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Chemical noxious emissions from road vehicles and their possible causes

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Abstract. The paper presents the authors own scientific representation and original point of view on the technical acceptance of the main road vehicle pollutants and their possible causes. Specialists in the field carry out detailed research in this area in order to understand all the harmful effects of the chemical noxious emissions generated by the thermal engines of motor vehicles, as well as the mechanical vibrations transmitted by cars to the road surface and users, in order to be able to determine and establish their effect on human habitats and the optimal criteria for the operation of means of road transport, which ultimately define their comfort and ergonomics. In this way, those interested can learn about the main polluting factors in today's motor transport, how responsibility for environmental protection is promoted, present some of the harmful thresholds of combustion gases from motor vehicle engines, present the main possible causes that decrease or increase chemical noxious emissions from internal combustion engines and the current situation in the problem of environmental pollution worldwide. At the end of the scientific article, conclusions in the field are presented.

Keywords: *cars, pollution, chemical noxious, noises, harmful thresholds, environmental protection..*

Introduction

The atmosphere is the gaseous part around the planet Earth. In turn, it is made up of three layers of gases of different densities. The thinnest atmospheric layer, about 7 km at the poles and 17 km at the equator, is the troposphere, the layer closest to the ground, the space where living things can live. This is also the space where the weather phenomena that influence our daily lives take place. Air is the main factor involved in the weather processes and phenomena that take place on the surface and within the Earth's crust. Thus, it acts as a thermal regulator, participates in the formation of geological and ecological processes, provides protection, through its movements creates energy resources, ensures the life of humans, animals and all living beings on and within the earth's crust. Chemically, air is made up of about 78.08% nitrogen, 20.94% oxygen and 0.93% argon. To these are added between 0.1% and 4% water vapour and small amounts of carbon dioxide (0.03%), and in negligible descending order: neon, helium, krypton, sulphur dioxide, methane, hydrogen, all in the form of waste

gases. Vehicles in the road transport system, which use carbon-based fossil fuels to obtain the energy used in the transport process, release gases into the atmosphere as a result of the combustion process in internal combustion engines which pollute the atmosphere to a greater or lesser extent. Today's human society is constantly developing as a result of advances in science and technology, but is unaware that this development comes at enormous environmental cost. Air pollution is the phenomenon whereby the chemical composition of the air is altered, either in the form of a change in the proportion of its constituents or the appearance of new components that are harmful to biotopes and biodiversity, ultimately affecting the health of flora, fauna and humans. Today, thanks to technological progress, cars have been equipped with catalytic converters, which convert the noxious substances resulting from the combustion of fuels in internal combustion engines into less polluting substances with no harmful effect on the environment. Catalytic converters, or catalytic converters as they are still known among motorists, are a result of technological developments that were introduced to the car manufacturing industry in the second half of the '70s. Since then, their performance has improved continuously. Functionally, oxidation-reduction reactions take place in catalytic converters, using noble metals such as rhodium (Rh), palladium (Pd) or platinum (Pt). The latter metal, being a precious metal, is used less frequently in the construction of catalytic converters, the most commonly used being rhodium and palladium. The three-way catalytic converter converts the pollutants removed by a thermal engine burning a carbon-based fuel and combines ***two oxidation reactions*** to convert hydrocarbons and carbon monoxide, plus ***a reduction reaction*** to convert the noxides. Oxidation-reduction reactions take place only in the presence of oxygen and are accelerated by the noble metals in the catalytic converter. Catalytic converters in a car are mounted in the exhaust gas path and the role of the noble metals in them is to chemically react with the noxious gas components (HmCn, CO and NOx) removed by internal combustion engines, converting them into neutral substances.

The chemical reactions that take place in a catalytic converter transform harmful chemicals into safer and more environmentally friendly substances, such as:

- hydrocarbons (HmCn) and oxygen (O_2) are converted into carbon dioxide (CO_2) and water vapour (H_2O);
- carbon monoxide (CO) and oxygen (O_2) are converted into carbon dioxide (CO_2);
- nitrogen oxides (NOx) and hydrogen (H_2) are converted to nitrogen (N_2) and water vapour (H_2O).

1. The main pollunats in today's motor transport

The main environmental pollutants resulting from the motor vehicle transport process are *chemical pollution (exhaust pollution), noise (sounds) and vibration (mechanical effect).*

The pollutants released into the atmosphere by the internal combustion engines of cars can be:

- pollutants with a direct effect on morbidity and mortality (e.g. nitrogen oxide, sulphur dioxide, hydrogen sulphide, carbon monoxide and heavy metals);
- pollutants with an indirect effect (e.g. global warming, acid rain).

60% of overall environmental pollution by noxious gases is created by exhaust gases from internal combustion engines in cars. It has been shown that within the first two minutes of starting an internal combustion engine, 80% of the pollutants released into the atmosphere are carbon monoxide (CO).

A. Chemical pollution (exhaust pollution) occurs when chemical gases resulting from the combustion of a fossil (carbon-based) fuel in a cars internal combustion engine are released into the environment.

Exhaust emissions have the following characteristics:

- they are discharged very close to the road (ground), which creates high concentrations at low heights. This effect is quite dangerous due to the fact that low-density gases have the ability to diffuse easily into the environment;
- it is carried out over large areas, especially in densely populated cities. Here the concentrations of harmful gases are at their highest when road traffic is high and the possibilities of ventilating the streets are diminished by nearby building elements.

The volume, concentration and nature of pollutants are directly proportional to the type of fuel burned, the type of car and its technical condition, the running condition and wear of the engines.
The most important pollutants released into the atmosphere by combustion engines are: carbon dioxide (CO_2), hydrocarbons (HmCn), carbon monoxide (CO), nitrogen oxides (NOx), sulphur dioxide (SO_2).

- *Carbon dioxide (CO_2)* results from the combustion of carbon based fuels in the cylinders of thermal engines. It is one of the most important gases contributing to the greenhouse effect (global warming). It is readily soluble in water, in combination with which it forms carbonic acid (H_2CO_3). This process leads to acidification of surface waters, especially seas and oceans.
- *Carbon monoxide (CO)* is formed due to the low combustion efficiency of thermal engines. It has the property of accumulating in large quantities in conditions of heavy traffic and atmospheric calm, especially in winter and spring, because of its chemical stability at low temperatures. When CO mixes with the organic compounds resulting from the incomplete combustion of fossil fuels in car engines and other oxides (e.g. sulphur dioxide), a yellowish, foul-smelling haze known as „smog" (from *„**sm**oke"* and *„**fog**"*) is formed over large cities (Figure 1), which contains chemical compounds that are hazardous to health.

Figure 1. Picture of smog from road transport in the world's major citiesv [10].

- *Hydrocarbons (HmCn)* are chemical compounds made up of carbon and hydrogen. As pollutants, they come from the unburned fuel that is released into the atmosphere by thermal engines. These substances have no direct harmful effect on human health (with the exception of polycyclic aromatic hydrocarbons, which have a carcinogenic effect). Together with nitrogen oxides and under the effect of the sun's rays, the hydrocarbons emitted into the atmosphere form photochemical smog, which has a direct effect on human health by irritating the eyes and mucous membranes and on traffic safety by reducing visibility.
- *Nitrogen oxide (NO_x)*, combinations of nitrogen with oxygen in various proportions, mainly resulting from the combustion of diesel in internal combustion engines. In combination with water in the atmosphere, it generates acid rain which has destructive effects on buildings and vegetation.

They are a constant contributor to environmental pollution and *Nitrogen dioxide* (NO_2), which is formed at high temperatures, is considered one of the most dangerous pollutants. Released into the atmosphere, NOx contributes to smog formation, along with hydrocarbons. They affect the health of living beings by blocking the haemoglobin responsible for transporting respiratory gases in the blood and damaging the lungs.Nitrogen oxides and sulphur oxides contribute to the formation of acid rain, which has a damaging effect on biosystems, poisoning water, flora and fauna (figure 2) and has a slow harmful effect over time on urban art objects and buildings.

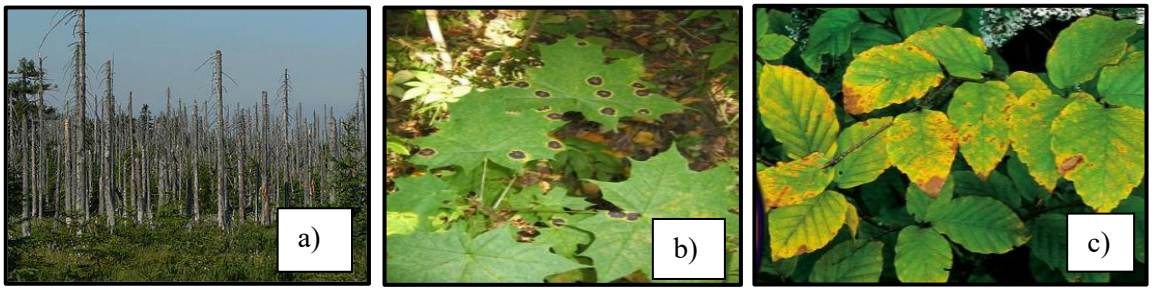

Figure 2. Effect of acid rain on ecosystems. a) Effects of acid rain in the Czech Jizera Mountains [11]; b), c) Impact of air pollution on vegetation [12].

Other harmful substances resulting from the motor vehicle transport process are: volatile organic compounds (VOCs), soot, asbestos, dust particles, lead compounds, benz-α-pyrene, aldehydes and heavy metals. Ozone depletion and global warming are the effects of CO and HmCn pollution, which are intensified when a car's engine is idling, at traffic lights or in traffic jams, which are common in large cities at peak times, while NOx emissions become more pronounced when the car is starting up [1].

B. Noise (sounds) is the noise produced by cars during operation and is created by frictional forces between moving parts or components. Noise pollution is also produced by cars in dynamic motion when tyres are in contact with the road and when air is rubbing against the outer bodywork. In figure 3 shows a typical decibel scale, where national noise limit regulations are also shown.

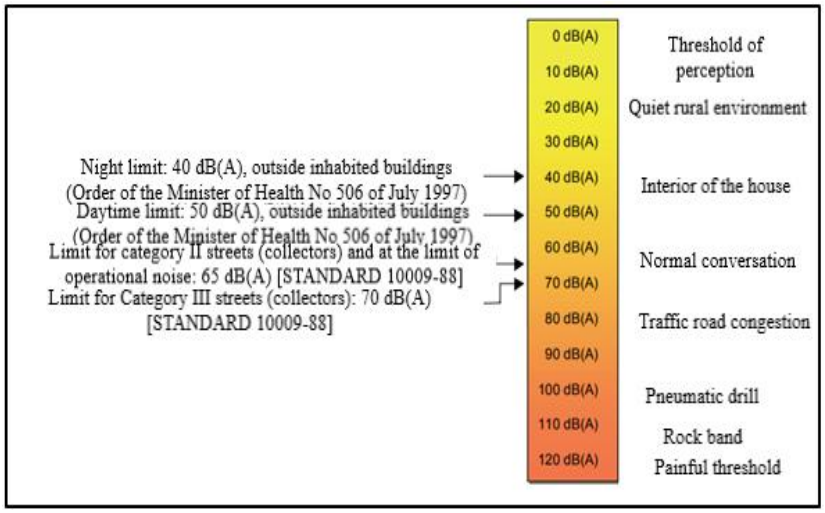

Figure 3. Typical decibel scale indicating national regulations on noise limits [13].

From the point of view of the present research theme, the following two components are of interest:

- acoustic comfort, defined by the level of noise produced by engines, rotating or translating parts, tyre contact with the ground or friction of the moving car with the air.
- vibrational comfort, defined as the resonance of mechanical waves in the structure of the car, perceived by the body of the passenger, are caused by the rotating or translating parts of the car's organs or by irregularities in the surfaces on which the car runs.

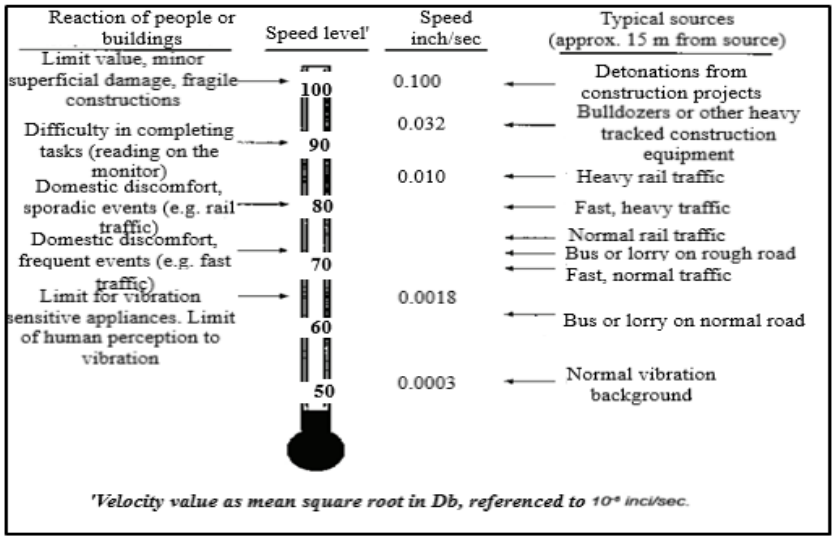

Figure 4. Reaction of people and buildings to different sources of vibration in relation to vehicle speeds [13].

In everyday life, the effects of road transport noise are felt by people and sometimes become unbearable in large urban agglomerations where road traffic is heavy. Figure 3 shows a typical decibel scale, including national noise limit regulations. Modern cars are getting quieter. However, when traffic is heavy, the noise multiplies, and is further amplified by the vertical walls of nearby buildings. Literature research shows that 20% of the European population is currently affected by road traffic noise, which means that noise pollution targets in Europe have not been met. High levels of noise and vibration have various effects on human health, creating discomfort (22 million cases per year), sleep

disturbance (6.5 million cases per year), adversely affecting the cardiovascular system (48,000 cases of ischaemic heart disease per year), the metabolic system (12,000 premature deaths per year) and cognitive impairment in children (more than 12,000 children have difficulty reading).

C. Vibrations (mechanical effect) are transmitted to the ground (roadways) and the surrounding air by the suspension and running systems of moving vehicles and the sound produced by their engines in operation. Vibration is directly proportional to the weight and size of the vehicle or machine that produces it and affects the environment and people in the area, but also the vehicle as a whole. Regardless of the category of roadway, when motor vehicles move, there are inevitably greater or lesser oscillations or mechanical shocks, which are in turn transmitted to the structure of the vehicle bodywork and hence to the goods being transported or to the people using the vehicle. Figure 4 shows the reactions of people and buildings to different sources of vibration, relative to the speed of several types of vehicle.

Vibrations have harmful consequences on exposed persons, leading to fatigue and discomfort [2]. At the same time, they also irreversibly affect vehicle parts, aggregates or organs, weakening their strength, causing mechanical fatigue and affecting their reliability.

2. Promoting environmental responsibility in the automotive industry

From the data researched so far and those presented by the EEA (European Economic Area), it can be said that the average pollutant emissions for new cars registered in the EU Member States (27 countries) plus Iceland, the UK and Norway were 122.4 grams CO_2/km in 2019, an increase of 1.6 g compared to 2018.

Although these emissions were below the EU's 2018 target of 130 grams CO_2/km, pollutant emissions still increased rather than decreased. As a result, the European Commission has set even tougher measures on CO_2 emissions from cars for 2020. These should not exceed 95 grams CO_2/km, based on 2019 levels.

