
Analysis of Environmental Aspects and Minimisation of the Negative Impact of Adhesive Bonding using Quality Management Tools

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ABSTRACT

Purpose: This study aims to investigate the combined application of 5 Why and E-FMEA for evaluating of gluing technology, its quality and waste management.

Methodology/Approach: The research adopted a technical paper. The method of analysing the basic stages of gluing machine parts. Negative impact on the environment is described using algorithms, the Ishikawa diagram, 5 Whys, and 5W2H implemented from the area of quality management.

Findings: The study revealed significant influences and analyses of errors during the manufacturing, minimising of hazardous waste from gluing. The study revealed, based on an employee survey, the impacts and analysis of errors during production, the minimisation of hazardous waste from gluing, and pointed out the effectiveness of teamwork.

Research Limitation/Implication: Focusing on the production with material gluing may not fully represent the environmental impact of production on environment.

Originality/Value of paper: This paper contributes to the limited literature using in the area of influence of gluing technology on the environment.

Category: Technical paper

Keywords: adhesive bonding; environmental Ishikawa diagram; environmental 5 Whys; 5W2H; waste management

Research Areas: Quality Engineering

1 INTRODUCTION

Bonding is still one of the attractive and necessary techniques for joining parts together. It requires the use of an appropriate preparation procedure and meeting specific conditions during the application of the adhesive layer and its curing, but with the current state of technology and the advancement of manufacturing systems, this is not a major problem. Many companies in the world produce adhesives. The adhesive production sector is growing due to the very good properties of the bonded products, high efficiency of the assembly and sealing process. Adhesives are also used as intermediate products in the production of labels, laminates, paper, cardboard and others (Crisostomo, 2020). In the work (Watcharakitti et al., 2023), it is stated that the global market for adhesives and sealants is growing rapidly and is expected to be worth about USD 85.8 billion by 2026. Such dynamic development allows us to assume that bonding technology will be relevant and used for a long time. However, in addition to the undoubted advantages of such connections and their use in many industries, environmental issues should be considered (Cavalanti et al., 2021). They are important due to the variety and number of chemical substances used in gluing and the regulations and directives regulating, among others, hazardous waste issues (Rodriguez et al., 2024). Due to the fact that many activities, both preparatory and related to the creation of an adhesive joint, require the use of preparations that are not always neutral to health and the environment, it is necessary to analyse and search for easy ways to verify the environmental safety of this technology (Montalvo-Romero et al., 2022; Packham, 2009; Badida et al., 2022; Chirdon, 2015).

Methods of estimating environmental impact are a fundamental tool in environmental management, planning and sustainability assessment of projects, technologies or products. These methods are used to quantify and analyse the impacts of human activity on the environment from air, water, soil pollution to resource consumption and climate change. Also, these methods can be used in the adhesive production section.

The main methods for estimating environmental impact include LCA – Life Cycle Assessment, EIA – Environmental Impact Assessment, CF – Carbon Footprint, Ecological Footprint, MFA – Material Flow Analysis, ERA – Environmental Risk Assessment (Tolls et al., 2016; Yang & Rosentrater, 2020; Soos, 2022; Minliang & Rosentrater, 2015).

2 MATERIALS AND METHODS

2.1 Theoretical foundations of analysis

The adhesive bonding process is a complex and multi-stage task, requiring the use of appropriate materials and methods to make a correct connection. In addition to achieving the assumed quality of assembly, environmental issues are of great importance. The adhesive bonding process is divided into three stages (Brezinova,

Guzanova, & Draganovska, 2018; da Silva, Ochsner & Adams, 2011; Ang et al., 2014; Baranska-Miturska et al., 2024):

- I – preparatory – concerning the initial treatment of the surface, selection of glue and the method of its application,
- II – proper – using a primer, preparing the glue mixture, setting the joint, applying glue and gluing the elements together,
- III – final – setting the elements, curing the joint, finishing activities related to, for example, removing excess glue.

Stage I takes into account production requirements, such as joint strength, resistance to external factors, and operating conditions of glued parts. Analysis of the guidelines is the basis for the proper selection of materials (unless imposed by the designer), type of glue and its properties, method of surface pre-treatment (washing, removing old layers or corrosion, removing grease, giving a specific surface roughness, washing again and drying). Sometimes, an additional substance is applied to the prepared surface, increasing the adhesion of the glue to the surface. Correct execution of these activities increases the durability of the joint, reduces the risk of defects and regluing the same elements, and due to environmental protection, contributes to material losses, excessive water consumption for washing the surface, and electricity for heating and drying the parts (Marques et al., 2020).

Stage II is crucial due to the execution of activities aimed directly at connecting the elements. It is carried out as part of the sequentially performed activities, the consequence of which is obtaining a connection of a specified quality. It may start with the application of a primer, i.e. an additional substance improving the adhesion conditions. If it is not needed, stage II begins with the proper preparation of the glue – squeezing, if it is single-component or mixing in the right proportions - if two-component. Measuring and mixing the glue may require the use of additional equipment in the form of containers and mixers. Then, the glue is applied to the surface manually using applicators, spatulas, brushes or mechanically using automatic dispensers with special nozzles (Packham, 2009; Dilger & Fraunhofer, 2017; Krishnasamy et al., 2024; Zhang et al., 2020).

After these activities, stage III begins, related to the determination and hardening of the joint. The glued elements are pressed, if necessary, their position relative to each other is determined using additional clamps, grips or handles, for the time necessary for the glue to harden and to obtain a permanent connection with the assumed properties. Sometimes, the fixing and hardening operation is performed by heating the glued elements. The conditions and time of hardening should be selected taking into account the technical specifications of the glue. After obtaining a joint with the desired properties, the clamps are removed, and if necessary, the joint is levelled, e.g. with files, sandpaper or mechanically, e.g. using hand milling machines (Borges et al., 2023).

2.2 Case description

In the analysed case, gluing at the plant is carried out according to the algorithm given below in three stages. Customers most often order elements made of steel or aluminium alloys, and the plant selects the gluing technology with regard to the strength, operational, aesthetic and cost requirements defined by the ordering party. The plant has various types of adhesives, and if they are not available, adhesives are ordered on an ongoing basis. The same applies to other chemical substances and equipment. For the specific shape of the product, appropriate clamps are designed using standard and readily available elements on the market. In rare cases, there is a need to design special devices or holders. The plant has a prototyping shop, galvanizing shop and heat treatment department, which are adapted to the assembly needs. Various problems were identified in the plant, including waste and hazardous waste, water and electricity consumption. Employees also reported other problems related to the use of various substances, such as health problems and difficult working conditions. To solve these problems, and in particular to identify the types and scale of impact and significance, methods and approaches known from quality management were proposed.

3 ANALYTICAL METHODS AND RESULTS

There are many well-known and widespread methods of managing the quality of products or processes. They are usually not very technically complicated, but they require knowledge that can be successfully gathered, especially in production conditions, where the course of activities and resources are known.

