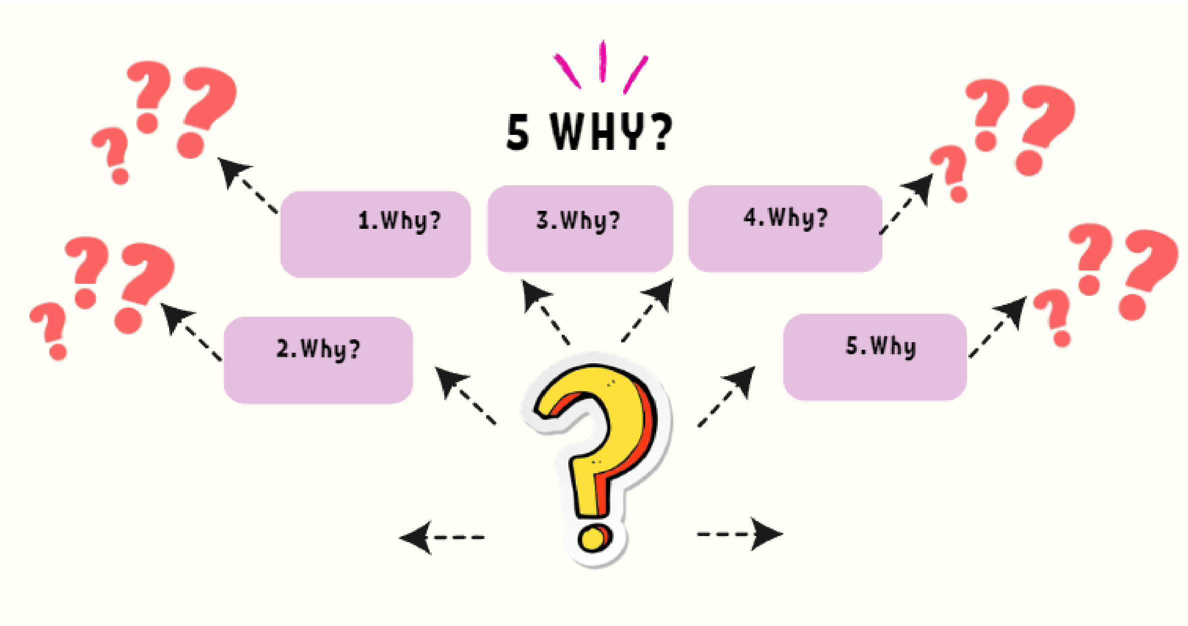


Figure 7. 5 Why?

➢ Defining the family of causes

To define the cause, it is agreed to consider the "7Ms" – sources of errors, which are appropriately applied to the needs of the analysis.

- **Measurement Means**: installation, apparatus, working or control instruments, etc.;
- **Method**: job documents, method sheet, original project;
- **Machine**: machines, equipment, installations;
- **Material**: raw material, type of emulsion, type of cooling oil;
- **Environment**: temperature, humidity, ambiance, effort, pressure;
- **Management**: quality management, manufacturing management;
- **Man**: knowledge, skills, behavior, workplace organization.