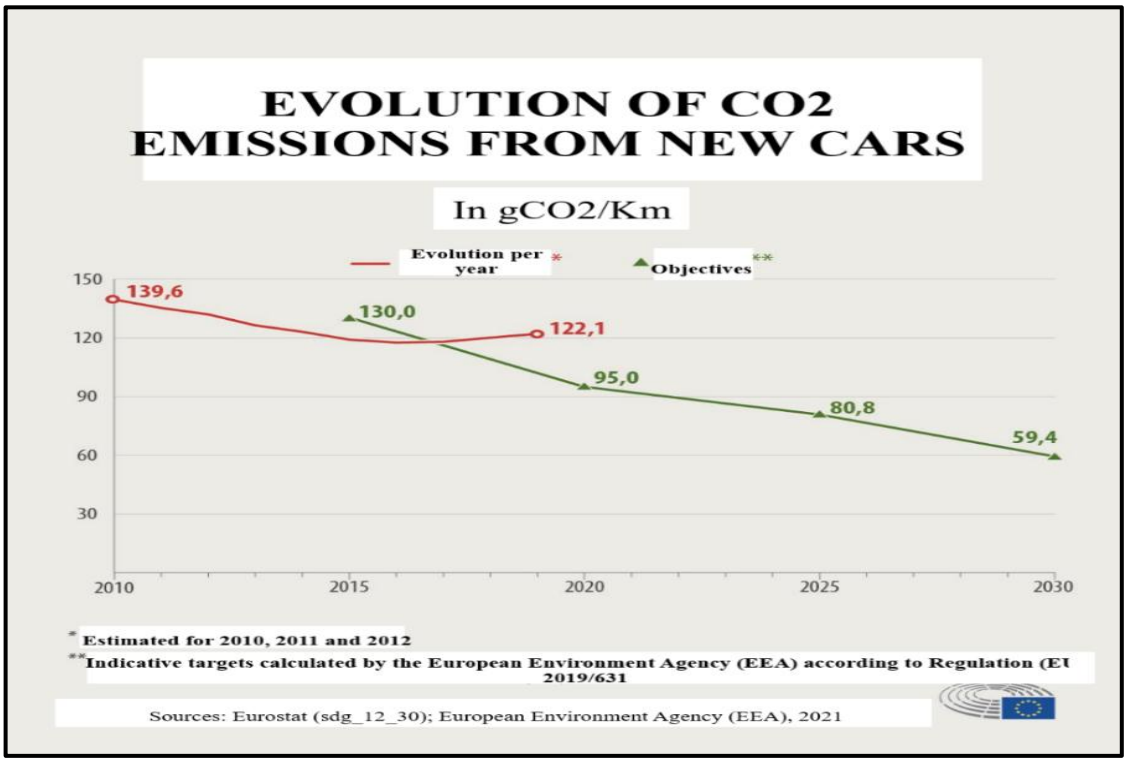

Figure 5. Evolution trend of CO_2 emissions from new cars (2010-2030) [14].

According to data provided by the European Environment Agency (Figure 5), the level of carbon dioxide (CO_2) from internal combustion engines in cars made by European manufacturers will have to fall steadily so that by 2030, this gas will reach the legal value of 59.4 grams CO_2/km. European car manufacturers are therefore obliged to stick to this figure if they do not want to face penalties.

Research and surveys show that the figures have risen as a result of the public's appetite for buying new medium and large SUVs. This type of vehicle has high fuel consumption due to powerful engines with large displacement, poor aerodynamics (massive bodywork with poor aerodynamic coefficient), but also due to the technical operating conditions given by four-wheel drive (4x4), which implies low speeds to ensure high traction powertrain, with high fuel consumption and therefore higher NOx levels. Statistics show that Europeans bought 38% more of these vehicles in 2020 than in 2019, despite the SARS CoV-2 pandemic affecting the economies of EU countries, including car production. The increases are also due to the massive purchase of passenger cars in 2019 by Europeans, in parallel with the decrease in car sales.

In order to reduce harmful gas emissions, decarbonise car transport and reduce the growing greenhouse effect, the European Commission is further tightening environmental protection legislation and is asking all Member States to propose and introduce new incentive schemes for the public to readjust their vision of buying new, clean, environmentally friendly cars.

Authorities will also need to invest heavily in providing the infrastructure to power these vehicles and come up with viable new ideas, proposals and options to support domestic manufacturers to meet emissions targets. Germany and France are the first countries to have already taken action at European level. They are providing substantial incentives for manufacturers and buyers of electric vehicles as part of the recovery packages for their own savings affected by the coronavirus pandemic.

3. Harmful exhaust emissions from motor vehicles

The harmful threshold of flue gas is defined as the maximum value of the chemical that exceeds a certain concentration in the atmospheric air, measured over a certain period of time. The unit of measurement is the cubic centimetre (cm^3). Volumetric units are used and are interpreted as the number of cubic centimetres (cm^3) of gas per 1 cubic metre (m^3) of air. 1 cm^3 is one millionth of a m^3. In this context, the unit of measurement, which can be defined as one millionth part per cubic metre (m^3), is hereafter referred to as part per million (ppm).

To demonstrate the above, we have used the relationship:

$$10.000\ ppm = 10.000\ \frac{1\ cm^3}{1.000.000\ cm^3} = \frac{1}{100} = 1\% \qquad (1)$$

The harmfulness of a pollutant emission is defined by the following factors: the concentration of the toxic gas in the air, expressed as a percentage [%], and the time of exposure to that gas, expressed in hours. A concentration not exceeding 70-80 ppm for an exposure time of 0-8 hours becomes dangerous at longer exposure, with a toxic effect on the human body. The threshold of 70-80 ppm has subsequently been lowered.

Figure 6 shows the influence of exposure time on the degree of carbon monoxide [CO] poisoning.

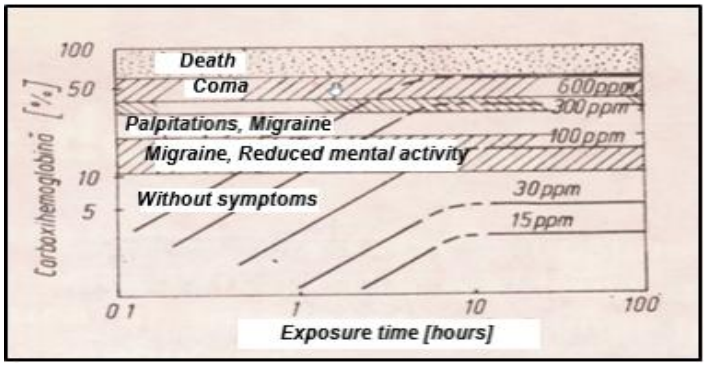

Figure 6. Influence of exposure time on the degree of CO [3].

For some European Union countries, the harmful thresholds have been set at the following values: 9 ppm for 8 hours of exposure to carbon monoxide (CO); 5 ppm for 8 hours of exposure or 0.08 ppm for 1 hour of exposure to nitrogen oxides (NOx); 5 ppm for 8 hours of exposure to hydrocarbons (HmCn). In our country, the harmful threshold for CO has been set at 4.8 ppm for 30 minutes of exposure and 1.6 ppm for 24 hours of exposure [3].

4. Possible causes that decrease or increase chemical noxious emissions from internal combustion engines

The reduction or increase in the level of chemical noxious emissions from an internal combustion engine may be due to factors that directly influence the operation and combustion in the cylinders. These factors may be related either to the construction of the engine or to the operation of the vehicle. Table 1 shows the most common causes that can alter chemical noxious emissions from internal combustion engines.

Table 1. Possible causes that decrease or increase chemical noxious emissions from internal combustion engines.

Name of chemical noxious substances	Cause of occurrence	Mode of manifestation on the noxious		Explanations, observations, comments
		Decrease	Increase	
	A. Construction factors of heat engines			
Carbon dioxide CO_2 [%]	Use of the Atkinson principle in engine cylinder air intake [4]	x	-	The pinciple was invented before the First World War by the British engineer James Atkinson, who applied his invention using certain mechanical elements on the Otto engine (an assembly of three articulated connecting rods, one of which has an attachment point to the engine crankcase. The mechanism also has camshafts that can change the rotational advance to delay the closing of the intake valves). The principle is much more efficient than Otto's internal combustion engine principle of operation [5]. It consists of delaying the closing of the inlet valve at the end of time 1, the inlet. Thus, by means of the engine and exhaust gas distribution mechanism, modified and adapted for the engine cycle, the closing of the inlet valve on each cylinder is delayed and overlapped over the beginning of time no. 2, compression. Closing the intake valve with a delay causes some of the air sucked into the engine (the oxidant) to be exhausted by the piston by moving it from the Interior Neutral Centre (INC) to the Top Dead Centre (TDC) in the intake manifold at the start of the compression stroke. With a reduced amount of air in the cylinder, the Electronic Control Unit (ECU) is commanded to dispense a reduced amount of fuel (relative to the amount of air in the cylinder) for injection, making combustion almost complete and efficient. The efficiency of the engine using the Atkinson principle is high, close to that of a diesel engine (35-45%), compared to a classic petrol engine (Otto), which has a lower efficiency (25-35%). At low quantities of air-fuel mixture, the problem always arises of a decrease in engine power. This is why it is necessary to make a certain compromise in the correct operation of the thermal engine, the principle not being used permanently during its operation. The internal combustion engine, which uses this principle, is used exclusively in hybrid vehicles and only operates when the speed is constant (not when starting or under load). In this case the electric motor(s) compensate and provide the power difference. In summary, the Atkinson principle reduces fuel consumption, greatly improves combustion in the cylinders (near ideal combustion), the engine does not overheat, there is no high pressure force (compression ratio drops considerably

Name of chemical noxious substances	Cause of occurrence	Mode of manifestation on the noxious		Explanations, observations, comments
		Decrease	Increase	
				from 16:1 to 12:1) and CO_2 pollution levels drop considerably, all of which is achieved on an aspirated petrol engine [6].
	B. Factors relating to vehicle operation			
	High temperature in the combustion chamber of the engine cylinder	-	x	CO_2 dissociation occurs at high combustion chamber temperatures. During the fourth stroke of the combustion engine, the exhaust, carbon monoxide (CO) ignites in the exhaust column in the presence of oxygen (O_2), forming carbon dioxide (CO_2). In the presence of air or oxygen CO burns with a bluish flame, releasing a lot of heat and generating CO_2.
Carbon monoxide CO [%]	**A. Construction factors of heat engines**			
	Compression ratio (ε)	-	x	Increasing the combustion chamber has negative effects on CO production. In order to reduce pollution, the aim at this time is to stagnate or even reduce ε from 9.5 to 8.5 and even lower. Higher values are achieved at smaller bores where the combustion chamber is more compact and does not generate detonation burn conditions. Detonation burns generate CO.
	Engine cylinder combustion chamber construction	-	x	It has a direct proportional influence on the combustion velocity of the fuel mixture, on which the heat transfer surface and the combustion front path depend. An inversely proportional influence of the combustion speed is achieved, however, through the physical factor that generates turbulence in the fuel mixture. In order to prevent the influence of turbulence on the fuel mixture turbulence, turbulence reduction thresholds are provided in the nozzle or piston.
	Material of combustion chamber walls	x	-	Using aluminium as the material of construction for the nozzle and pistons produces a lower temperature in the combustion chamber, reducing the conditions for detonation combustion. This allows the compression ratio to be increased by 0.5 units and the octane number to be lowered by 4-5 units.
	Intake manifold construction	-	x	It influences the increase of CO due to an uneven distribution of the fuel mixture on each cylinder, thus negatively influencing its quality (in thermal engines whose fuel mixture is formed outside the cylinder). It increases the dosage which is richer with higher CO emissions.
	Use of the Atkinson principle in engine cylinder air intake [4]	x	-	The principle brings the same benefits, which substantially reduce CO emissions. It is explained in detail under CO_2 emissions.
	B. Factors relating to vehicle operation			
	Air-fuel dosage	-	x	CO occurs as a result of incomplete combustion, generated by the lack of oxygen in the mixture. In incomplete combustion of carbon-based fuels at high dosage (*power dosage* λp = 0.8-0.9), fuel consumption increases due to incomplete combustion. When burning enriched mixtures the percentage of CO increases. If air-fuel mixtures are enriched, for each 0.1 unit reduction of λ, the CO concentration increases by 3.5%.
		x	-	At low dosing (*economic dosing* λe = 1.05-1.15), fuel consumption decreases and burns are complete. The minimum amount of carbon monoxide is obtained for λ = 0.95. When burning lean mixtures the percentage of CO decreases.
	Ignition advance	x	-	The amount of CO decreases with reduced ignition advance.

Name of chemical noxious substances	Cause of occurrence	Mode of manifestation on the noxious		Explanations, observations, comments
		Decrease	Increase	
	Ambient temperature	-	x	The operation of heat engines in a high-temperature environment influences the initial temperature rise of the combustion process, leading to detonation combustion and the release of CO into the atmosphere. In the middle of hot summer days, when the ambient temperature reaches 30-40 ˚C, the frequency and intensity of detonation combustion in the cylinders of heat engines is higher, compared to cooler days or at night when the ambient temperature is lower and the humidity is higher. However, more attention needs to be paid to this aspect as it has been experimentally demonstrated that high humidity of the air sucked in by engines (including supercharged engines), when using a petrol with octane number reduced by 8-15 units, at humidity variations of 10g/kg fuel, fuel consumption increases by 2.7% and fuel power decreases by 2%, generating excess CO.
	Working speed of the heat engine	x	-	At high engine speeds, the intake velocity increases and the flow turbulence in the intake manifold increases. A high engine speed decreases the duration of combustion in the cylinders, reduces the pressure regime that occurs in front of the combustion front and reduces the tendency for detonation. The consequence of this is a reduction in CO.
	Engine working load	-	x	At decreases in workload, heat engines operate at overall engine cycle temperatures which also tend to decrease, generating variations in CO.
	Engine thermal regime	-	x	Increasing the thermal regime increases the heating of the part of the fuel mixture in front of the combustion front. Under these conditions, the possibility of fuel combustion in the detonation cylinders increases and therefore secondary combustion is favoured and CO emissions increase slightly.
	Lubrication and wear condition of the piston-seals-cylinder assembly	-	x	Wear on the piston-cylinder seal assembly causes insufficient scraping of the lubricant film (engine oil) that ensures lubrication. As a result, a quantity of lubricant remains unremoved from the inner surface of the cylinder and is burnt in the combustion chamber. The burning of the lubricant results in scale, which is deposited on the piston head and the walls of the combustion chamber. The scale self-ignites and causes secondary combustion. Secondary burns are CO generators.
	Engine operation at idling speed (idle)	-	x	The idling mode of the thermal engine generates large amounts of CO due to the enriched mixture.
	Nature of fuel	-	x	The nature of the fuel has a direct influence on the initial and final phase of the combustion that takes place in the engine cylinders. A petrol with a low octane number creates detonation (the formation of ignition nuclei in front of the combustion front), resulting in incomplete fuel combustion and the release of unburned petrol containing CO compounds into the atmosphere. The anti-knock qualities of petrols are assessed by octane number. The octane number of petrols is the percentage by volume of isoctane in a standard mixture (isoctane with octane number = 100 and n-heptane - normal heptane with octane number = 0), which has the same sensitivity to detonation (auto-ignition) as the fuel used for testing. For the gasoline used at this time octane number (Co) 95 we have 95 isooctane and 5 nheptane; for Co 98 gasoline we have 98 isooctane and 2 nheptane, and for Co 100 gasoline we have 100 isooctane and 0 nheptane.
	Reduced amount of O_2 (air) in engine	-	x	Due to the lack of oxygen (air) in the combustion chamber, there is poor atomisation of the fuel, the flame is slowed down, the combustion front does not extend and cold-faceplate reactions occur. This phenomenon occurs at