3.1 Adhesive bonding process algorithm

In the context of analysing the sequence of actions performed and assigning decisions and their effects in descriptions and procedures concerning quality, algorithms are used. An algorithm is a simple drawing; its execution allows for visualisation of an ordered sequence of actions. The algorithm was used in the described case to identify the actions necessary to perform in the gluing operation. Known symbols were used to mark the beginning and end of the process, individual stages, emerging documentation and decisions. For the analysed process and the three stages listed earlier, the algorithms shown in the Figure 1 were developed.

In the context of environmental analysis, it does not yet provide direct information on the relationship with the environment, but it serves to organise knowledge about the process and can be used to further identify the impact on this environment. In the case studied, specific means of production, i.e. equipment and substances, were assigned to each stage. Examples of these are shown in Figure 2, Figure 3 and Figure 4.

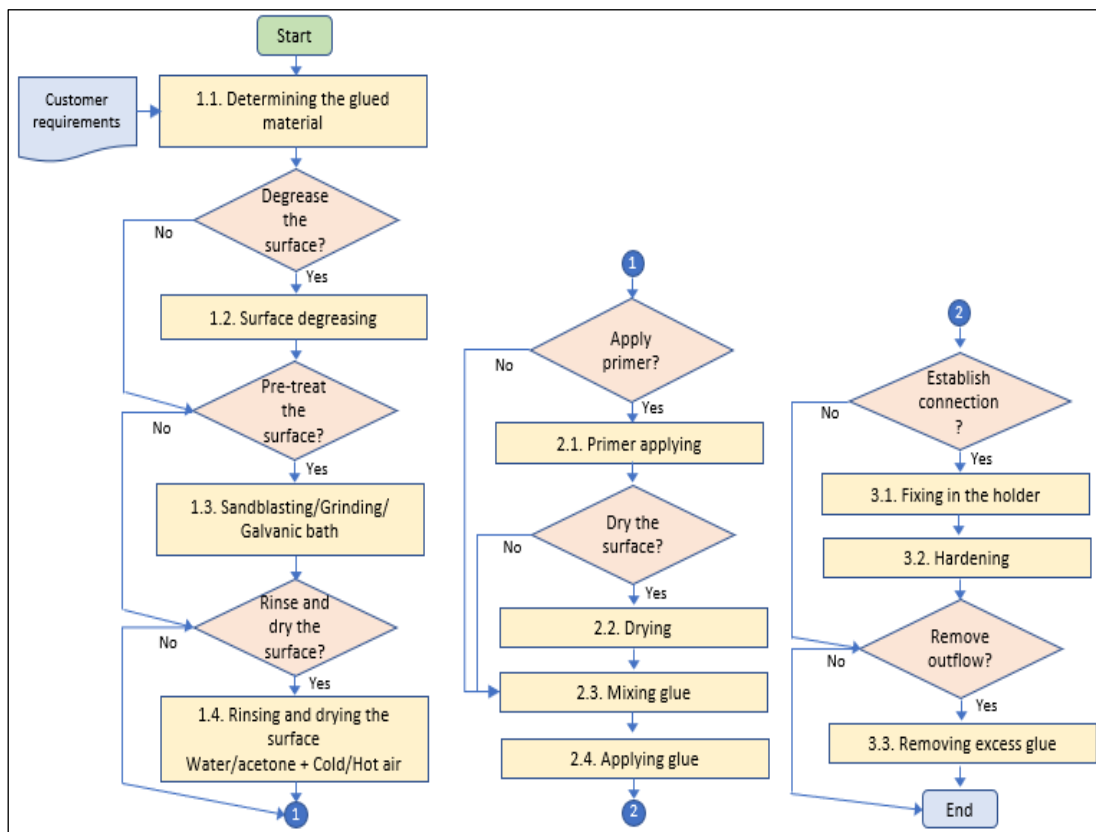


Figure 1 – Algorithms of procedure during gluing: a) stage I – preparatory, b) stage II – gluing, c) stage III – finishing the connection

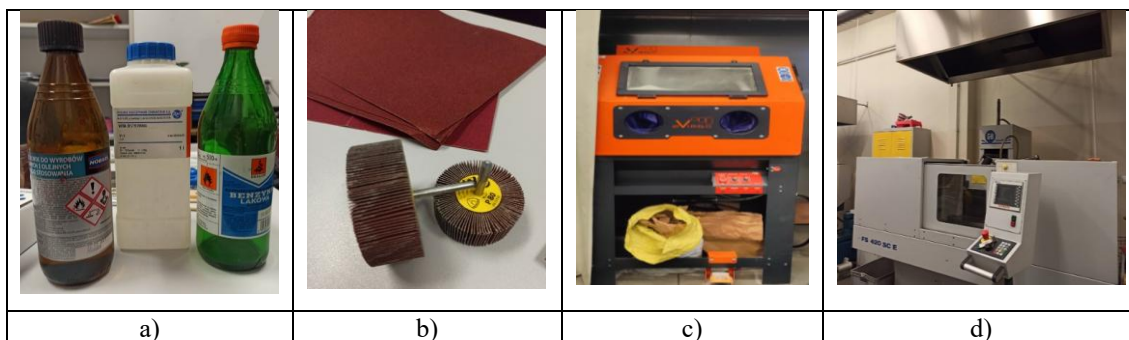


Figure 2 – Examples of equipment and substances characteristic of stage I – preparatory: a) degreasers, b) abrasive tools, c) sandblaster, d) grinder



Figure 3 – Examples of substances and necessary equipment for gluing (stage II): a) primers, b) adhesives for mixing, c) adhesives in tubes, d) brushes, putty knives, tips for glue application, e) devices for squeezing two-component adhesives

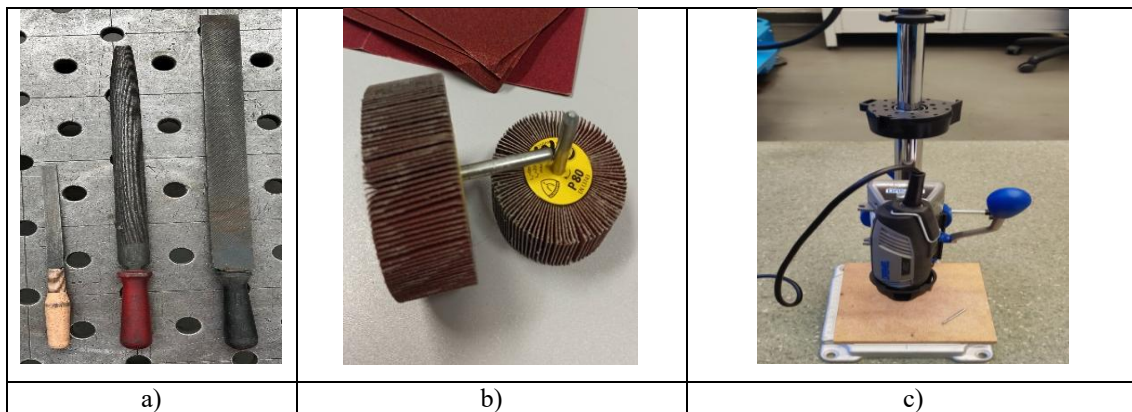


Figure 4 – Examples of production means for carrying out the third – final stage: a) metal files, b) paper grinding wheels, c) hand milling machine

Such systematisation enabled logical and comprehensive identification and assessment of environmental aspects at a later stage of the analysis.