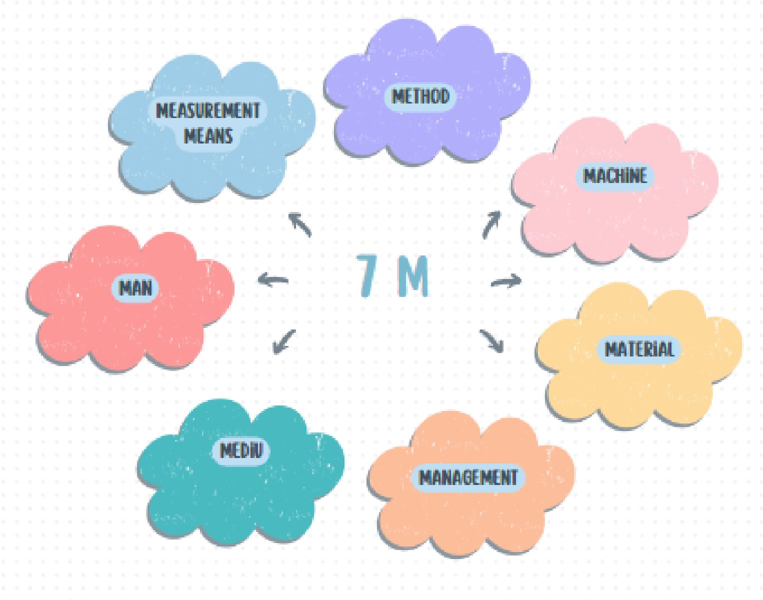


Figure 8. 7Ms Representation

➢ Constructing the Diagram

For the construction of the diagram, each identified cause through brainstorming is defined one by one and positioned on a small (level 2) horizontal arrow, supported by the large (level 1) arrow of the chosen category. Going deeper into the analysis, when another cause (level 3) is discovered, related to a cause already positioned on the diagram, the corresponding arrow will be supported by the arrow of that cause. The diagram is more effective the more tree-like it is.

➢ Exploiting the Diagram

After determining the causes, it must be determined how to eliminate them. By consensus or weighted voting, the "root" causes can be identified with a fairly high probability; these must be validated in the process and then analyzed using Pareto analysis to prioritize them. Created in a large format (e.g., A0) and displayed for a specific period (appropriate to the nature of the problem), right at the location of the treated problem, it can be used very effectively by operators themselves to mark incidents actually arising from the identified causes/sub causes on the diagram.

➢ Brainstorming and the Ishikawa Method

The brainstorming session aims to highlight ideas for identifying the root causes that generated the problem mentioned above. To identify the causes, the 5 Whys method is applied. The main causes are identified with the help of each participant through active contribution to this debate. It is verified whether each cause is real or apparent. The real cause allows the direct and unambiguous identification of the corresponding corrective actions.

The causes identified during the debate are presented in table 4.

3.Results

The application of the Ishikawa method to determine the causes of the problem in the laser cutting process followed these steps:

- The team for the analysis debate was formed (the team gathered: process engineer, quality engineer, project manager, workshop manager, and maintenance engineer);
- The problem was defined using the WWWWHW method (Positioning deviations of holes on the X and Z axes);
- The effect of the considered problem was clearly defined (Risk on the client's assembly line (assembling impossibility);
- The effect was written on the right and a line was drawn from left to right;
- It was verified whether each team member clearly understood the problem and its effect;
- A brainstorming session was organized to discuss in detail the causes and to determine those with the highest probability of causing the studied effect - they are tracked and recorded as corresponding sub-branches, thus forming the Ishikawa diagram;
- The main categories of causes, which are the main branches of the diagram, were determined using the 5 Whys method;
- The Ishikawa diagram was graphically created.

Following the analysis, 11 possible causes associated with the 7Ms criteria were identified. These 11 causes were established using the aforementioned steps. From the 11 causes, further analysis resulted in 3 of them leading to the generation of the effect. All the possible causes identified during the discussions are indicated in Table 4.

Table 4. Centralization of Root Causes

No.	Causes Identified	7 M
1	Verification tools promote non-conforming parts. Dimensional verification templates are erroneously designed.	Measurement Means
2	The working method does not ensure repeatability.	
3	Working instructions are not well defined.	
4	The measurement method is not clearly defined.	Method
5	The laser is not properly calibrated.	Machine
6	The blocking elements on the X and Z axes are deformed at the top.	
7	The laser devices do not secure the part in the correct cutting position on the X and Z axes.	Machine
8	Material composition variations. Different batches of material with the same chemical composition but in different percentages are received.	Material
9	Insufficient light in the workstation.	Environment
	The positioning device supports are contaminated with material residues/waste.	
10	Insufficient operator training. The operator is not qualified to work on this laser equipment.	Management
11	Positioning the reference in the device. A new operator lacks the dexterity to ensure repeatable movements.	Man

After establishing the causes through a brainstorming analysis, the Ishikawa diagram is graphically represented (Figure 9), attributing the causes to the 7Ms. This is done on a large format and displayed for a determined period at the location where the treated problem exists.