Name of chemical noxious substances	Cause of occurrence	Mode of manifestation on the noxious		Explanations, observations, comments
		Decrease	Increase	
	cylinders			altitudes where oxygen is scarce or when the air intake path into the engine is blocked (the air filter is clogged with dust particles). In this context the engine runs with a rich mixture and fuel consumption increases. The engine releases unburned or incompletely burned fuel rich in CO into the atmosphere.
	Flue gas recirculation	-	x	By recirculating the hot exhaust gases using the exhaust gas recirculation circuit in the engine's lower crankcase (EGR - Exhaust Gas Recirculation - valve circuit), an increase in the temperature of the engine fluid in the intake manifold is created, which leads to a reduction in the flame-out phenomenon. The phenomenon created stimulates the production of CO.
Hidrocar-bons HmCn [ppm]	**A. Construction factors of heat engines**			
	Compression ratio (ε)	-	x	The principle produces negative effects by generating HmCn emissions. It is explained in detail under CO_2 emissions.
	Engine cylinder combustion chamber construction	-	x	The principle produces negative effects by generating HmCn emissions. It is explained in detail under CO_2 emissions.
	Material of combustion chamber walls	x	-	Using aluminium as a material of construction for the nozzle and pistons results in a lower combustion chamber temperature, reducing the conditions for detonation combustion. This allows the compression ratio to be increased by 0.5 units and the octane number to be lowered by 4-5 units.
	Use of the Atkinson principle in engine cylinder air intake [4]	x	-	The principle brings the same benefits that substantially reduce HmCn emissions. It is explained in detail under CO_2 emissions.
	B. Factors relating to vehicle operation			
	Lack of or delayed spark plug spark	-	x	Hydrocarbons are known to be generated by incomplete fuel combustion due to flame interruption in the air-fuel mixture in the engine cylinders. The phenomenon is also called flameout and can occur at the wall (near the cylinder wall), or in the gas mass. HmCn become harmful when they are released into the atmosphere by internal combustion engines as by-products. A technical fault in the ignition system can cause a lack of spark or delayed spark (cyclic dispersion), which can lead to high HmCn emissions.
	Longer delay in closing the exhaust valve	x	-	It occurs as a result of improper thermal clearance between the exhaust valve stem and the cylinder head or cam. It has the effect of increasing the fractions of the exhaust gas returning to the engine cylinders at the end of the process.
	Stepping up the post-harvest process	x	-	The exhaust gases contain a lot of O_2 due to lean mixtures. The exhaust gases are very hot (high temperature) due to the displacement of combustion from the engine cylinders to the exhaust gas de-gasing process. Both aspects are possible causes that reduce the amount of HmCn in the combustion gases.
	Reduction of the combustion boundary layer	x	-	The decrease in HmCn concentration in the combustion boundary layer occurs when lean mixtures (lean dosing or economic dosing) burn in the cylinders of the thermal engine, where $\lambda > 1$.
	Air-fuel	-	x	At incomplete combustion of carbon-based fuels, i.e. at high dosage (*power*

Name of chemical noxious substances	Cause of occurrence	Mode of manifestation on the noxious		Explanations, observations, comments
		Decrease	Increase	
	dosage			*dosage λp* = 0.8-0.9) fuel consumption increases. Flue gas toxicity is influenced by dosage. The minimum amount of hydrocarbons is obtained for λ = 0.95. When burning enriched mixtures the percentage of HmCn increases.
		x	-	At low dosage (*economic dosage λe* = 1.05-1.15) fuel consumption decreases, burns are complete. The minimum amount of carbon monoxide is obtained for λ = 0.95. When burning lean mixtures the percentage of HmCn decreases.
	Ignition advance	x	-	At optimum ignition advance when the engine reaches maximum temperature and pressure, the HmCn level drops.
			x	With an exaggerated reduction in ignition advance, it reduces engine power, increases fuel consumption and boosts HmCn production.
	Ambient temperature	-	x	The operation of heat engines in a high-temperature environment influences the initial temperature rise of the combustion process, leading to a detonation combustion and the release of HmCn into the atmosphere. The operating conditions of heat engines at elevated temperatures behave identically to CO emissions.
	Working speed of the heat engine	x	-	At high engine speeds, the intake velocity increases and the flow turbulence in the intake manifold increases. A high engine speed decreases the duration of combustion in the cylinders, reduces the pressure regime that occurs in front of the combustion front and reduces the tendency for detonation. The consequence of this phenomenon is a reduction in HmCn.
	Engine working load	-	x	At decreases in workload, thermal engines operate at overall engine cycle temperatures which also tend to decrease, generating variations in HmCn.
	Engine thermal regime	-	x	Increasing the thermal regime increases the heating of the part of the fuel mixture in front of the combustion front. Under these conditions the possibility of fuel combustion in the cylinders with detonation increases. If secondary combustion is favoured, conditions arise that generate and slightly increase HmCn emissions.
	Lubrication and wear condition of the piston-seals-cylinder assembly	-	x	Wear on the piston-cylinder seal assembly causes insufficient scraping of the lubricant film (engine oil) that ensures lubrication. As a result, a quantity of lubricant remains unremoved from the inner surface of the cylinder and is burned in the combustion chamber. The burning of the lubricant results in scale which is deposited on the piston head and combustion chamber walls. The scale ignites and causes auto-ignition, which in turn generates HmCn. To prevent the formation of scale on combustion chamber components, detergent-type additives with dissolving and cleaning properties are introduced into petrol.
	Nature of fuel	-	x	The nature of the fuel has a direct influence on the initial and final phase of the combustion that takes place in the engine cylinders. A petrol with a low octane number (Co) creates detonation (formation of ignition nuclei in front of the combustion front) and this results in incomplete fuel combustion and the release of unburned petrol, i.e. HmCn, into the atmosphere.
	Reduced amount of O_2 (air) in engine cylinders	-	x	Due to the lack of oxygen (air) in the combustion chamber, there is poor atomisation of the fuel and the flame is slowed down, the combustion front does not extend and cold-faceplate reactions occur. The phenomenon is also found in CO production. The engine releases unburned or incompletely burned HmCn-rich fuel into the atmosphere.
	Reduced amount of O2 (air) in engine cylinders	-	x	After starting the engine in the morning, or after a long rest, hydrocarbons (HmCn) are produced until the optimal thermal operating regime is reached. The large quantity of hydrocarbons released into the atmosphere by engines in this context is due to the lack of combustion or incomplete combustion of fuels

Name of chemical noxious substances	Cause of occurrence	Mode of manifestation on the noxious		Explanations, observations, comments
		Decrease	Increase	
				in the cylinders, the mixture being enriched. The presence of HmCn in the exhaust gas is due to the heterogeneous mixture of the stoichiometric air-gasoline ratio. In the vicinity of the cylinder walls, the cylinder head and the piston, in the so-called "re-enrichment zones", the combustion flame is extinguished and the chain of reactions taking place in the cylinders is interrupted. The fuel burns incompletely and aldehydes are formed. Aldehydes are organic compounds containing an aldehyde group (CH_3, C_6H_5). They are formed at idling and low loads when the temperature is low.
	Engine operation at idle and low loads	-	x	As in the previous case (cold engine effect), aldehydes are formed. Exhaust gases contain more than 200 types of HmCn, classified into aliphatic hydrocarbons (closed or open chain) and benzene (aromatic ring).
	Flue gas recirculation	-	x	By recirculating the hot exhaust gases using the exhaust gas recirculation circuit in the engine's lower crankcase (EGR - Exhaust Gas Recirculation - valve circuit), an increase in the temperature of the engine fluid in the intake manifold was created, which resulted in a reduction of the flameout phenomenon. This phenomenon generates excess HmCn production.
	Pressure/ depression in the intake manifold	-	x	At high depressions (low load), flame extinction occurs in the gas mass; At low depressions (high load), flame extinction occurs at the wall (near the cylinder wall of the mould); Both cases produce the appearance of HmCn.
Nitrogen oxides NO [ppm]	**A. Construction factors of heat engines**			
	Change in simultaneous valve opening time Δαds	x	-	It is an efficient method to increase the amount of waste gas required to recirculate through the EGR valve circuit, reducing NOx. This method can also return the amount of hydrocarbons exhausted at the end of the engine's thermal engine time 4, the exhaust, back into the engine cylinders from the exhaust manifold by the reverse flow process.
	Using the Atkinson principle for air intake into engine cylinders	x	-	The principle brings the same benefits, substantially reducing NOx emissions. It is explained in detail under CO_2 emissions.
	B. Factors related to vehicle operation			
	Air-fuel dosage	-	x	At low dosing (*economic dosing* λe = 1.05-1.15), fuel consumption decreases and burns are complete. At lean burn the burns are incomplete and NOx increases to a certain value, after which the amount starts to decrease again.
	Ignition advance	x	-	At optimum ignition advance when the engine reaches maximum temperature and pressure, the amount of NOx removed by the combustion gases decreases.
			x	Excessively low ignition advance reduces engine power and increases fuel consumption, boosting NOx production.
	Working speed of the heat engine	-	x	At high engine speeds between maximum torque and maximum power, NOx emissions increase.
	Engine working load	x	-	At decreases in workload thermal engines operate at overall engine cycle temperatures which also tend to decrease, generating decreases in NOx.
	Engine thermal regime	-	x	Increasing the thermal regime increases the heating of the part of the fuel mixture in front of the combustion front. Under these conditions, the possibility of fuel combustion in the cylinders with detonation increases, so secondary combustion is favoured and NOx emissions increase slightly.

Name of chemical noxious substances	Cause of occurrence	Mode of manifestation on the noxious		Explanations, observations, comments
		Decrease	Increase	
	Thermal regime and high pressure in thermal engine cylinders	-	x	At high pressures and temperatures nitrogen reacts actively with oxygen. In the flue gas released from thermal engines into the atmosphere, about 90% of the total NOx is NOx (Nitrogen Oxide). NOx is actually made up of two components: nitrous oxide (NO) and nitrogen dioxide (NO_2). NO_2 is found in the exhaust gas in a proportion of 1/10 - 1/20. Both together are represented by the term NUx (NOx). They are a chemically reacting set of gases made up of varying amounts of nitrogen and oxygen molecules. Nitrous oxide (NOx) meets oxygen (O_2) in the vehicle exhaust pipe at the end of compression, combines with it and forms nitrogen dioxide (NO_2). When the temperature in the combustion chamber of the thermal engine rises in the range [2,500-2,700˚K], the reaction rate increases by 2.6 times, which leads to an increase in the amount of nitrogen oxide (NOx). Lowering the temperature in the combustion chamber is usually done by introducing an inert gas collected through the EGR valve (valve) circuit in the lower crankcase of the engine, which is reintroduced into the cylinders through the intake manifold. If the combustion flame temperature falls in the range [2,500-2,300˚K], the reaction speed decreases 8-fold, substantially reducing the amount of NOx released into the atmosphere.
	Temperature, reaction time, location and amount of oxygen	-	x	Where and when the flue gases are formed is very important. NOx is formed as a result of a successive chemical reaction, called the Zeldovici mechanism. The amount of oxygen in the cylinder during the evolution of the combustion flame is of primary importance. It develops the Zeldovici mechanism, evaluated by the dosage coefficient λ. The Zeldovich mechanism is based on chemical reactions of nitrogen with oxygen, which are as follows: 1) $O+N_2=>NO+N$; 2) $NO+N=>O+N_2$; 3) $O_2+N=>NO+O$; 4) $NO+O=>N+O_2$. From the analysis of the four chemical reactions it follows that reactions 1 and 3 are NO generating. It is known that the amount of atomic O_2 in the cylinders of heat engines is 100 or even 1,000 times higher than that of atomic nitrogen. This causes reaction 1 to initiate the sequence of reactions. Reactions 2 and 4 are NO decomposition reactions and take place at low temperatures with a low burning rate. It is found that the combustion gases formed at the start of combustion, as well as the combustion gases formed in the vicinity of the spark plug, produce excess NOx.

The factors influencing the emission of chemical pollutants from thermal engines in road vehicles presented in table 1 have been identified by the authors, based on the literature and experience gained during years of professional activity in the automotive and motor transport sector.

5. The state of global environmental carbon dioxide (CO_2) pollution

Carbon dioxide is the main noxious gas responsible, in addition to the other gases from the combustion of fossil fuels in internal combustion engines of road vehicles that have been described above, for contributing substantially to the greenhouse effect. Figure 7 shows the evolution of continental CO_2 emissions over the period 1750-2023 and figure 8 shows the evolution of global CO_2 emissions over the period 1750-2023 for the world's major industrial powers (group of 7 world powers-G7).

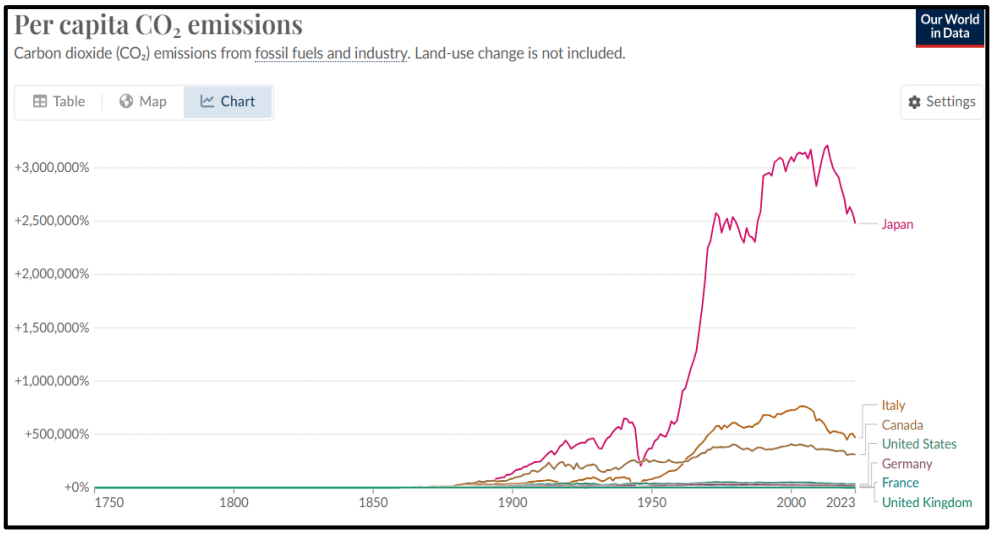

Figure 8. The evolution of CO_2 emissions in the period 1750-2022, for the great industrial poweres of the world (group of 7 world powers-G7) [9].

It is therefore a natural by-product of human activities (natural anthropogenic product of human or plant respiration, decay of organic matter, burning of fossil fuels or volcanic eruptions). It is often used as a yardstick and accounts for 65% of total greenhouse gas emissions in the earth's atmosphere, making it the most abundant.

The carbon dioxide (CO_2) emission values shown in the two figures come from fossil fuel combustion in the transport industry and from industrial activities. A CO_2 molecule has a lifespan of 300 to 1,000 years. More than 50 billion tonnes of CO_2 are released into nature every year from the transport industry and power generation, accounting for about 1/3 of total annual CO_2 emissions.

From the data researched, it was found that the level of environmental pollution with carbon dioxide and other harmful gases in the world has continued to increase. In this field, more than 200 scientific papers have been published in international journals dealing with CO_2 emissions from various sources [7].

Transport, as a branch of the world's industries, emits huge amounts of pollutants into the atmosphere, which attract and trap heat. In this context, if projected for the coming decades, it is argued that the demands on human mobility are expected to increase worldwide because the global population is growing, incomes are rising, living standards are rising, people's appetite for travel is growing and the car is becoming their number one favourite, becoming more and more indispensable to their transport needs [8].