3.2 Ishikawa diagram

The typical approach to the Ishikawa diagram concerns products or processes from the point of view of the quality of workmanship or the correctness of the process. The diagram is a graphic method that allows for the division of various, sometimes chaotic, information and its systematisation according to the initial hierarchy of importance. Information is arranged and assigned to a specific area of activity (Oakland, Oakland, & Turner, 2021). The typical causes of the occurrence of the effect defined at the beginning of the analysis are presented in the form of a fishbone diagram. The diagram for quality most often includes five components of 5M: Man, Methods, Machinery, Materials, Management (Ciecińska, 2023; Ciecińska, Majka, & Sobotová, 2024). Sometimes the E – Environment area is added in the context of the influence of the environment on the product or process (Ilie & Ciocoiu, 2010) (Table 1). The arrows in the diagram direct the influence: how the listed action affects the defined problem (What effect does it bring?). By expanding a given area of causes, you can enter the answers, “Why?”, “For what reason?” this action contributes to the final effect. This gives you a hint on what to do, what to remove, reduce, increase, or change - so that a given negative effect is limited. The Ishikawa diagram used to analyse the defects of bonded products may look as shown in Figure 5.

Table 1 – Ishikawa diagram 5M+E (Ciecińska, 2023)

Field	Problem
Man	Is the loss of quality due to human error?
Method	What work or production methods were used?
Machine	Maybe the error is generated by a faulty machine?
Materials	Could the problem lie in the material from which the product is made?
Management	Do problems arise as a result of lack of supervision, planning, work organisation, poor motivation and leadership, lack of control, and lack of conceptual, technical, and social skills?
Environment	Is the problem the environment of the production station, working conditions, or other people?

A modification of the Ishikawa diagram was proposed and its application for the analysis of the impact of the tested technology on the natural environment. Areas typical of quality were replaced with negative impacts on environmental components, which may be air, water, soil, waste load, demand for raw materials, and other factors burdensome to people (Table 2). Then, for the analysed gluing, a diagram was developed, shown in Figure 6.

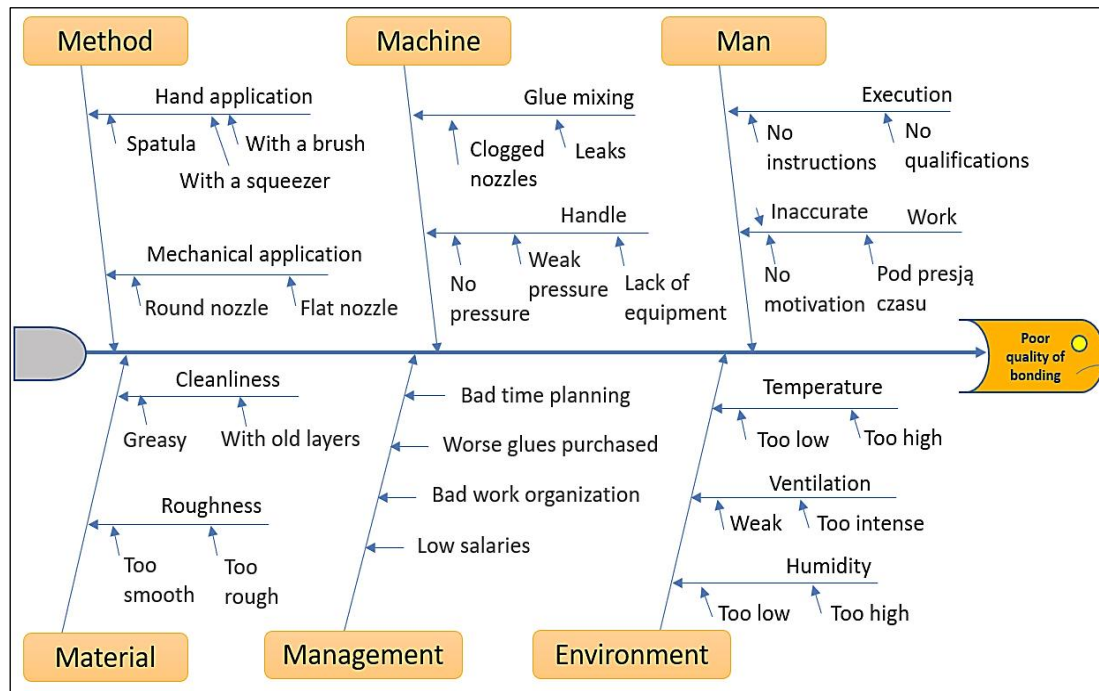


Figure 5 – Ishikawa diagram for bonding quality

Table 2 – Modified Ishikawa influence areas for environmental impact analysis

Field	Problem
Atmosphere	What type of air emissions can cause deterioration of air quality?
Water	How can technology contaminate water intakes?
Soil	How can technology affect soil pollution?
Waste	Why does the problem of waste accumulation arise?
Raw materials/ Energy	Does technology require the use of materials? For what reason? Why is it necessary to use energy? What type or origin?
Nuisance to humans	What poses a threat or what worsens the quality of life of people in the vicinity of the plant or workplace?