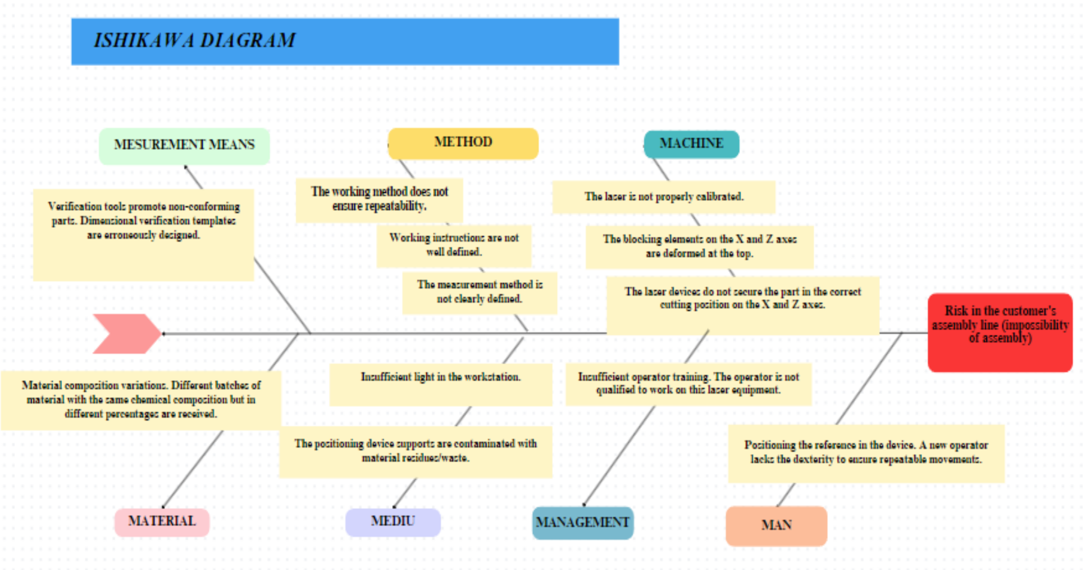


Figure 9. Completed Ishikawa Diagram

4. Conclusions

Based on the results and information presented in the paper, it can be concluded that the quality improvement method successfully led to identifying the causes that generated the problem and the effect on the client. The 7Ms Ishikawa diagram was used for the study: Measurement Methods, Method, Machine, Material, Environment, Management, and Manpower (Labor).

In the study, 11 possible causes were identified, classified into the 7M groups. After identifying the possible causes and conducting additional analyses at the cutting station, it was concluded that only 3 were confirmed by production activity. Corrective actions were established for all identified causes to reduce/eliminate the real causes, and preventive actions were implemented for probable causes.

Using specific quality management methods, such as WWWWHW and the 5 Whys, led to identifying all possible and real causes that generated the analyzed effect.

References

[1] Slobodan STEFANOVIC, Imre KISS, Damjan STANOJEVIC, Nenad JANJIC, 2014 Analysis of technological process of cutting logs usig Ishikawa *diagram ACTA TEHNICA CORVINIENSIS – Bulletin of Engineering Tome VII* [2014] Fascicule 4 [October – December] ISSN: 2067 – 3809

[2] The 7 Basic Quality Tools for Process Improvement, *https://asq.org/quality-resources/seven-basic-quality-tools*

[3] Nadia BELU, Luminita STIRBU, 2006 Cause effect diagram a tool used to identify the root causes of quality incidents, *Ovidius University Annals of Mechanical Engineering* Volume VIII, Tom I, 2006

[4] Liliana LUCA, Assoc. Minodora PASARE, Alin STANCIOIU, 2017 Study to determine a new model of the Ishikawa diagram for Quality Improvement, *Fiabilitate si Durabilitate - Fiability & Durability No 1/ 2017 Editura "Academica Brâncuşi"* , Târgu Jiu, ISSN 1844 – 640X

[5] American Society for Quality, *Fishbone diagram.* http://www.org/learn-about-quality/cause-analysis-tools/overview/fishbone.html