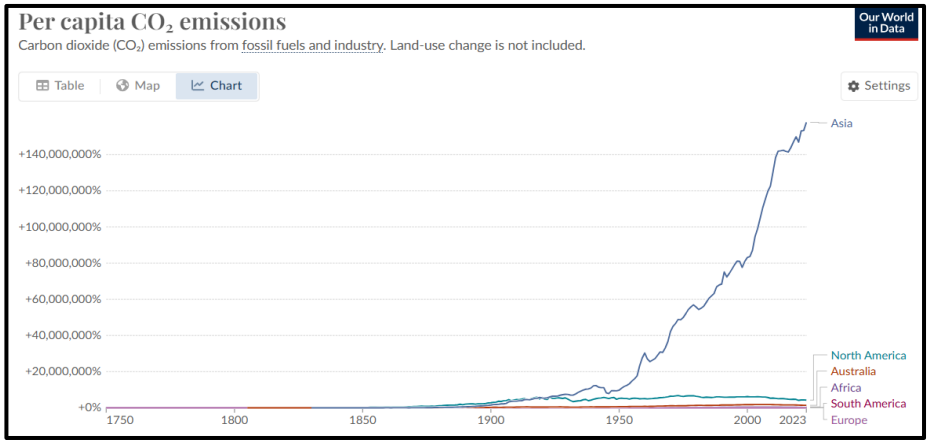

Figure 7. The evolution of CO_2 emissions at the continental level in the period 1750-2023 [9].

6. Conclusions

The fundamental element that ensures the sustainability of change and is the solution to all road transport problems is innovation and technology. Current trends in the sustainable and sustainable development of this sector are the development of electric and hybrid vehicles, which will gradually replace combustion engine vehicles. Hybrid vehicles are the intermediary between thermal and electric vehicles. At present, the electric vehicle is the most efficient and viable replacement for the internal combustion engine vehicle. A sustainable and durable future of the road transport system cannot be ensured unless all sources of environmental pollution are limited or even eliminated.

The classic car has reached its peak - meaning that decline is now on the way - while the electric car is winning the competition. More and more countries are banning the use of polluting cars. The imposition of ever higher taxes and charges for the use of such vehicles, the banning of low-pollution diesel vehicles (Euro 1-3) from certain areas of major European cities is not a random phenomenon, but an increasingly consistent reality. This is driving the citizens of those cities to move towards electromobility.

Mankind urgently needs to decarbonise its transport systems. Undeniably, it is very difficult to replace a country's entire fleet with new, clean, environmentally friendly cars. The economic and financial effort is enormous, but it can be done gradually and in stages.

More and more car manufacturers are phasing out diesel engines and concentrating on petrol, hybrid and electric engines. Today every car brand in the world produces and sells at least one model with a hybrid or electric engine.

The hybrid car is the bridge, the bridge, the interface between the conventional and the electric vehicle. It is now a temporarily viable alternative that mankind has found to the classic combustion engine car. The internal combustion engine will soon disappear, due to environmental pollution and the depletion of fossil fuel reserves. The electric engine is coming on fast and furious and, alongside other types of environmentally friendly engines (e.g. hydrogen - fuel cells), will be the alternative for future car propulsion. Clean engines will be the backbone of sustainable and sustainable development of the road transport system.

It is felt that the authorities in the European countries must legislate to compel urban and interurban public transport organisations, as well as freight and passenger transport operators, to renew their fleets with new, modern, environmentally friendly vehicles, while at the same time taking measures to decommission and scrap old, polluting, physically and morally worn-out cars. To this end, it is necessary to tighten up environmental legislation on pollutants from the combustion engines of motor vehicles.

Until fossil fuels are exhausted and mankind has completely switched over to electromobility, it is very important to improve combustion processes and to design more efficient, high-performance catalytic converters (catalytic converters) for the use of cars with thermal engines in order to reduce chemical pollution as much as possible.

It is also necessary to maintain or increase the value of eco-bonuses to the general public for the purchase of environmentally friendly vehicles, while eliminating the incentives offered for the purchase of internal combustion engine vehicles.

Efforts to popularise and educate the population in the field of electromobility must be stepped up. In order to make electric vehicles as attractive as possible to users, the authorities must increase the number of facilities for access to and use of hybrid/electric vehicles (e.g. dedicated and free parking spaces, free or cheap electricity for charging, reduced or zero tax, dedicated lanes, free and easy access to certain areas of cities, charging stations in car parks at home, extension of charging stations on all categories of roads, reduction of charging times, maintenance of advantageous eco-bonuses for customers when purchasing a new electric car, etc).

There is also a need to keep electricity prices low, gradually replace fossil liquid fuels used in conventional engines with environmentally friendly liquid fuels (biofuels), gradually switch from carbon-based fuel stations to electricity and hydrogen filling stations, and switch to the production and use of hydrogen-powered vehicles (fuel cells).

In order to meet its current mobility needs, mankind needs to invest rapidly in the power supply infrastructure for plug-in hybrids and electric cars, increase the power of charging stations, while increasing the range of electric cars through the use of new electric battery manufacturing technologies, which will increase the storage capacity of electric energy, thus solving the problem of inactivity due to the short range of electric cars. Plug-in hybrid propulsion systems are considered to be the transitional solution to new technologies, based on the electric vehicle with a REV unit, i.e. a vehicle equipped with a heat engine driving a generator to charge the electric traction battery, without participating in the actual propulsion of the vehicle.

Lowering the purchase price and weight of electric cars is more than necessary. This can be achieved by using cheaper and lighter materials (aluminium, polymers, carbon fibre, etc.) in the manufacturing process.

In order to become truly efficient, hybrid and electric vehicles need to increase the range of their electric batteries, the traction power of their motors and the efficiency of their generator charging.

In order to increase the reliability of environmentally friendly vehicles, high quality, original spare parts and materials must be used in the maintenance process, and maintenance work must be of very high quality and carried out within the time limits set by the manufacturer. These objectives can only be achieved by reducing costs, working times and training of electromobility specialists.

All these aspects are considered to improve the social, health and environmental conditions of people, the quality of service and management in road transport and, not least, road safety, ergonomics and comfort of modern environmentally friendly means of transport.

Carbon monoxide is a dangerous gas which, when inhaled instead of oxygen, causes death by blocking haemoglobin (the compound that carries oxygen in the blood). Nitrogen oxides (NO) have similar toxic effects.

Photochemical smog is formed from hydrocarbons from unburned fuels, in combination with NOx from car exhaust, through a complex mechanism involving a series of chemical reactions catalysed by the sun's rays. Smog also contains fine water droplets formed by the oxidation of hydrocarbons, which affect visibility.

At present, electromobility is defined by certain disadvantageous technical conditions, in particular in terms of range, which means that users still prefer conventional vehicles.

Because they are silent, electric vehicles are not audible to pedestrians and can cause panic and road accidents. All electric vehicles should be fitted with sound generators.

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Welding technologies for aluminum alloy naval parts - propeller shaft guide bushing made of ALMG5

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Abstract. The article presents the welding technology of a "Guide bushing - propeller shaft" type made of AlMg5 material and the problems that arise during welding depending on the way of obtaining the product (cast or rolled) and the chemical composition. The components have thicknesses between 20 – 40 mm and their welding raises some problems related to the welding temperature and its maintenance during welding. Defects that appeared during welding, pores, cracks, breaks and others are presented. These defects occurred not due to the parameters of the welding regime but due to the way the casting was performed (gravitational and low temperature) and the presence of copper in the alloy. After checking the chemical composition, an attempt was made to remove the pores from the surface and near the surface, but without obtaining a corresponding result. The solution to this problem was to change the semi-finished product as a type of production. In conclusion, parts made by welding from cast aluminum alloys must first be carefully checked for non-destructiveness, microcracks and granulation (especially the degree of porosity) so that these factors do not become crack primers.
Keywords: *welding, aluminium, cracks, alloy casting*

Introduction

The propeller shaft guide bushing has the functional role of guiding the cardan shaft that starts from the boat engine and reaches the propellers to the outside of the ship. This subassembly works in seawater, where there is a highly corrosive environment and mechanical stresses are variable. Since the distance between the motor assembly (motor + gearbox) and the propellers is relatively large, about 8 - 12 m, one bushing or two intermediate bushings are used for guidance. The guide tube is a component part of this rotational motion transmission assembly. It is fixed mechanically and by welding with the help of stiffening and clamping wings arranged longitudinally, at 90 degrees to each other, by the hull of the vessel. Encapsulated radial bearings are fixed at its ends, see figure 1.

Because lately it has been found that the price of maintenance works on small vessels are much higher than the costs of making aluminum alloys / plastics exterior structures, the materials used outside the ship have been changed, especially those that sit / operate in the water. Steel-aluminum clad or explosion-welded materials are used (e.g. thickness 20 -10, aluminum steel). The inner structure is made of steel and the outer one is made of aluminum. In this way, a resistance structure is made of steel on the inside, without problems when welding, and on the outside a material resistant to corrosive environment.

The high-alloy steel radial bearings on the tube ends have been replaced by polymeric plastic bearings. In this way, the endurance of mechanical assemblies working in a saline environment has greatly increased.

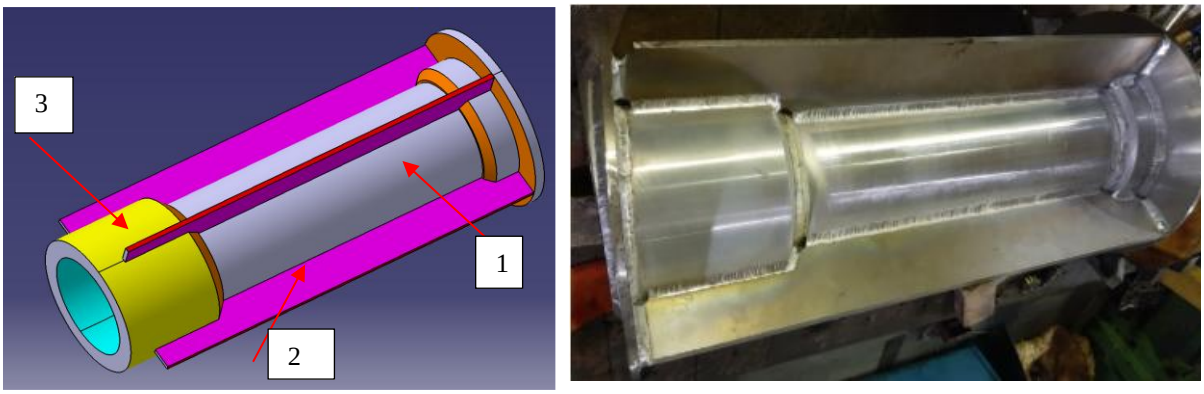
2. Material

The material from which the sealing bushing is made is an aluminum alloy (5083) and the external components are mostly also made of the same alloy.

The technical and functional characteristics of the "Propeller shaft guide tube" landmark are presented in Table 1.1.

Table 1.1. Technical-functional characteristics of "Tub de ghidare Ax elice"

Inner diameter 1	215 mm
Inner diameter 2	201 mm
Maximum outer diameter - flange	383 mm
Bearing length 1	203 mm
Bearing length 2	88 mm
Total length	901 mm
Weight	52.4 Kg



a) Drawing b) Assembled parts

Figure 1. Guide bushing:, 1) guide tube, 2) stiffening wings, 3) upper bushing.

The chemical composition of the base material is shown in Table 2.1, the mechanical properties of this aluminum alloy are shown in Table 2.2, and the physical properties in Table 2.3.

Table 2.1. Chemical composition of the base material

Al	Si	Mn	Mg	Cr	Ti	Cu	Fe	Zn
Rest	0,4	0,4 - 1	4 – 4,9	0,05 – 0,25	0,15	0,1	0,4	0,25

Table 2.2. Mechanical properties of the base material

Name	Rm	$R_{p0.2}$	KV	A_5
	N/mm^2	N/mm^2	[J]	[%]
Al - 5083	220 - 240	100-120	16	17

Where: Rm- tear strength; Rp0.2- Flow Limit; KV- Resilience; A5- elongation at break;

Aluminum is a well-known metal with a wide range of applications, from household utensils to pressure vessels, seagoing vessels, airplanes or automobiles.

There is a great diversity of aluminum alloys, depending on the main alloying groups and the way of consolidation (by plastic deformation or by heat treatments). The main groups of aluminum alloys, depending on the alloying classes are:

1) non-alloy aluminum;
2) aluminum - copper;
3) aluminum-manganese;
4) aluminum - silicon;
5) aluminum - magnesium;
6) aluminum - silicon - magnesium;
7) aluminum - zinc;
8) aluminum – lithium; other types of aluminum alloys.

Al-Mg alloys contain between 0.5 and 15 % Mg and are characterized by appreciable mechanical strength, good corrosion resistance, lower density compared to other aluminum alloys, good machinability by cutting and can be excellently polished. Corrosion resistance is diminished due to the formation of continuous precipitates on the grain boundaries of type β - Mg3Of2, which causes intergranular corrosion to occur. These precipitates occur during cold processing with high degrees of deformation or in high-alloy alloys with Mg exposed to temperatures between 120 and 2000 C. The corrosion resistance of Al-Mg alloys is influenced by the presence of copper impurities that can cause generalized corrosion, but less dangerous than localized corrosion.

Also, corrosion resistance improves in the presence of additions of chromium, manganese, zirconium, molybdenum, beryllium, silicon, stibium, zinc, cadmium and titanium. As for oxidation resistance, it can be improved by adding beryllium which favors the elimination of solid non-metallic inclusions during casting, protects the alloy well against oxidation at high temperatures and provides it with anti-sparking properties. The simultaneous introduction of beryllium, titanium and zirconium results in a substantial improvement in resilience and corrosion resistance. Aluminium forms with magnesium a compound defined as Al8Mg5 and a eutectic compound at 34.5 % Mg, with a melting temperature of 4510 C. The solubility of magnesium in aluminium is considerable, but decreases rapidly with decreasing temperature.Silicon, in the form of impurities, influences the properties of these alloys to the greatest extent, causing the mechanical characteristics to progressively decrease to values above 0.5 %. The addition of silicon in Al-Mg binary alloys allows the improvement of mechanical characteristics as a result of the formation of the Mg2Si phase which, during heat treatment, due to dispersed precipitation, causes the alloy to harden. Some elements such as nickel and zirconium are added in Al-Mg alloys to increase the recrystallization temperature, while silicon is added to increase fluidity, manganese and chromium to improve corrosion resistance and neutralize the negative effect of iron, copper to diminish the effect of intercrystalline corrosion, and zinc to improve mechanical properties and fluidity. Increase of iron content within 0.2... 0,8 % is manifested by a slight improvement in breaking strength without a significant change in elongation. The disadvantages of these alloys are related to the tendency to oxidation during the casting process, the low fluidity, the tendency to form rehashes, blows and the high tendency to form hot cracks in the welded seam. The weldability of these alloys has been improved by the addition of silicon and chromium.

The main problems in welding are:

1) hot cracking - which occurs under the conditions of strong clamping of the welded structure and the susceptibility to higher cracking of high-alloy alloys with Mg
2) the appearance of pores - in the welded seam due to the dissolution of hydrogen in the solidification process

The alloys of the 5xxx series are widely used in the production of welded pressure vessels, for which the mechanical characteristics of the welds are acceptable, without the need for heat treatment.

The use of a filler material from the 4xxx series causes the strength characteristics of the welded joint to decrease. The use of a filler metal alloyed with Si, Mn and Fe (e.g. 5183) leads to an increase in the amount of eutectic formed in the seam and a decrease in ductility.

Hot cracking occurs when slightly fusible eutectics are formed, in the end areas of the bead, during the solidification process.