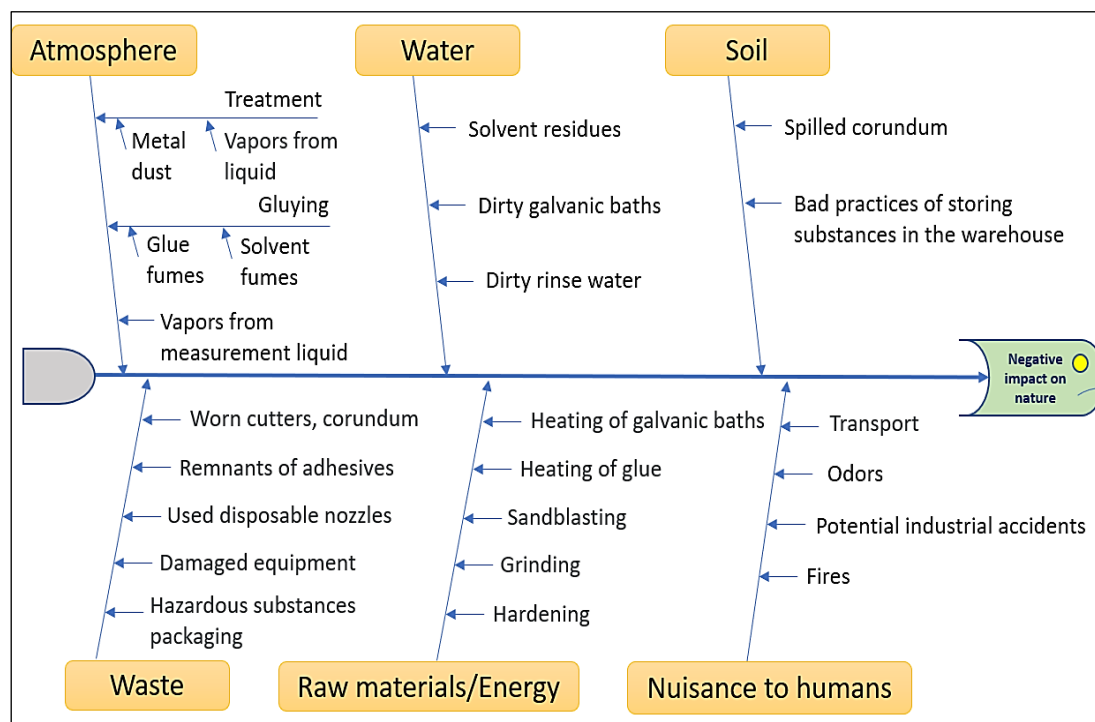


Figure 6 – Ishikawa diagram for assessing the environmental impact of adhesive bonding

The proposed solution can be modified and expanded in subsequent steps, and a given area can become the “head” of the diagram. Additionally, another approach to areas known for quality was proposed, so that they could be related not to the product but to the natural environment. For known 5 M+E areas, their meaning was changed, as shown in Table 3. Using the second modified diagram, the problem of potential industrial failures with environmental effects was analysed concerning the carried-out assembly, Figure 7.

Table 3 – Problem analysis in 5M+E Ishikawa diagram modified for environmental impact

Field	Problem
Man	What human activities negatively impact the natural environment?
Method	How do the methods used affect the demand for raw materials or generate other environmental burdens?
Machine	Is the environmental problem generated by faulty machinery?
Materials	Could the problem lie in the material from which the product is made?
Management	Do problems arise as a result of lack of supervision, planning, work organisation, poor motivation and leadership, lack of control, and lack of conceptual, technical, and social skills?
Environment	Is the problem the environment of the production station, working conditions, or the behaviour of other people?

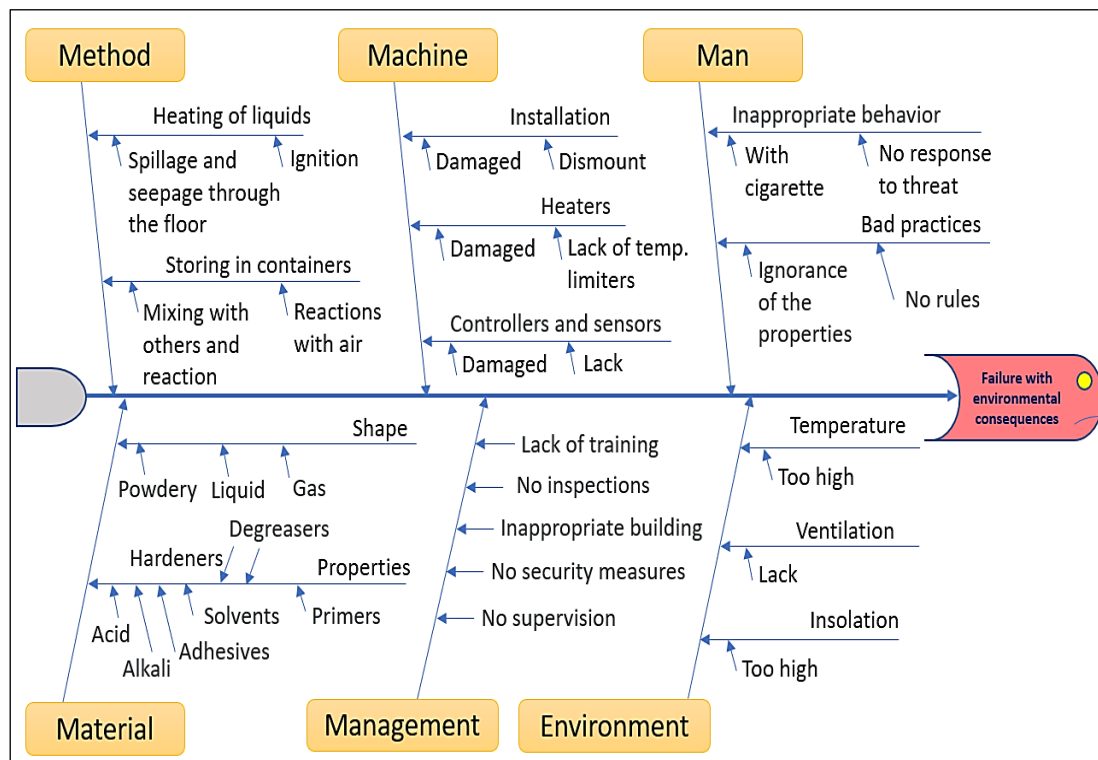


Figure 7 – Ishikawa diagram used to identify potential failure modes due to environmental effects during bonding

In the above example, there was an opportunity to use areas known for quality, while the purpose of the analysis was defined in the context of environmental management.

4 RESEARCH ON AWARENESS AND KNOWLEDGE – ENVIRONMENTAL SURVEY

A natural need in enterprise management, also in the context of environmental problems, is to learn about awareness and state of knowledge among employees at various levels. This is important for determining the scope and difficulty of actions that need to be taken for effective management. A simple method, often used for various marketing or pro-quality studies, is a survey. A survey is a technique using a questionnaire, a specific form of interview used to collect a large amount of information on a given phenomenon, using little effort and resources. The survey questionnaire may contain open questions, allowing the respondent to enter their own answer, semi-open questions – which have proposed answers, but also allow for entering their own, and closed questions – constituting a set of ready-made answers, from which the respondent selects the one that best fits their assessment of the given situation (Midor & Zarnovsky, 2016; Dacko, 2013).

In the analysed case, an environmental survey was prepared to collect information on environmental awareness in a group of 25 employees on the assembly line. The survey questionnaire is shown in Table 4, and the results obtained in Figure 8.

Table 4 – Employee survey project and obtained responses

Environmental survey			
The survey concerns the opinions of employees on the organisation of space for various substances used during gluing. It aims to learn your opinion on this subject and is completely anonymous. Please mark the selected answer in the YES/NO questions (e.g. × and enter your answer in the dotted lines. Thank you for taking the time to answer.			
Type of position held: <i>assembly line worker</i>			
No.	Question	Answer	Results
1.	Can the work you do be done without chemicals? What substances do you use most often? Please list the 3 most frequently used:	YES <input type="checkbox"/> NO <input type="checkbox"/>	YES 0 NO 25 glue, acetone, naphtha, TRI, galvanic bath solutions
2.	Have you read the safety data sheets of the substances you use?	YES <input type="checkbox"/> NO <input type="checkbox"/>	YES 5 NO 20
3.	Do you follow the guidelines given in the material safety data sheet?	YES <input type="checkbox"/> NO <input type="checkbox"/>	YES 5 NO 20
4.	Does your workstation have an organized place for these substances?	YES <input type="checkbox"/> NO <input type="checkbox"/>	YES 7 NO 18
5.	Do you consider the current storage location for these substances safe?	YES <input type="checkbox"/> NO <input type="checkbox"/>	YES 13 NO 12
6.	Do you know the general rules for waste management?	YES <input type="checkbox"/> NO <input type="checkbox"/>	YES 23 NO 2
7.	Do you know which substances you use will create hazardous waste?	YES <input type="checkbox"/> NO <input type="checkbox"/>	YES 8 NO 17
8.	Do you have an organised place for this waste?	YES <input type="checkbox"/> NO <input type="checkbox"/>	YES 8 NO 17
9.	Is there enough training related to substances and their waste?	YES <input type="checkbox"/> NO <input type="checkbox"/>	YES 4 NO 21
10.	If the stations are properly organised, are you prepared to comply with the provisions of the substance card?	YES <input type="checkbox"/> NO <input type="checkbox"/>	YES 25 NO 0

The survey shows that employees use various chemical substances (Question 1, 25/25), Figure 8. The busiest stations are those for preparing surfaces before gluing, where preparations for various purposes were mentioned: for removing corrosion, for degreasing, washing, creating an oxide layer, solvents (Q1). However, most employees did not read the material safety data sheets (Q2, 20/25). The same employees admitted that they did not comply with the provisions of these sheets (Q3, 20/25). Employees also admitted that not all stations had a place for such substances (Q4, 18/25), and in the opinion of many, the current place of their storage was not safe (Q5, 12/25). Analysing the answers obtained, one can see a connection between the lack of knowledge of the properties of substances and the rules of handling them (from the material safety data sheet of the chemical preparation) and the characteristics of the waste generated by these substances. If an employee does not know that a given substance exhibits environmentally hazardous characteristics, they are also unable to indicate that any items contaminated with it are also hazardous. The general principles of waste

management were declared by most employees (Q6, 23/25), but only eight respondents were aware that a given waste is hazardous (Q7, 17/25 are not aware of this). Many employees responded that there is no organised place for waste (Q8, 17/25). In turn, the amount of training is sufficient in the opinion of only some employees (Q8, 4/25), although this does not translate into everyday practices (according to Q3, 20/25 do not use or have no knowledge). However, all respondents expressed their willingness to follow good practices in connection with waste, if only the assembly stations are organised in the right way (Q10, 25/25).

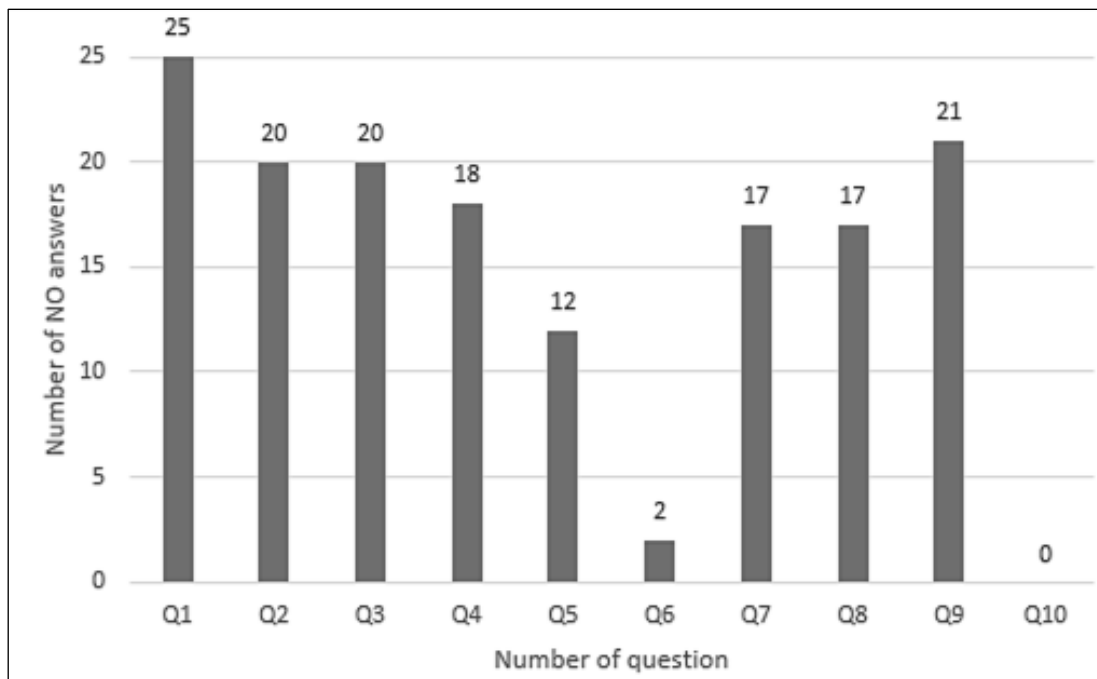


Figure 8 – Summary of the results of the environmental survey, which illustrates the scale of poor environmental practices

The chart shows the scale of negative phenomena in the plant in the context of environmental protection: unawareness, ignorance, bad practices or negative feelings of employees. To improve, it is necessary to make the real conditions be assessed more favourably and the numerical values shown in the chart be lower.

4.1 5 Whys and 5 W2H

The aim of the 5 Whys method is to discover the root cause of the problem by successively asking the question “Why?” – why it is happening as indicated in the previous answer. In this way, it is easier to understand the cause of the problem, and also to define the means to eliminate it. The initial stage is to collect as much knowledge as possible about the problem that has arisen, while each subsequent step increases the probability of discovering the root cause. The diagram for 5 Whys is in the form of a tree, such a graphical representation is easier for logical reasoning (Ciecińska, 2023; Ciecińska, Majka, & Sobotová, 2024). The survey

conducted at the gluing stations shows, among other things, that the problem in the context of environmental impacts is the improper and dangerous storage of chemical substances during assembly, which are particularly abundant in gluing operations (Kovács, Weltsch, & Berczeli, 2024). The cause of this state was determined using 5 Whys, the results of which are shown in Figure 9.