The susceptibility to hot cracking of Al-Li alloys, as well as aluminum alloys in general, is related to the concentrations of copper and magnesium in the metal bath, depending on which Al-Cu-Mg eutectics can be formed. Alloys with a lot of copper and little magnesium (e.g. 2219) are weldable, as are alloys with little copper and a lot of magnesium (e.g. 5083).

If large amounts of copper and magnesium are present in the alloy at the same time, for example in high-strength aerospace alloys like 2024 or 7075, problems can arise when welding. In the present case, WIG welding at the root and completion with MIG was chosen as a welding process. Preheating temperature, between 210 – 250 0C. The filler material was wire 5183, with a diameter of 1.2. The welding was carried out in pulsed current. The pieces were degreased, positioned, shaped and then welded. During the welding, nothing appeared. The part, figure 1, has cracked cold, see the table with figure 2.

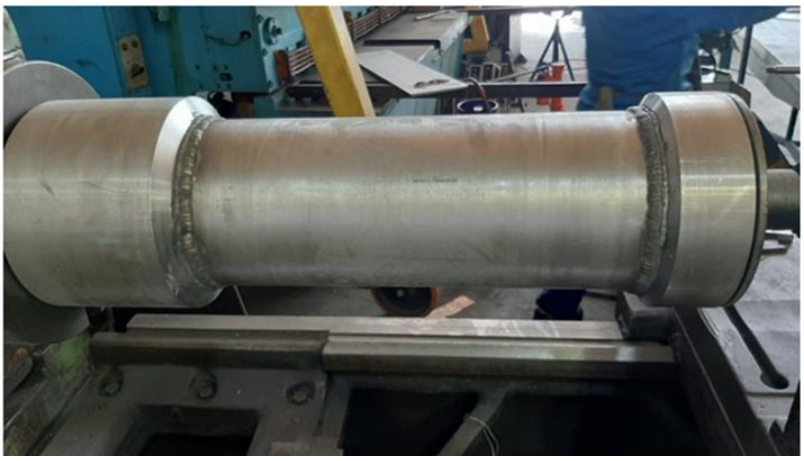


Figure 1.

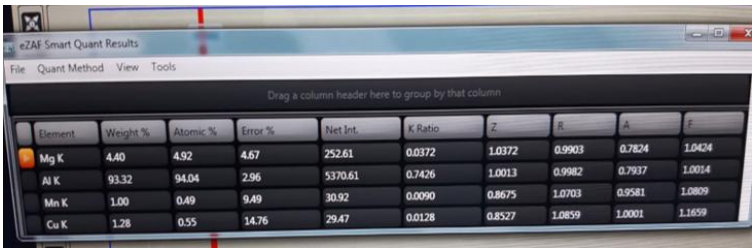
Table 2. Images of the cracked part

a b c d

e f g h

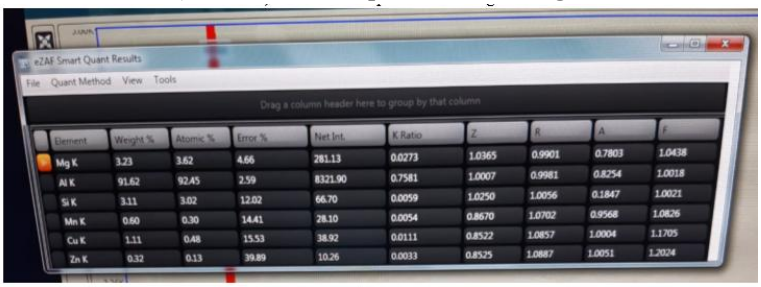
The cracks started from the ZIT and reached the root. The cracked layers were removed on the lathe and a NDT-OV and LP control was applied. The presence of many cracks and pores was found. As a result, a check of the chemical composition and granulation was also carried out.

The values of the chemical composition of each round piece (upper bushing, lower bushing and tube and) are centralised in Table 2. The images of the chemical compositions can be found in Figure 4.



a) Chemical composition Bushing 1

b) Chemical composition Bushing 2



c) Chemical composition of the connecting pipe

Figure 4 – Images of the chemical composition

In the base material, chemical elements were found that should not have been in the composition of the alloy. In the centralizing table, the values that come out of the standard are written in red. The chemical element that causes the cracking is copper. According to the standard, the percentage had to be up to 0.1%. In this case, all 3 components have values of 10 – 15 times more, 1.11 – 1.6%.

Table 2. Chemical composition of the parts

	Al	Si	Mn	Mg	Cr	Ti	Cu	Fe	Zn
5083	Rest	0,4	0,4 - 1	4 – 4,9	0,05 – 0,25	0,15	0,1	0,4	0,25
Bucsa 1	93.32	-	1	4.4	-	-	**1.28**	-	-
Bucșa 2	90.07	**1.74**	1.45	**5.14**	-	-	**1.6**	-	-
Teavă	91.62	**3.11**	0.6	**3.23**	-	-	**1.11**	-	0.32

The percentage values of copper are very high, and values above 0.5% increase the tendency to crack.

On the other hand, having different chemical compositions, we have different structure, granulation, different thermal conductivity, different coefficient of thermal expansion. All this leads to the formation / propagation of cracks much more easily.

From the results of the non-destructive testing, OV + LP, we observed a large grain size and a very high porosity, see figure 5. The high porosity came from the way of obtaining the semi-finished product – casting. Aluminum melts at about 670^0C. By gravity casting, the blank is quite porous. If magnesium is added, the alloy becomes much more viscous and the porosity increases. To reduce porosity, Al-Mg alloys are poured at much higher temperatures, at least 200^0C above the melting temperature of aluminium, and the cooling time is much longer. The cooling time is longer to favor the evacuation of air bubbles from the alloy.

In the images below you can see the porous structure of the blank.

a b c

Figure 5

3. Welding technology

In order to clog the pores resulting from the casting, the bushings were loaded by welding with the WIG process. Some of the pores were still clogged, but being a structure with many pores, the result was not the desired one, see figure 6.

a b

Figure 6

In this case, the cracking of the parts had 2 main causes:
- the chemical composition, different and with a lot of copper, above the allowed limit of 10 – 15 times;
- Casting temperature, solidification time and casting method (gravitational)

For the realization of the piece, the decision was made that all the pieces (semi-finished products) should be laminated and not cast.

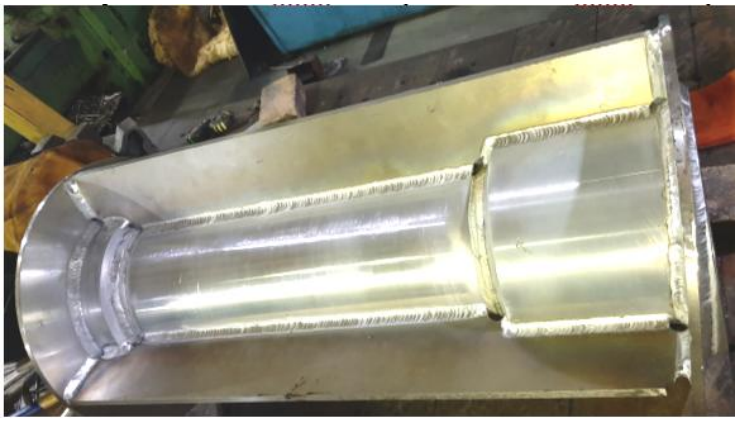
The welding technology involves the use of two welding processes, WIG and MIG, in pulsed current. The preheating temperature was at a value of 200^0C. Temperature between layers 210 – 250^0C. The welding was done on a 'hot bed' with a pipe-type multiflame burner, inserted inside the pipe.

The blanks were pre-milled with the help of the WIG process. The first layer deposited was with WIG, the following with MIG. The values are given in the table below:

	Is [A]	Us [V]	Frequency [Hz]	Ø electrode/wire diameter	Gas flow rate	Waveform
WIG	230 – 250	23 - 24	50 - 60	3.2	12l/min	Rectangular
MIG	210	32	-	1.2	15 l/min	Superpulse

The images with different stages of the assembly are below, figure 7

a) rolled semi-finished products b) Haftuit assembly 1 c) Haftuit assembly 2



d) the welded assembly
Figure 7 Guide bushing

4. Conclusions:

1) In chemically demanding materials, high-alloy steels, non-ferrous Al or Cu bases, the chemical composition plays a very important role in ensuring the quality of the finished product. That is why these types of materials must be checked very carefully, regardless of the type of quality certificate;

2) producers of semi-finished products, castings, extruded, laminates, etc., in order to be competitive in terms of price, are most of the time below the lower limit of the standard;

3) Depending on the desired application, the importer/distributor of the base material can offer certain batches of product, with different chemical compositions and of course with different mechanical properties;

4) The technological engineer must know these quality variations and, depending on the application, impose the requirements for mechanical properties, structure, etc., and be able to ask for a real price;

5) The choice of a technology for manufacturing a semi-finished product (molding, plastic deformation) must be made in accordance with the destination of that semi-finished product, otherwise, the discontinuities that may occur when making the semi-finished product will turn into defects in the finished part

6) The quality welding of aluminum alloys can be done only with specialized equipment that has integrated software for them (synergistic lines, multiple ways of adjusting the waveform, frequency, superpulse, etc.);

7) The following must be ensured: logistics, machinery, equipment, tools specific to mechanical processing, consumable materials in order to obtain a quality weld;

8) The deformations after welding are large and the welding order must be ensured. The workpiece must be measured several times during welding in order to be able to compensate for the deformations that have occurred by welding;

9) Parts with many pores are susceptible to hot cracking, because during cooling, after welding, the pores become crack primers.

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The Influence of Execution Technology on the Precision Turning of Mechanical Parts: Case Study on Manufacturing a Complex Component Using a Three-Axis CNC Lathe with Active Tooling

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Abstract. This paper investigates the impact of execution technology on the turning process of precision mechanical parts, focusing on a case study involving the manufacturing of a complex component using a three-axis CNC lathe with active tooling. Precision turning plays a critical role in the production of parts with strict tolerances and intricate geometries, commonly used in industries such as aerospace and automotive. The study explores the advantages of modern CNC lathes, emphasizing their ability to achieve high accuracy and reduced production times compared to traditional methods. Additionally, the use of active tooling is analysed, highlighting its role in real-time adjustment of cutting parameters, such as cutting speed, feed rate, and depth of cut, which improves the overall efficiency and quality of the turning process. The case study demonstrates the practical application of these technologies in the production of a complex part, with attention to setup, programming, and the impact of real-time adjustments. Results indicate that the CNC lathe with active tooling significantly enhances precision, reduces errors, and allows for faster production cycles. This research underscores the importance of integrating advanced manufacturing technologies in the production of high-precision parts, offering insights into future developments and optimizations for the turning process.
Keywords: CNC lathes, mechanical parts, production, cutting parameters, CAD software

Introduction

The turning process plays a fundamental role in the manufacturing of precision mechanical parts, particularly in industries such as aerospace, automotive, and medical engineering, where high accuracy and strict tolerances are required. Over time, turning technology has evolved significantly, transitioning from conventional lathes to advanced CNC (Computer Numerical Control) systems. These modern machines have revolutionized machining processes by enhancing precision, repeatability, and efficiency while reducing production time and material waste. Among the latest advancements in turning technology, three-axis CNC lathes equipped with active tooling have emerged as a powerful solution for machining complex components [1,2].

Active tooling, also known as live tooling, allows for real-time adjustments to machining parameters such as cutting speed, feed rate, and tool positioning. This capability significantly enhances the flexibility of CNC lathes, making it possible to perform multiple machining operations—including milling and drilling—without the need for repositioning the workpiece. The integration of active

tooling in CNC turning operations leads to superior surface finishes, increased dimensional accuracy, and improved productivity.

This paper explores the influence of execution technology on the turning process of precision mechanical parts, focusing on a case study involving the manufacturing of a complex component using a three-axis CNC lathe with active tooling. By analysing various aspects of the machining process, including tool selection, process parameters, and the impact of real-time adjustments, this study aims to provide a comprehensive understanding of how modern CNC systems contribute to optimizing manufacturing efficiency and ensuring high-quality production.

Traditionally, turning operations were performed on manually controlled lathes, where skilled machinists were responsible for adjusting cutting parameters based on experience and intuition. While these conventional methods allowed for a degree of flexibility, they were also prone to human error, inconsistency, and limitations in terms of production speed and complexity. The introduction of CNC technology marked a major breakthrough, allowing manufacturers to automate and standardize machining processes with precise control over cutting conditions [3,4].

CNC lathes use pre-programmed instructions to execute complex machining operations with minimal operator intervention. This automation eliminates the variability associated with manual turning, ensuring uniformity and repeatability in part production. Furthermore, CNC technology enables the efficient machining of intricate geometries, which would be challenging or impossible to achieve using conventional methods.

One of the key advantages of CNC turning is its ability to optimize machining parameters dynamically. Unlike traditional lathes, which require manual adjustments for speed, feed rate, and depth of cut, CNC machines can be programmed to make real-time modifications based on cutting conditions and material properties. This adaptability results in improved surface quality, reduced tool wear, and enhanced overall efficiency.

A significant advancement in CNC turning technology is the incorporation of active tooling, which extends the capabilities of standard CNC lathes by enabling additional machining operations beyond simple turning. Active tooling allows for live adjustments of tool orientation and cutting speed, making it possible to perform milling, drilling, and tapping operations in the same setup. This multifunctionality eliminates the need for multiple machine setups, reducing production time and increasing overall efficiency.

The integration of active tooling also enhances precision by ensuring optimal cutting conditions throughout the machining process. For instance, in traditional CNC turning, fixed cutting tools operate under predefined parameters that may not always be ideal for varying material conditions. Active tooling, on the other hand, can adapt dynamically, adjusting parameters in real time to maintain consistent cutting performance. This results in higher accuracy, reduced tool wear, and improved surface finishes [5]. Moreover, active tooling facilitates the machining of complex components with intricate geometries, such as parts with internal grooves, asymmetrical features, or multi-axis profiles. By allowing a single CNC lathe to perform multiple operations, manufacturers can achieve greater design flexibility and reduce the need for secondary machining processes.

This study aims to investigate the impact of execution technology—specifically, the use of a three-axis CNC lathe with active tooling—on the precision turning of mechanical parts. Through a detailed case study, the research will analyse various factors influencing machining performance, including tool selection, cutting parameters, and the role of real-time adjustments in optimizing efficiency. The study will also compare CNC-based machining with traditional turning methods, highlighting the advantages of advanced CNC technology in terms of precision, productivity, and process reliability [6,7].

By examining the practical application of CNC turning with active tooling, this research seeks to provide valuable insights into best practices for high-precision manufacturing. The findings will contribute to the broader understanding of how modern execution technologies can enhance the quality and efficiency of machining processes, paving the way for further advancements in precision engineering.

Methodology

The methodological approach of this study focuses on analyzing the impact of execution technology on the turning process of precision mechanical parts, particularly in the case of manufacturing a complex component using a three-axis CNC lathe with active tooling. This research examines both the machining process and the influence of technological parameters on the final product's accuracy, efficiency, and overall quality.

To conduct the study, a state-of-the-art CNC lathe with three-axis control and active tooling was selected. This machine offers advanced capabilities, allowing for high precision and efficiency in machining complex components. The cutting tools used include a combination of fixed and active tools, such as carbide inserts for turning, end mills for milling operations, and drills for hole-making.

A high-precision chuck was chosen for clamping the workpiece, ensuring stability and minimizing vibrations during machining. The machining process was programmed using specialized CAD/CAM software, which facilitated accurate toolpath generation and optimized machining parameters.