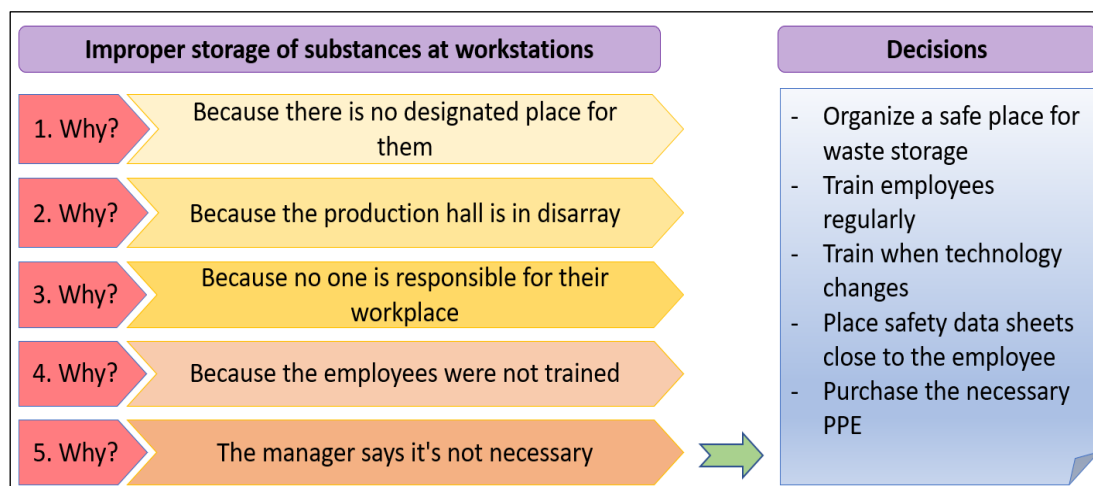


Figure 9 – Finding a solution to the waste problem using the 5 Whys method

A variation of 5 Why is the 5 W2H analysis, in which the questions are defined in a different way. Referring to the impact on the natural environment, the interpretation of the analysis elements given in Table 5 is proposed.

Table 5 – 5W2H for waste environmental burden analysis

Question	Problem
What?	What happened? What is the environmental problem?
Who?	Who reported the problem? Does it directly affect them?
Where?	What area is affected by the harmful impact? Is it large or small?
When?	When was the problem reported? Was it a one-off or recurring situation?
Why?	Why did the problem occur and what effects it might have?
How?	How was the problem assessed? Did the assessment concern measurable parameters, or are other, further studies and measurements needed?
How many?	What is the scale of the problem over a specific time period?

The results of the analysis performed in this way are shown on Figure 10.

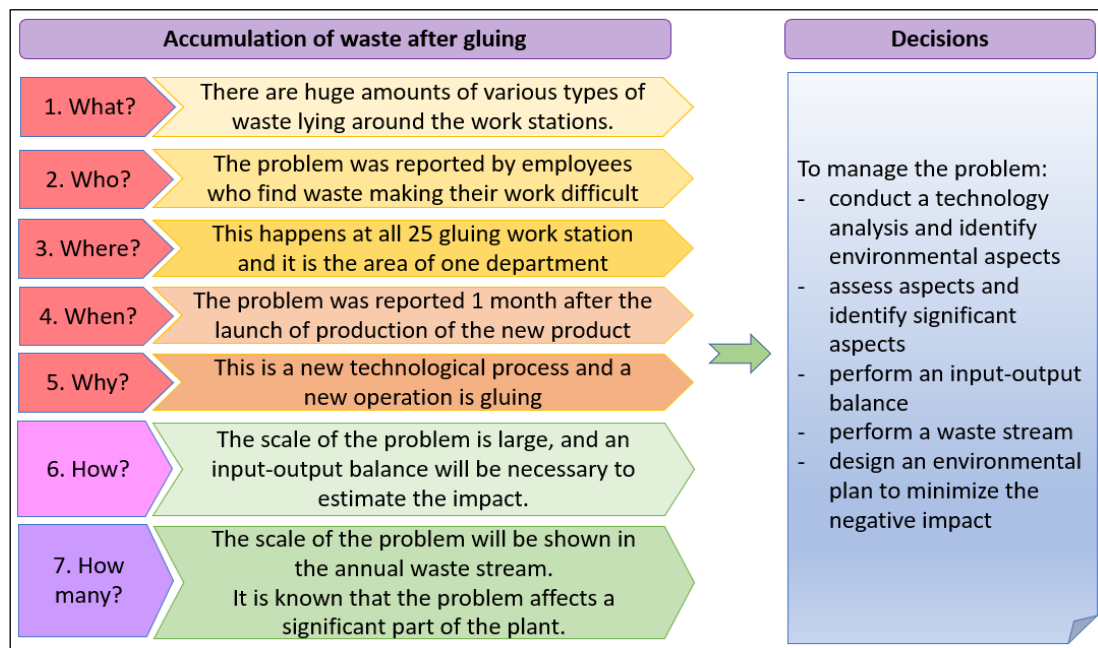


Figure 10 – Result of 5W2H analysis of waste from substances used in adhesive bonding

Due to the findings made during the 5 Why and 5 W2H analysis, a comprehensive identification of environmental aspects was carried out to assess the scale of impact. Although employees reported one problem, it is likely that there will be more environmental impacts and they may be diverse.

4.2 Register of environmental aspects

In the next step, a detailed analysis of the gluing process was performed and factors that could cause a negative environmental effect were identified. Based on this, a register of environmental aspects was created, according to the division into stages shown in the algorithms in Figure 1. The results of aspect identification are given in Table 6 to Table 8.

Table 6 – Register of environmental aspects identified in stage I of adhesive bonding

Register of environmental aspects		
Applying to the station / process: <i>assembly of metal machine parts - preparatory activities before gluing</i>		
No.	Environmental aspect / Activity	Method of impact on the environment
1.1 Determining the glued material / Accepting an order from a customer		
	Removing packaging material from sheet metal, securing products secured for transport	Packaging waste burden: unnecessary paper, cardboard, plastic foil, wooden pallets, metal clamps

Register of environmental aspects		
Applying to the station / process: <i>assembly of metal machine parts - preparatory activities before gluing</i>		
No.	Environmental aspect / Activity	Method of impact on the environment
1.2. Surface degreasing		
	Using a cloth moistened with a degreasing liquid	Hazardous waste load: used cleaning materials
	Ultrasonic bath in solvent	Potential water pollution in the event of pouring used liquid into the sewage system Load of hazardous liquid waste suitable for disposal Load of hazardous waste in the form of empty liquid packaging - metal cans, bottles Electricity demand
1.3. Sandblasting / Grinding / Galvanic bath		
	Manual abrasive processing or using mechanized tools	Waste load from used abrasive tools Abrasive material particle emissions to air Hazard to human health
	Machine abrasive processing	Dust emissions to air Waste burden – spent corundum and potential soil contamination from spent corundum Electricity demand
	Chemical surface treatment	Demand for chemicals Load of liquid hazardous waste in the form of dirty acid, alkali and salt baths Emissions of harmful aerosols into the air and a threat to human health Potential risk of spillage and contamination of soil and groundwater Demand for clean process water and the creation of hazardous waste after rinsing Potential risk of failure with an environmental impact - ignition and fire of liquids, secondary emissions into the air, secondary contamination of water and soil Load of hazardous waste from packaging of chemical reagents (glass bottles, plastic or metal containers)
1.4. Rinsing and drying the surface		
	Cleaning	Demand for demineralized water, depletion of natural resources Demand for chemicals (acetone, naphtha) Load of waste from water packaging Load of hazardous waste from packaging for other liquids
	Drying	Electricity demand in furnaces and heaters Waste from spare parts from devices Waste from control systems (e-waste)

Table 7 – Register of environmental aspects identified in stage II of adhesive bonding

Register of environmental aspects		
Applying to the station / process: <i>assembly of metal machine parts - preparatory activities before gluing</i>		
No.	Environmental aspect / Activity	Method of impact on the environment
2.1. Primer applying		
	Covering the surface with primer	Load of hazardous waste from used workshop application aids (putty knives, brushes), pressurized metal cans, dirty plastic containers, dirty cleaning cloth Load of packaging waste: paper, cardboard, plastic foil Emissions of harmful vapours into the air
2.2. Drying		
	If the layer is to be dry before applying the glue - drying	Electricity demand Hazardous waste load: used cleaning materials
2.3. Mixing glue		
	Dosing resin and hardener	Hazardous waste load in the form of: dirty tubes, applicators, mixers, containers Emissions of harmful substances from adhesives and hardeners into the air Threat of damage to human health Electricity demand during adhesive dissolution
2.4. Applying glue		
	Covering the surface with glue mixture	Hazardous waste load in the form of: dirty spatulas, brushes, applicators, containers Emissions of harmful substances from adhesives and hardeners into the air Threat of damage to human health Electricity demand for mechanical application

Table 8 – Register of environmental aspects identified in stage III of adhesive bonding

Register of environmental aspects		
Applying to the station / process: <i>assembly of metal machine parts - preparatory activities before gluing</i>		
No.	Environmental aspect /Activity	Method of impact on the environment
3.1. Fixing in the holder		
	Bonding using retaining elements	Load of metal waste in the form of destroyed equipment elements (pressure pads, flaps, spacers, etc.)
3.2. Hardening		
	Obtaining a join with specified properties	Energy demand during heat or hot curing Waste load from possibly used heaters or control elements
3.3. Removing excess glue		
	Manual or mechanical finishing of the join	Electricity demand during the use of mechanized tools (milling machines) Load of hazardous waste in the form of hard glue chips Emissions of glue particles into the air Threat to human health resulting from inhalation of particles and dust Load of waste from poorly made products, damaged tools (milling cutters, files)

The comparisons show that many types of impacts are repeated in individual activities performed during gluing. Since they are repeatable, the scale of the negative impact increases, and the impact on human health is also greater, due to more frequent exposure to harmful factors. It can be said that by performing environmental analyses, one can also refer to problems with occupational safety and occupational risk. Looking at this problem more broadly, any action that minimizes the environmental impact will also improve working conditions and reduce the risk of occupational diseases in people.

4.3 Assessment and Register of Significant Aspects

Due to the recommendations resulting from the 5 W2H analysis concerning the need to reliably determine the significance of the environmental impact of the reported problems, an assessment of the identified aspects was carried out and significant aspects were selected. The assessment of aspects was carried out using the FLIPO method, which was analysed in five steps:

- Flow – flow of materials, energy, information – what substances, materials, types of energy or waste are introduced into the manufacturing processes in the plant, how they are processed, what their use is in the context of the flow of products in the process.
- Legislation – what standards, laws, and regulations apply in a given scope in the context of the environment, whether the plant complies with these provisions, whether the requirements are exceeded, how higher environmental protection standards can.
- Impacts – what are the direct and indirect impacts of the activity on the environment, whether these are emissions, pollutants released into water, soil, atmosphere, degradation of ecosystems, consumption of natural resources, especially non-renewable ones, waste generation and impact on human health, then it is possible to qualify the impact according to importance and take appropriate corrective measures.
- Practices – What is done in the plant to protect the environment? The analysis includes production methods, waste management methods, savings e.g. water, energy, emission monitoring, as well as applied improvements and assessment of the effectiveness of these actions.
- Opinions – collection of opinions of employees and external stakeholders: customers, suppliers, local community, non-governmental organizations, etc. Feedback is received on the need, meaning, effectiveness, and efficiency of actions.

The importance of an aspect is determined by adding the partial scores collected in the above five areas. The numerical score is determined according to the principle given in Table 9.

Table 9 – Categories and criteria for assessing environmental aspects

No.	Category	Criteria and number of points		
		1	2	3
1.	Flow	Very important	Important	Normal
2.	Legislation	There is a regulation and it is not fulfilled	There is regulation and there is a risk of exceeding	There is a regulation and it is fulfilled
3.	Impacts	The aspect is dangerous, reacts with the environment, affects human health	The aspect is probably not harmful, but in large quantities it can cause hazards	The aspect is not harmful
4.	Practices	To cease immediately	To change	To check
5.	Opinions	There are complaints about the company's impact on the environment	There is general interest	Lack of interests

The previously identified aspects were assessed by 30 people and the average results obtained are shown in Table 10.

Table 10 – Aspects assessment in adhesive bonding

No.	Field of impact	Environmental aspect	Environmental impact	Category and number of points					Σ
				F	L	I	P	O	
1.	water	water consumption for galvanic baths	consumption of non-renewable resources	3	3	2	1	1	10
2.	soil, water	nuisance leaks of substances from machines and devices	environmental pollution	2	2	1	3	2	10
3.	soil	incorrect securing of hazardous substances	environmental pollution, risk of failure, threat to life	2	3	3	2	3	13
4.	air	excessive dust and dust accumulation at processing stations	air pollution	1	1	1	2	1	6
5.	air	too high concentration of harmful substances and dust	environmental pollution	2	2	1	3	3	11
6.	air	faulty mechanical exhausters	air pollution	3	2	2	2	3	12
7.	risk	missing or damaged personal protective equipment	environmental pollution threat to life	2	2	1	1	2	8
8.	risk	faulty or leaky installations	environmental pollution threat to life	2	2	1	1	2	8
9.	energy	high electricity consumption	depletion of non-renewable natural resources	2	1	2	3	2	10
10.	waste	incorrect storage of packaging waste	soil pollution, waste generation	1	1	1	1	2	6
11.	waste	excessive accumulation of raw materials not intended for further processing	waste generation	3	3	2	3	3	14

No.	Field of impact	Environmental aspect	Environmental impact	Category and number of points					Σ
				F	L	I	P	O	
12.	waste	too infrequent garbage collection	creation of local landfills, environmental pollution	2	1	1	2	1	7
13.	waste	a large amount of hazardous waste undergoing disposal	waste generation, environmental pollution, risk of failure	3	3	3	2	2	13

The result of the assessment is a register of aspects, combined with the input - output balance and the list of waste types (Table 11 – 13).