The workpiece selected for this study was designed to reflect the complexity of industrial applications, featuring intricate geometries and requiring high precision. Stainless steel (AISI 304) was chosen as the material due to its widespread use in aerospace and automotive industries, as well as its machining challenges, which make it a relevant test subject. The component's design included cylindrical and prismatic features, internal and external threading, high-tolerance surface finishes, and milled slots. The CAD software was used to develop the design, followed by toolpath generation in CAM software to ensure precise machining sequences.

The machining process was carried out in several stages, starting with rough turning, which involved removing excess material to form the initial shape of the workpiece. Fine turning followed, refining the dimensions to meet strict tolerance requirements. Milling operations were performed using active tooling to create slots and flat surfaces, enhancing the part’s complexity. The process continued with drilling and threading, ensuring the required internal and external features were machined accurately. Various machining parameters, such as cutting speed, feed rate, and depth of cut, were optimized throughout these stages to improve efficiency and minimize tool wear.

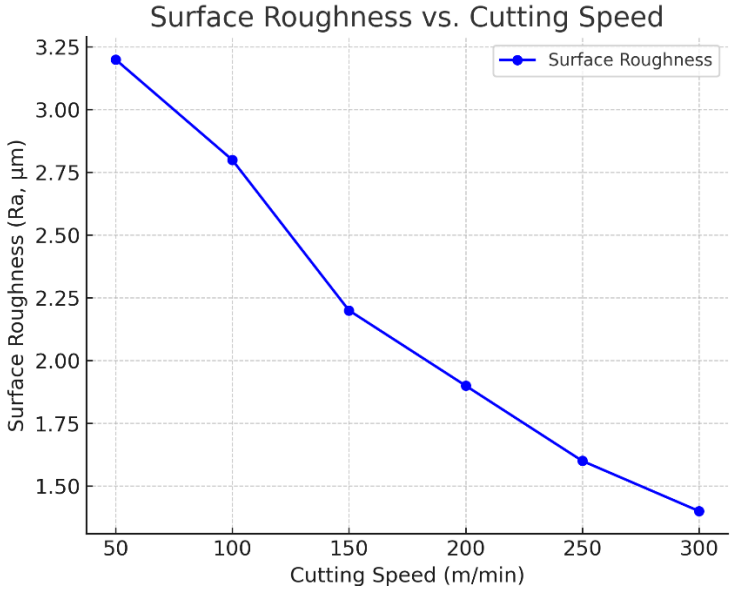

Figure 1. Surface roughness vs. cutting speed

The first graph shows the variation of surface roughness depending on the cutting speed, highlighting that a higher speed reduces roughness, leading to a better-quality machined surface.

The integration of active tooling in CNC turning significantly influences machining performance. One of the key advantages is the ability to make real-time adjustments to cutting parameters, ensuring optimal conditions throughout the machining process. Unlike traditional fixed tools, active tooling provides multifunctionality, allowing for turning, milling, and drilling operations in a single setup. This reduces production time while increasing efficiency. Moreover, active tooling enhances precision by minimizing dimensional deviations and improving surface finish quality, making it an essential technology for manufacturing high-accuracy components.

To further analyze the impact of execution technology, a case study was conducted, focusing on the manufacturing of a precision mechanical part using a three-axis CNC lathe with active tooling. The workpiece was securely clamped in the lathe chuck to ensure stability, followed by rough turning operations where approximately 70% of the material was removed to shape the external contours. Fine turning refined the dimensions, ensuring compliance with the tolerance limits. Milling operations were then performed, utilizing active tooling to create complex geometries such as slots and flat surfaces.

Drilling and threading were executed with high precision, facilitated by real-time adjustments in tool positioning and cutting speed. Upon completion of the machining process, the finished component underwent quality control through dimensional measurements and surface roughness analysis.

The evaluation of machining results focused on several critical aspects. Dimensional accuracy was assessed using high-precision coordinate measuring machines (CMM), ensuring compliance with design specifications. Surface finish quality was analyzed using profilometers, confirming that the component met the required standards. Production time efficiency was also examined, revealing that CNC turning with active tooling reduced machining time by approximately 30% compared to conventional CNC turning without active tools. Additionally, an analysis of tool wear indicated that real-time parameter adjustments helped extend tool life, reducing overall production costs.

To highlight the advantages of using a three-axis CNC lathe with active tooling, a comparative analysis was performed against traditional CNC turning. The results demonstrated significant improvements in machining time, surface finish, and precision. Traditional CNC turning required multiple setups for different operations, leading to longer production times, whereas active tooling allowed for continuous machining without repositioning the workpiece. The study also showed that surface quality was greatly enhanced due to real-time adjustments in cutting parameters, while dimensional accuracy was more consistent compared to traditional methods. Furthermore, tool wear was significantly reduced in the active tooling setup, prolonging tool life and lowering maintenance costs.

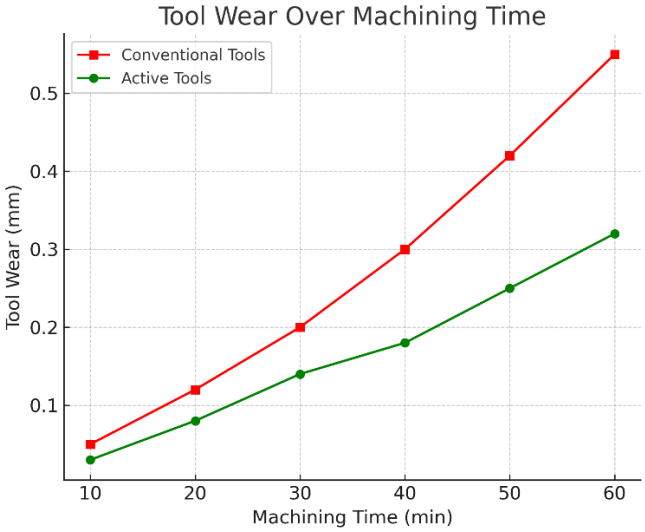

Figure 2. Tool wear over machining time

The second graph compares tool wear between conventional turning and turning with active tools, demonstrating that the use of active tools significantly reduces wear over time, which helps extend tool life and optimize production costs.

The findings of this study confirm that CNC turning with active tooling offers substantial benefits in terms of precision, efficiency, and flexibility. The ability to perform multiple machining operations in a single setup eliminates the need for repositioning, reducing overall cycle time while maintaining high accuracy. This technology is particularly advantageous for industries that require complex and high-precision components, such as aerospace and medical engineering. The implementation of real-time parameter adjustments leads to better surface finishes, minimized errors, and optimized machining efficiency.

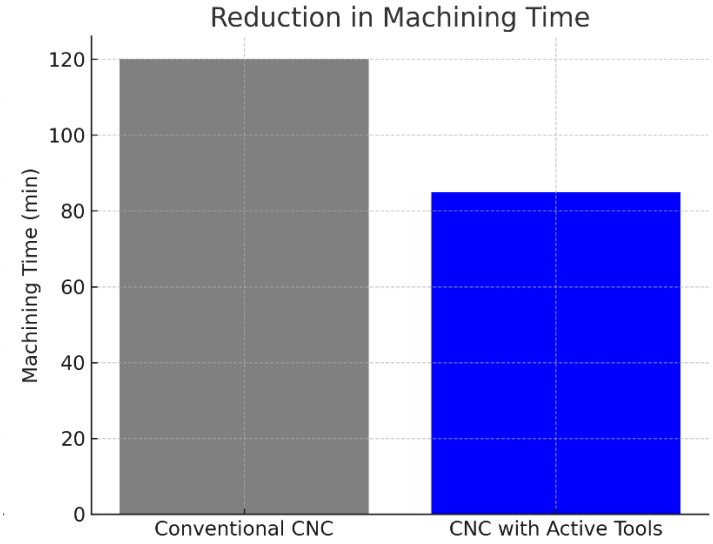

Figure 3. Reduction in machining time

The third picture illustrates the reduction in machining time using active tools, showing that this technology allows for a significant decrease in total processing time compared to the conventional method.

Conclusion

As a result of the research conducted on the influence of execution technology on the turning of fine mechanical parts, several key aspects regarding the efficiency and quality of the machining process on a three-axis CNC lathe using active tools were highlighted. The case study demonstrated that the application of advanced technologies can significantly improve both dimensional accuracy and the durability of tools, as well as the efficiency of the production process.

One of the most important aspects identified was the impact of cutting speed on surface roughness. The results showed that an increase in cutting speed leads to a reduction in surface roughness, which improves the final quality of the part. This conclusion is essential for choosing optimal machining parameters, allowing manufacturers to optimize the process based on the specific requirements of the final product.

Furthermore, the comparative study on tool wear between conventional machining and machining with active tools showed a significant difference. The use of active tools led to a reduction in tool wear, resulting in a longer tool life and a decrease in production costs. This observation is particularly relevant for the fine mechanical industry, where precision and operating costs are determining factors in market competitiveness.

Another important benefit of using active tools was the reduction in machining time. By applying this technology, a significant decrease in the total execution time was observed compared to conventional methods. This reduction not only improves productivity but also contributes to better resource management and an increase in the overall efficiency of the manufacturing process.

In addition, the implementation of CNC lathe machining with three axes and active tools allows for greater flexibility in the production of complex parts. This flexibility is crucial in the fine mechanical field, where precision requirements are high, and adaptability to different geometries and materials is essential. This aspect provides the opportunity to expand the range of parts that can be produced with superior quality and reduced execution time.

In conclusion, the research demonstrated that adopting active tool machining technology on a three-axis CNC lathe brings multiple advantages in the turning of fine mechanical parts. Reducing surface roughness, minimizing tool wear, and shortening machining time are essential factors that contribute to increasing the efficiency and competitiveness of the manufacturing process. These results underline the importance of integrating advanced technologies in the mechanical processing industry, having a direct impact on the quality of final products and production costs. In the future, the development and optimization of these technologies could lead to further improvements in the field of fine mechanics, opening up new opportunities for innovation and increased performance in the manufacturing process.

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Study regarding the quality of machined surfaces from a sustainability point of view

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Abstract. Considering the competitive environment within the machining field, researchers and engineers alongside with machinists focused on increasing their productivity from an economically point of view, but nowadays, lining up with the current challenges, the personnel within the domain focused on developing tools and machining strategies as friendly as possible with the environment. Through having a rational usage of resources, maintaining the imposed technical condition, as desired, it can be said that the process has a good level of sustainability within it.
Keywords: *Sustainability, CNC milling, machined surface quality*

1. Introduction

From an engineering point of view, there was always a desiderate regarding the improvement within the technological process, mainly in increasing the working capacity as much as possible. Although, nowadays, taking into consideration the changing environment, regarding all domains, the worldwide trend was to lower the usage of resources, therefore, being more sustainable. Obviously, there are specific drawbacks within the technical field, since there are specific imposed conditions that must be satisfied within the processes, confronting therefore a great challenge: decreasing the usage of resources while maintaining the same quality and characteristics of the specific product. [1], [2].

Within the machining field, there was always a high competitivity between the tool manufacturers, CNC machines manufacturers, CAM software developers and post-processors dealers, but through this paper the focus was laid upon the quality of the obtained machined surface based on the chip evacuation and lubrication method. [1], [3-8].

As is known, the usage of emulsions within the machining process has great advantages regarding the machinability of the part, chip evacuation, lubrication and avoiding premature tool degradation, but also comes with specific further issues regarding the recycling process of it. [1], [5], [9-11].

2. Materials and methods

For the developed research it was taken into consideration the machining of a □20mm bore through circular milling, with a depth of 10mm, having the following elements of the technological system:

- Machined raw material: 65x64x20mm S235JR steel block
- Machine tool: DMC 70V (3 axes CNC milling machine)
- Cutting tool: RIME □10mm end mill (z=3, L=80mm, L'=36mm)
- Tool holder: SK-40 end mill holder
- Clamping device: Hydraulic Rohm 125 LV vice.

The elements of the technological system are presented in figures 1 a-e.

Figure 1a. Semifinished part

Figure 1b. CNC machine

Figure 1c. Cutting tool

Figure 1d. Tool holder

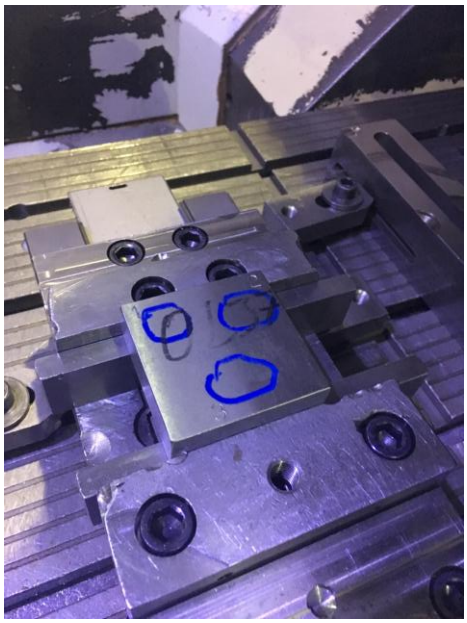

Figure 1e. Clamping device

By using the same technological system elements and manufacturing conditions (feeds and speeds), as given by the tool manufacturer: S=2500rpm, F=900mm/min and Ap=0.15mm, three variants were established for the bore manufacturing:

- V1 – machining while using cooling and lubrication liquid (emulsion)
- V2 – airflow chip evacuation machining
- V3 – dry machining

For each variant of the manufacturing process were elaborated 9 tests, summing up to 27 experiments. Obviously, for every single experiment, a new cutting tool was used.

The result after the machining of the three bore variants is presented in figure 2, carrying on to the quality control of them, taking into consideration the obtained roughness and dimensions alongside with the inspection of the tool's cutting edge, focusing on the usage of it.

Figure 2. Obtained results after the manufacturing under the three given conditions

Firstly, by using the ECO210 Microset inspection machine, it was managed the determine the usage of the tools for each machining variant. In figure 3 the interface of the machine with the tool used for the first variant result and the cutting edge under microscope are presented and within table 1 the data is centralized for each variant, consisting in the mean values for each manufacturing type.

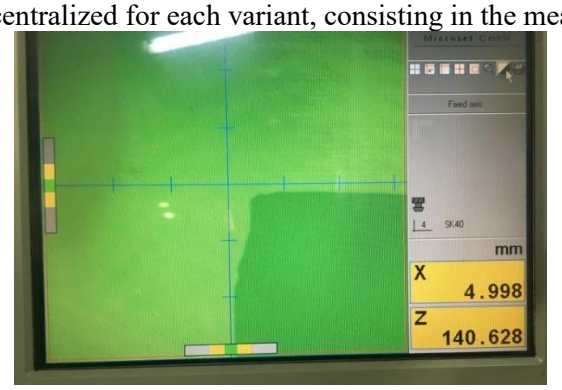

Figure 3a. Dimensional tool usage

Figure 3b. Tool usage under microscope

Table 1. Tool usage results

Machining variant	Mean values of tool dimensions (radius) [mm]	Mean values of the tool usage (radius) [mm]
V1	4.997	-0.003
V2	4.996	-0.004
V3	4.992	-0.008

Furthermore, each machining result has been dimensional measured using a bore 3-point measuring instrument alongside with their roughness, data being centralized within table 2.

Table 2. Obtained roughness and dimensions

Machining variant	Mean roughness values, Ra [µm]	Mean dimensional values [mm]
V1	7.739	∅20.06
V2	6.115	∅20.05
V3	9.767	∅20.07

By synthetizing the results obtained, it is remarkable that from a quality point of view, machining by using airflow as a mean of tool cooling and chip evacuation, has been the optimal approach, considering the most precise dimensional value (Ø20.05mm) and the lowest roughness (6.115µm). Indeed, regarding the tool usage, through both the dimensional analysis and the visual inspection, this variant (V2) turned out to be place second, after the machining with emulsions (V1), but the difference is quite small, being around 0.001mm on the radius.