Table 11 – Register of significant aspects in adhesive bonding

Register of significant aspects in adhesive bonding					
No.	Environmental aspect	Field/process stage	Environmental impact	Significance criterion	Proposal for corrective action
1.	Hazardous waste	Preparatory stage Gluing	A large amount of hazardous waste undergoing disposal	High - threat to the local environment	According to the environmental program
2.	Air emissions	Primer and glue application	Air pollution, health hazard	High - impact on air quality	According to the environmental program

The analysis conducted so far referred to qualitative, descriptive assessments. It was necessary to supplement it with numerical data, what was the scale of the problems reported. In connection with this, an input-output balance was performed and the amount of substances used was determined on the scale of one year of production.

Table 12 – Input-output balance for gluing

Inputs	Outputs	Environmental impact
Semi-finished products	<ul style="list-style-type: none"> finished item volatile organic compounds 	<ul style="list-style-type: none"> hazardous waste dust fumes from the gluing process high air pollution energy consumption during the curing stage
Tools	<ul style="list-style-type: none"> adhesive material 200 l/year resin 140 l/year hardener 50 l/year packaging for hazardous substances 150 kg/year degreaser 120 l/year used contaminated materials 10 kg/year 	
Equipment	<ul style="list-style-type: none"> damaged brushes 10 kg/year damaged squeezer 2 kg/year worn-out grinding discs 2 kg/year worn-out files 1 kg/year damaged clamps 5 kg/year 	

In connection with the balance sheet carried out, which took into account the actual amounts of waste generated, a waste register was developed with the identification of properties and hazard codes (Table 13).

Table 13 – Register of hazardous waste from gluing

Process	Waste	Quantity	Properties of hazardous waste
Adhesive bonding	volatile organic compounds	No data	H6 “toxic”
	hazardous substances (adhesive material, resin, hardener, degreaser)	520 l/year	H3-A “highly flammable”
	packaging waste (pressurized cans)	150 kg/year	H1 “explosive”
	used tools made of various materials (brushes, files, grinding wheels, clamps)	17 kg/year	H2 “oxidizing”

4.4 Environmental Program

The comprehensive analysis of environmental aspects carried out using methods known from quality management influenced the acquisition of knowledge about the activities in the assembly department, where various materials are glued. The plant management also received a signal about the need to take corrective actions, signalled in various ways by employees and the plant environment. The final result of the conducted research was the development of an environmental program in relation to the significant aspect, which turned out to be hazardous waste. Two environmental goals were proposed:

- Improved handling of hazardous waste to reduce soil and water pollution.
- Minimization of air emissions – including limiting the harmful effects on employees’ health.

In connection with the goals defined in this way, the necessary tasks were developed and presented in the environmental programs shown in Table 14 and 15.

Table 14 – Environmental program for the assembly department – goal 1

Environmental program for the assembly department														
1. Environmental goal: Improving the management of hazardous waste														
Task	Responsible person	Estimated costs	Implementation schedule											
			I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Verification and completion of the safety data sheets for the given substances	Health and safety department	500 EUR			*									

Environmental program for the assembly department														
1. Environmental goal: Improving the management of hazardous waste														
Task	Responsible person	Estimated costs	Implementation schedule											
			I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Training employees on the harmfulness and handling of waste	Health and safety department	3,500 EUR			*			*				*		*
Organising a waste storage site	Production Manager	4,000 EUR				*								
Purchase and labelling of appropriate containers	Supply Department	5,000 EUR		*										
Organisation of a warehouse / place for storing hazardous waste	Maintenance Manager	16,000 EUR						*	*					
Marking the place of storage of solid waste and liquids	Health and safety department	2,000 EUR							*					
Purchase of installation and start-up of ventilation and air conditioning systems	Technical Manager	30,000 EUR									*	*		
Purchase and installation of substance emission sensors	Technical Manager	10,000 EUR										*		
Installation, testing and commissioning of fire protection systems	Security Manager	20,000 EUR					*							
Establishing an emergency procedure in the event of an industrial accident	Health and safety department	2,000 EUR							*					
Signing a contract with an external company for the collection of hazardous waste	Administrative Manager	5,000 EUR				*								

Table 15 – Environmental program for the assembly department – goal 2

Environmental program for the assembly department														
2. Environmental goal: Reducing air emissions														
Task	Responsible person	Estimated costs	Implementation schedule											
			I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Purchase of masks with filters for working with organic substances	Production Manager	600 EUR			*									
Purchase of protective aprons and gloves for working with chemicals	Supply Department	700 EUR			*									
Purchase and installation of extraction and filtration systems at the work stations	Maintenance Manager	5,000 EUR		*	*									
Carrying out additional training for employees	Health and safety department	5,000 EUR			*				*				*	

5 CONCLUSIONS

Identification and assessment of environmental aspects is a current and necessary problem in the company. In order to perform it effectively and in the shortest possible time, simple methods are needed, but they allow for logical organisation of the collected knowledge. Such methods can be the Ishikawa diagram and 5 Whys/5W2H known from quality management.

The advantages of these graphic methods are that they facilitate work by organising the transfer of information, assigning a specific hierarchy to data, ease of locating the causes of problems and the possibility of eliminating them. In connection with the systematisation of causes in designed areas, they allowed for a new perspective on known problems in gluing and the free introduction of ideas and proposals. The combination of methods also broadened the cognitive horizon and made it possible to recognize the causes in many areas: technological, organizational and employee.

As shown in the article, both the Ishikawa diagram combined with 5Whys and modified 5W2H, as well as the survey, resulted in the recognition of behaviours and practices occurring in the plant. This was the basis for further analytical work, using methods already known in environmental management. A natural continuation of the analyses performed was the preparation of the input-output

balance and the assessment of aspects related to the implementation of the environmental program project.

From a practical point of view, it can also be stated that in addition to the advantages, the proposed methods of identifying environmental nuisances and their causes using the example of gluing may have difficulties. Most often, they are concerned about the non-obvious classification of the discovered causes (they could result from various reasons) and difficulties in assigning them to the appropriate area of analysis. In addition, the causes in a more complex and extensive problem required discussion. The proposed use of an algorithm to analyse the course of the gluing process facilitated this process. Another inconvenience is the lack of reference to the importance of issues by expressing them in numbers, but this problem was solved by designing a waste balance and list. To sum up, it can be concluded that the implementation of methods from the area of quality management to environmental management is a beneficial and effective solution. This also proves that it is possible to look at already known methods in a universal way, going beyond the stereotypical approach.

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