3. Conclusions

Considering the current demand regarding the rational use of resources, due to the important climate changes and pollution resulting in the manufacturing industry and industry in general, the level of sustainability is a term more frequently used, and an indicator more frequently taken into consideration, and sometimes even imposed by the customer or specific regulations. Therefore, such a scientific study could lead to important decreases regarding the resource use, as in the presented case, in which, the best results within both of the surface quality indicators (roughness and dimensional precision) alongside with one of the lowest cutting edge usage was obtained through using the airflow tool cooling and chip evacuation. Spending time and resources for elaborating such a study regarding the most frequently used working cycles could be justified by resulting in the possibility of replacing the usage of emulsions, which leads to different environmental related issues, with other methods of removing the chips and cooling the cutting tool, more environmental-friendly, therefore, increasing the sustainability of the process.

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Chatbot task-technology fit and conversational intelligence on customer service encounter satisfaction in the Zimbabwean banking sector

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Abstract: The study explores the interactions among chatbot tasks, technology, and conversational intelligence, and their effect on customer service encounter satisfaction to improve customer gratification in the Zimbabwean banking sector. The aim of the research study is to determine the influence of chatbot task-technology on conversational intelligence characteristics and customer service encounter satisfaction in the Zimbabwean banking sector. The empirical evidence was acquired using structured questionnaires from 365 bank employees and 500 bank customers in Zimbabwe, using a concurrent nested approach. The study indicated that chatbot task and technology characteristics directly influenced chatbot task-technology fit, customer service encounter satisfaction, proactivity, and communicability. The study contributes to chatbot task-technology theory and chatbot-human interaction studies. The research shows that conversational intelligence must align with chatbot task and technology characteristics to achieve a better fit between the task and technology in the banking sector, which can help improve customer service encounter satisfaction. The study contextualizes the framework in the banking sector in Zimbabwe, and the outlined research questions may apply to other service sectors where service digitalization is occurring (i.e., health care). Additional research studies in different regions of the world might be conducted to provide cross-cultural comparability and empirical validation.
Keywords: *chatbot, technology characteristics, task-technology fit, conversational intelligence, task characteristics, service encounter satisfaction*

1. Introduction

Technology integration in various contextual dimensions into service encounters has been highly achieved through artificial intelligence (AI) and information and communication technology (ICT) advancements (DeKeyser *et al*., 2019). The migration of customers to digital platforms has prompted an increase in demand for interactivity between brands and online customers (Kurilchik, 2017). Due to the conversational nature of chatbots, their integration into messenger applications seems to be more seamless compared to social media applications. Furthermore, studies have revealed that, on average, 65% of online users do not

download new mobile applications monthly due to a phenomenon called "app fatigue." Hence, customers have shown a preference for the continued use of core popular messenger apps such as Facebook and WhatsApp (Saunders, 2017). Although the implementation cost structure of chatbot technology is often expensive for firms, in the long run, it saves costs, according to Business Insider (2016). This is due to the applicability of contextual conversation in chatbots, as they can be used to streamline online customer service, thus reducing the need for human sales encounters.

The adoption of AI-based technologies by banks and insurance firms has increased due to the COVID-19 pandemic (McKinsey, 2020). The implementation of chatbot technology has enabled companies to transition into remote sales (Richard *et al.,* 2019). The understanding by businesses that chatbots are only used to handle rudimentary inquiries while complex and difficult inquiries are directed to or handled by live human agents is not accurate (Nili *et al.*, 2019). This is supported by Juniper Research (2020), which states that by the year 2022, over 90% of human-chatbot interactions will be successful without human interference in the banking sector. Examples of current service chatbots implemented by banks in Zimbabwe include Batsirai, an automated service chatbot developed by Steward Bank, aimed at assisting with customer requests on Facebook. If the chatbot fails to answer a question, the inquiry is forwarded to a customer service representative who will be on standby for such requests (Gatsi, 2018). Stan is a chatbot developed by Stanbic Bank, designed to generate responses for inquiries launched on the bank's social media pages and the web chat service. If Stan fails to respond to any queries, the questions are quickly escalated to customer care consultants (Stanbic Bank, 2021). Noku is a chatbot launched by FBC Bank, designed to assist customers with the bank's services on WhatsApp, allowing customers to open accounts instantly without going to any physical branch for assistance (FBC Bank, 2021).

Apart from the benefits associated with service chatbots, there are several practical drawbacks, such as poor interaction with humans (Brandtzaeg and Følstad, 2018). Chatbots have failed to meet perceived expectations since the technology started to trend (Asay, 2018). The foundational reasons for the failure to meet these expectations include platform development complexity and conversational limitations experienced by users during text-based interactions (Asay, 2018). Hence, service chatbot failures during encounters are detrimental to user trust and fuel negative word of mouth (Seeger and Heinzl, 2021).

Zimbabwean banks are not exempt from such anomalies in their implementation of service chatbots on customer service channels. Although chatbots autonomously communicate with users, they are only capable of answering a set of predefined queries, resulting in low user engagement. This is due to user expectations, which are based not only on relevant and useful responses but also on the desire to engage in a service encounter similar to that with human agents. Companies in Zimbabwe are discontinuing their chatbot-based services previously used for communication. For example, Steward Bank's Shosholoza chatbot, deployed in 2019, is currently inactive as of December 2021, due to a high failure rate in its inability to understand user intent (Rao and Euan, 2018). Thus, the failure of service chatbots during encounters is detrimental to user trust and fuels negative word of mouth (Seeger and Heinzl, 2021). The lack of understanding of customers' personal needs, in the same way a human would, has led to a lack of trust in chatbot technology (Rao and Euan, 2018).

The emotionless state of chatbots in responding to customer queries has resulted in their inability to understand complex user inquiries and detect user sentiments to respond correctly (Tsai *et al.,* 2021). Most existing chatbots in Zimbabwe can only handle basic and frequent queries based on a rule-based technique, which results in failure to address difficult queries. They fail to understand the context of conversations as they only use keywords to create responses or analyze user questions, resulting in similar responses to different users. Service chatbots, in particular, need to have the ability and capacity to detect specific user intentions and characteristics of user questions before generating appropriate responses (Agnihotri and Bhattacharya, 2024).

Furthermore, the majority of chatbots in Zimbabwe lack user engagement as they do not demonstrate empathy in their conversational responses. This is due to the use of a predefined conditional response library for response generation, stemming from templates of a series of predefined rules (Pompe, 2023). Consequently, such a response generation technique negatively affects the level of conversational flow flexibility, resulting in inefficient question answering. A transactional and "too serious" response will not inspire continued use due to negative chatbot service encounters. The chatbot neither learns on its own nor generates answers that are not predefined. Hence, there is a need to engage users with additional dialogue abilities, not limited to simply short responses (Huseynov, 2023).

For a general human-chatbot conversation, different response generation strategies are employed depending on the working style. The complexity of the task to generate and the intended task differ (Jiang *et al.*, 2023). Therefore, existing chatbots in Zimbabwe lack subject-specific question answering, making them unsuitable for responding to such queries. A combination of each strategy—template-based, knowledge-based, or network-based—should be used to generate more accurate and precise responses rather than relying on a discrete approach.

Poor information quality has led to a poor user experience, thus compromising service encounter satisfaction. Clearly, chatbots need decision-making abilities to apply the most viable strategy for response generation that is specific, precise, and appropriate (Rane *et al.*, 2023). These unsatisfying familiarities in human-chatbot interaction are key challenges in chatbot encounter satisfaction. This is because users tend to assign humanness to computers and treat them as real social actors (Chaves and Gerosa, 2021).

Thus, service chatbots in the Zimbabwean banking sector have demonstrated an inability to effectively use communicative behaviors, lack conversational assertiveness, and fail to engage users. Additionally, service chatbots lack the ability to understand user intent and chat errors, resulting in the generation of inappropriate responses. The lack of anthropomorphic design, chat errors, and low social presence has negatively influenced the acceptance of chatbots, resulting in negative customer responses. There is a misalignment between the intended task, chatbot technology, and the social characteristics that facilitate effective acceptance of human-chatbot interaction (Jain *et al.*, 2018).

Grammatical errors and the use of shorthand by users when inquiring with a chatbot result in the generation of incorrect responses. This is due to the inability of the conversational agent to comprehend or correct text errors, including semantic and syntactic issues (Izadi and Forouzanfar, 2024). Hence, there is a need for chatbots that identify text errors beforehand and inform the user of the error or recommend a correction before generating a contextually aligned response. However, existing chatbots implemented in Zimbabwe do not consider such an approach, resulting in their inability to generate relevant answers if the user has made a text error.

The lack of anthropomorphic design, chat errors, and low social presence has negatively influenced chatbot acceptance, leading to negative customer responses. During the COVID-19 pandemic, studies indicate a high prevalence of anger exhibited by customers (Shanahan *et al.*, 2020). Thus, the likelihood of service encounters with angry customers is high. Chatbot anthropomorphism negatively affects customer service encounter satisfaction when a chatbot interacts with an angry customer, thereby adversely affecting the customer's overall perception of the organization and their purchasing intent (Tang *et al.*, 2024). Such dissatisfaction stems from pre-interaction expectations regarding chatbot efficacy and the disconfirmation of those expectations. This leads to the development of a perceived competency construct around task-oriented chatbots, thereby unraveling the shortcomings of technological determinism (Adam *et al.*, 2021).

However, the degree of perceived financial, social, and privacy risk concerns influences user reactions towards human-chatbot interaction in the financial sector. Chatbots deployed by firms in the Zimbabwean financial sector are not exempt from experiencing such interaction failures. Hence, human interaction has been channeled to alleviate such risks due to a lack of anthropomorphic digitalization. Fewer studies have examined the implementation of chatbots in the financial industry, particularly in the insurance and banking

sectors (Cardona *et al.*, 2019; Sarbabidya and Saha, 2020). Shambira (2020) also assessed the adoption of AI in the Zimbabwean banking sector. Additionally, multiple studies carried out in different economic sectors regarding chatbot adoption may not be fully applicable in financial services, as the contexts differ (Cardona *et al.*, 2019). Furthermore, the interaction among chatbot tasks, technology, and conversational intelligence and their effect on customer service encounter satisfaction remains unknown. Based on previous claims in the literature, the study reveals the effect of chatbot task and technology characteristics and conversational intelligence on customer service encounter satisfaction.

This study sought to close the gap created by the misalignment between perceived user expectations and the chatbot system's functionality (Orlowski, 2017) by providing empirical evidence in the context of Zimbabwe (Nyagadza *et al.*, 2022). Additionally, within the Zimbabwean context, the study extends preceding investigations in human-chatbot interaction and engagement. Thus, the undertaken study explored the interactions among chatbot tasks, technology, and conversational intelligence and their effect on customer service encounter satisfaction to improve customer gratification in the Zimbabwean banking sector. Additionally, the research investigates the influence of chatbot tasks and technology on conversational intelligence characteristics and their effect on customer service encounter satisfaction in the Zimbabwean banking sector. The study objectives are:

1. To determine the influence of task and technology characteristics on chatbot task-technology fit.
2. To determine the influence of task and technology characteristics on chatbot conversational intelligence characteristics.
3. To examine the mediating effect of conversational intelligence characteristics on task-technology fit characteristics and customer service encounter satisfaction.
4. To assess the effect of chatbot task and technology characteristics on customer service encounter satisfaction.

The study generated new interactions or relationships, presenting a framework for effective positive acceptance of human-chatbot interactions in Zimbabwean banking services. In addition, the study makes informed recommendations for a future inclusive task-technology fit and conversational intelligence service chatbot design framework that could lead to improved customer service encounters in the Zimbabwean banking sector.

The research outcomes can guide commercial banks in Zimbabwe in developing service chatbots that can satisfy users and prospective users upon encounter. Hence, it may help senior management and chatbot developers in the banking industry determine the proper user, task, and technology fit with complementary conversational intelligence characteristics, thus improving human-chatbot interaction, reducing failure rates, and increasing perceived competency levels. Therefore, it positions commercial banks in Zimbabwe with the necessary tools to strategically achieve a sustainable technological competitive advantage. The study will also assist the government of Zimbabwe in policy formulation on the deployment of AI-based applications by firms in the banking industry.

2. Theoretical and Conceptual Development

2.1 Task-Technology Fit

The task-technology fit concept was established by Goodhue and Thompson (1995). This concept measures the link between different characteristics of tasks, technology, and individuals through the user's perceived task-technology fit. Goodhue and Thompson (1995) claimed that technology functionality must correspond with task requirements in order to achieve positive individual performance. Task characteristics include behavioral user actions in transforming inputs to outputs to meet their information needs (Goodhue and Thompson, 1995). Tasks vary in terms of interdependence, time criticality, and non-routineness.

Technological characteristics include the chatbot framework and tools designed to interact with chatbot tasks. The task-technology fit model emphasizes the significance of matching the technology's functionality and attributes to the demands imposed by individual requirements (Ali *et al.,* 2024).

2.2 Conversational Intelligence

Conversational intelligence allows a chatbot to effectively converse and participate beyond technical capacity to achieve the conversational objective (Jain *et al.,* 2018). Proactivity, conscientiousness, and communicability are characteristics of conversational intelligence that enable the chatbot to communicate effectively beyond technological capabilities to achieve a conversational goal (Chaves and Gerosa, 2018). Proactivity refers to a system's ability to operate independently on behalf of a user, thereby reducing the amount of human effort required to perform a task (Chaves and Gerosa, 2018). Thus, proactivity can leverage the conversational context in which contextual information is provided during a dialogue to increase the efficacy of interventions (Avula *et al.,* 2018). Additionally, insights about chatbots' knowledge assist in maintaining conversation continuity when prompted by proactive chatbot messages (Chaves and Gerosa, 2018).

Conversation continuity of a chatbot is critical for human-chatbot interaction, as it demonstrates the chatbot's capability to exert effort in tracking the conversation and maintaining the topic (Jain *et al.,* 2018). The chatbot's ability to keep the context across sessions is a personalization and empathy communication strategy. However, a failure of the chatbot to demonstrate an understanding of the conversational context can lead to user frustration and a loss of credibility.

Therefore, the relational and manner maxims are key factors in designing conscientious chatbots (Jacquet *et al.,* 2019). Conscientious chatbots provide meaningful responses, for example, through response generation approaches to find the most appropriate reply (Ramesh *et al.,* 2017). Chatbot communicability is the ability to convey its features and functionality to users within the chat interface (Valério *et al.,* 2017). Communicability failures result in user frustration and discontinuity in chatbot usage; hence, through various communication strategies, users gain insight into the functionalities of the chatbot (Labadze *et al.,* 2023).

2.3 Customer Service Encounter Satisfaction

Service encounter satisfaction is the post-consumption assessment of any direct contact between a consumer and a service provider related to the primary service offering through interaction and experience (Hsu, 2018). Financial institutions view chatbots as a means of communication and marketing, serving as an interface that allows them to relay information (Yu *et al.,* 2020). The inclusion of an anthropomorphic conversational tone by adding personality and moods to the design of a chatbot enhances user satisfaction (Radziwill and Benton, 2017).

Gupta and Sharma (2019) found a positive association between customers' perceptions of chatbots and their effectiveness, user-friendliness, and capabilities in the banking industry. Quah and Chua (2019) discovered low user satisfaction with banking chatbots due to the inability to generate instantaneous answers when required. The perceived usefulness and ease of use of the chatbot, as well as attitudes towards its use, were found to significantly impact behavioral intention (Richad *et al.,* 2019).

The generation of new knowledge relevant to the acceptance of chatbots and service encounter satisfaction in the banking sector can be achieved by examining the technology-fit on conversational intelligence using previously established conceptual and theoretical models (Richad *et al.,* 2019).

Conceptual framework

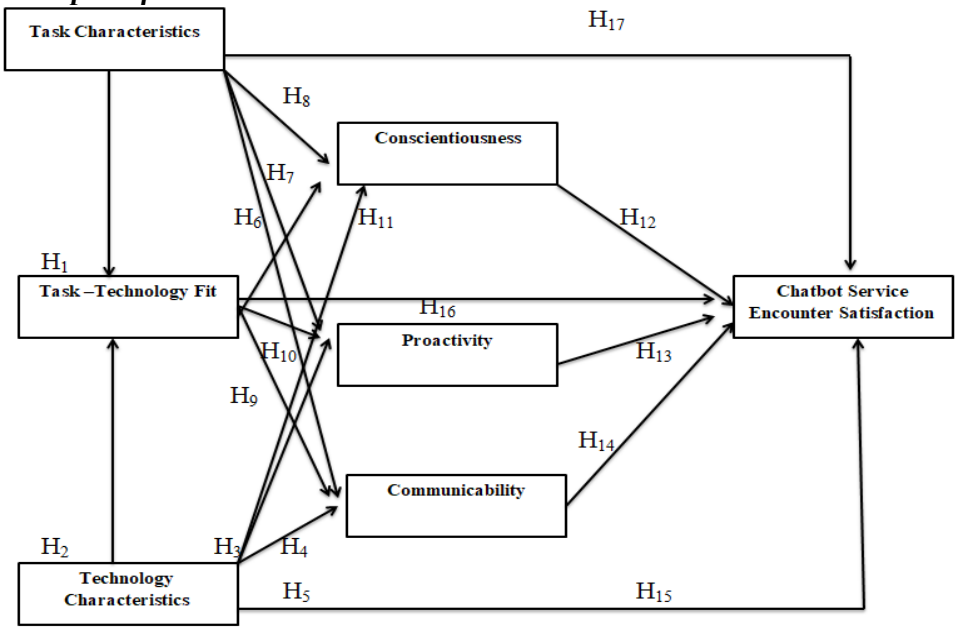

Figure 1. Conceptual model
Source: Authors' own

2.4 Chatbot Task and Technology Characteristics on Chatbot Task-Technology Fit

Chatbot frameworks and tools are designed to achieve various distinct goals and objectives for different chatbot groups. When these chatbot technology characteristics are applied appropriately, the intended task can be accomplished. The choice of tools, such as Google Cloud Dialogflow and Microsoft Bot Framework, influences the expected functionality and behavior of the chatbot. Technology characteristics are reflected through factors such as security, privacy and risk, reliability, ease of use, response time, availability of chatbot systems, and human-like interaction (Nguyen *et al.,* 2021). The system quality of a chatbot can be considered its technical ability to provide easy access to instant, reliable information to support users. Additionally, Carlos and Tiago (2016) observed that technological factors are linked to the degree of fit in the context of online banking. Therefore, the study hypothesizes that:

H1: Chatbot technology characteristics positively affect chatbot task-technology fit.

Task characteristics are the behavioral requirements needed to satisfy user information needs, carried out by converting inputs to outputs through a defined process using information (Abbas *et al.,* 2018). Task characteristics influence the degree of fit (Carlo and Tiago, 2016). Khan *et al.,* (2017) found a positive link between task characteristics and fit. Therefore, the study hypothesizes that:

H2: Chatbot task characteristics positively affect chatbot task-technology fit.

2.5 Task and Technology Characteristics on Chatbot Conversational Intelligence Characteristics

Proactivity, conscientiousness, and communicability are characteristics of conversational intelligence that enable the chatbot to effectively converse beyond its technical capabilities to achieve a conversational goal. These variables in this study are influenced by interactions between individuals and technology, as well as tasks and technology. Such interactions are perceived to influence the chatbot's capability to contribute, understand the context, and interpret information in a more meaningful way while conveying its features to users (Valério *et al.,* 2017). Research in conversational intelligence has shown that the quality of chatbot

interactions significantly influences user perceptions and attitudes towards the technology (Le Cun *et al.*, 2015). Therefore, assessing conversational intelligence allows researchers to evaluate the effectiveness of chatbots in delivering personalized and engaging customer service experiences.

The inclusion of conversational intelligence as a variable reflects an understanding of the importance of natural language processing and human-like communication in chatbot interactions (Mariani *et al.,* 2023). This aspect builds upon research in artificial intelligence and human-computer interaction, such as work by Le Cun *et al.,* (2015) on deep learning and natural language understanding. According to Hildebrand and Bergner (2020), customers trust conversational robo-advisors more than non-conversational or static ones. Furthermore, cues in anthropomorphic design, such as identity, empathy, and small talk, improve user compliance with chatbot service demands (Adam *et al.,* 2020). This aspect acknowledges the importance of chatbots' ability to engage in meaningful and contextually relevant conversations with users (Le Cun *et al.*, 2015). By assessing conversational intelligence, the study sheds light on the effectiveness of chatbots in understanding and responding to customer inquiries and concerns in a manner that simulates human-like interaction. This contributes to enhancing the quality of customer service experiences facilitated by chatbot technology.

Therefore, the study hypothesizes that:

H3: Chatbot technology characteristics positively affect chatbot's conscientiousness.
H4: Chatbot technology characteristics positively affect chatbot's proactivity.
H5: Chatbot technology characteristics positively affect chatbot's communicability.
H6: Chatbot task characteristics positively affect chatbot's communicability.
H7: Chatbot task characteristics positively affect chatbot's proactivity.
H8: Chatbot task characteristics positively affect chatbot's conscientiousness.
H9: Chatbot's task and technology fit positively affect chatbot's communicability.
H10: Chatbot's task and technology fit positively affect chatbot's proactivity.
H11: Chatbot's task and technology fit positively affect chatbot's conscientiousness.

2.6 The Mediation Effect of Conversational Intelligence Characteristics on Task-Technology Fit and Customer Service Encounter Satisfaction

Mediation describes the effect of a third variable on the main effect between independent and dependent variables. The most common mediators include psychological factors, service perception variables, and technology-related aspects. Technology-related considerations encompass the benefits of service delivery configuration and general data security (Payne *et al.,* 2021), as well as AI's perceived problem-solving capacity (Xu *et al.,* 2020). According to Adam *et al.,* (2020), social presence modulates the link between anthropomorphic design signals and chatbot request compliance. The continued usage of chatbot technology to perform tasks is considered an immediate predictor of behavior (Perrow, 2018). The task-technology fit extends to the technological features required by users to carry out tasks effectively. In prior social media studies, social characteristics have been utilized as mediators between variables (Perrow, 2018). Social impact was used as a mediator to assess user behavior in virtual communities (Perrow, 2018). Therefore, the study hypothesizes that:

H12: Chatbot's conscientiousness mediates the effect of chatbot's task-technology fit on customer service encounter satisfaction.
H13: Chatbot's proactivity mediates the effect of chatbot's task-technology fit on customer service encounter satisfaction.
H14: Chatbot's communicability mediates the effect of chatbot's task-technology fit on customer service encounter satisfaction.

2.7 The Effects of Chatbot Task and Technology Characteristics on Customer Service Encounter Satisfaction

A service encounter is any customer-company interaction that arises from a service system, including interconnected technology, human actors, physical or digital environments, and business/customer processes (Lariviere *et al.*, 2017). Users will be satisfied with information systems if service quality is high (Lien *et al.*, 2017). Reliability, assurance, personalization, and responsiveness of service are all regarded as conventional determinants of customer encounter satisfaction (Gao and Waechter, 2017). As a result, if chatbots are well-designed to understand users' concerns and respond in a timely and personalized manner, consumers will perceive excellent service quality, increasing their satisfaction. The individual (user) interacts with the technology through use; hence, the usability of the technology is crucial. Individuals will use technology more if it is easy to use. The technology must be able to support the task the user intends to accomplish, thus requiring technological compatibility with intended tasks (Sitorus *et al.,* 2016). Hence, the more the task and technology functionalities match, the more individuals will use the technology. Thus, the interaction between task and technology is considered. Therefore, the study hypothesizes that:

H15: Chatbot task characteristics positively affect customer service encounter satisfaction.
H16: Chatbot task-technology fit characteristics positively affect customer service encounter satisfaction.
H17: Chatbot technology characteristics positively affect customer service encounter satisfaction.

3. Research Methodology

3.1 Research Design

The aim of the research was to determine the effect of chatbot task and technology on conversational intelligence characteristics and customer service encounter satisfaction in the Zimbabwean banking sector. The study adopted a pragmatism research philosophy with a concurrent nested approach, in which both quantitative and qualitative data are collected to improve understanding of social processes. The effect of chatbot task and technology on conversational intelligence features and their effect on service encounter satisfaction was investigated using this design. The research approach required the simultaneous collection and analysis of quantitative and qualitative data (Creswell, 2010). The qualitative and quantitative approaches were blended in this study, making it a mixed-methods study. Given that the prior theory on the subject is still in a stage of development, a mixed-methods approach seemed acceptable. The fundamental strength of this strategy is the idea of elaborating on the mechanisms of how the variables interact through qualitative follow-up (Creswell, 2010). This approach simplifies the description and reporting of the outcomes.

3.2 Data Collection Method

The survey method was chosen as an appropriate method for the quantitative and qualitative data in this design to investigate whether there is an association or relationship between the dependent variables of perceived customer service encounter satisfaction, proactivity, communicability, and conscientiousness, and the independent variables of chatbot task and technology characteristics. The quantitative data in the study was validated and triangulated using qualitative techniques.

The target population comprised 13 registered commercial banks in Zimbabwe, which included a total estimated population of 7,151 bank employees and adults with bank accounts in Harare. This city has one of the largest percentages of financial inclusion in Zimbabwe as of 2022. The researchers used the Raosoft sample size calculator at a 95% confidence level with a 5% margin of error and a response distribution of 50%, attaining a sample size of 365 employees and 500 bank customers. The target population of the study consisted of bank employees and bank customers located in Zimbabwe. The bank employees were potential

respondents regarding the task and technology constructs, while the bank customers (i.e., 17% of the population) were potential respondents for the service encounter satisfaction-related constructs.

The study's respondents were chosen using a purposive sampling method. This sampling technique allowed the researcher to handpick participants appropriate for the study, specifically information systems and marketing employees, as well as adults with bank accounts. The questionnaire was designed based on literature (Daradkeh, 2019; Borsci *et al.,* 2021). It comprised six major sections: Sample Profile, Task and Technology Characteristics, Task-Technology Fit, Chatbot Conversational Intelligence, Customer Service Encounter Satisfaction, and Open-Ended Questions. Sections B, C, D, and E utilized a five-point Likert scale to address different levels of importance and satisfaction regarding task and technology characteristics. An online survey was conducted, and respondents received the questionnaire link via email. Ultimately, 458 respondents out of 865 completed the questionnaire, resulting in a response rate of 53%, which is slightly above the minimum level of 50% suggested by Dillman (2000).

3.3 Data Analysis

A structural model assessment was conducted on the quantitative data collected, which was transcribed into a Microsoft Excel spreadsheet and then uploaded to Warp PLS 8.0. A partial least squares (PLS) technique was used, with PLS-SEM being suitable for the study since it has strong statistical power, which is significant in a less developed or nascent theory (Hair *et al.,* 2019). The measurement model assessment included results illustrating indicator loading, composite reliability, convergent validity, and discriminant validity (Hair *et al.,* 2019; Mashingaidze, 2021). The structural model included results illustrating the coefficient of determination and variable collinearity (Hair *et al.,* 2019; Mashingaidze, 2021). For the qualitative data collected, the study used a thematic method of data analysis. The qualitative data acquired from the open-ended questions in the questionnaire was analyzed using thematic analysis (Braun and Clarke, 2006). The preset approach detected patterns in the data, which included data familiarization, generating codes to identify data, looking for themes, defining and labeling these themes, and producing a report of the observed patterns.

The validity and reliability of the questionnaire employed in this study determined the extent to which significant inferences could be drawn from the research data. The study instrument was assessed by statisticians to ensure that it would capture the essential data and that it measured what it was intended to measure. A pilot study was conducted with a sample of commercial bank employees, assisting the researcher in gaining the necessary experience with the instruments prior to the main study. The pilot study also helped identify ambiguities and weaknesses in the questions. Content validity and construct validity were conducted to ensure that the research instruments' questions assess the concept in question and the relationship between a measure and the theory that supports it (Saunders *et al.,* 2009). In the study, the subjects were kept completely anonymous. By including a voluntary consent section, the researchers ensured that all respondents were treated with respect throughout the questionnaire's introduction and that no respondents were ever forced to participate. Respondents also had the option to withdraw from the study at any time they deemed fit. Above all, the study followed scientific processes to arrive at its conclusions and their implications for stakeholders.

4. Results

4.1 Demographics

The majority of respondents were between the ages of 25 and 34 (42%), followed by the younger demographic of 18 to 24 (31%), and those between the ages of 35 and 44 (21%). There were 11 respondents aged 44 to 55, accounting for 5.6% of the total, and only one person over 55, accounting for 0.4%. Male respondents accounted for 63.6% of the total, while female respondents accounted for 36.4%. Bachelor's degree holders constituted 72%, followed by Master's degree holders at 27%, and PhD holders at 1%.

The category of chatbot experience was further divided into three variables: chatbot familiarity, chatbot experience, and chatbot usage frequency. Eighty percent of respondents were extremely familiar with chatbots, 20% were fairly familiar, and 100% had definitely used a conversational interface in the past. Sixty-seven percent of respondents use chatbots occasionally, while 33% use them rarely on a weekly basis. Because previous research has revealed that chatbot usage is significantly influenced by the user's dispositional traits, we included the demographic variables as control variables in the model (Lortie and Guitton, 2011).

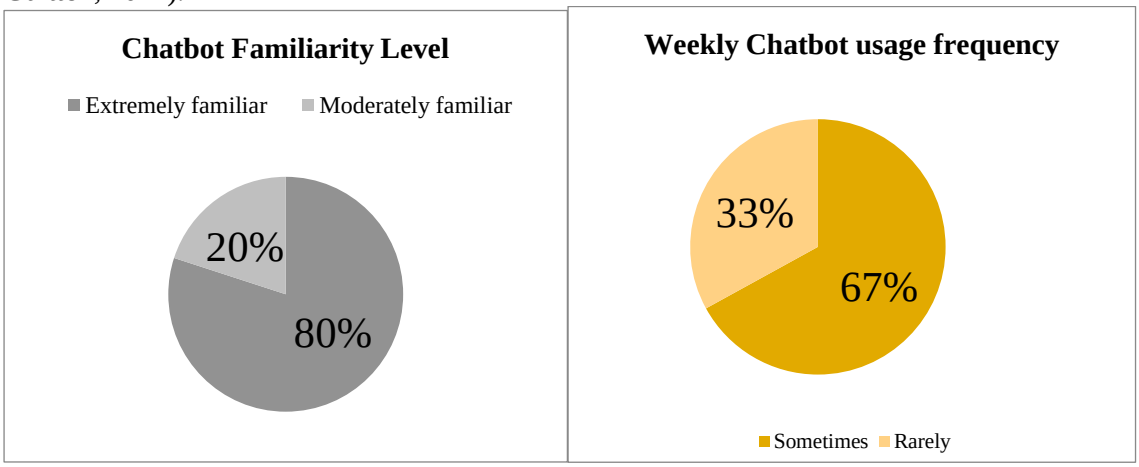

Figure 2. Respondents' chatbot familiarity and weekly usage

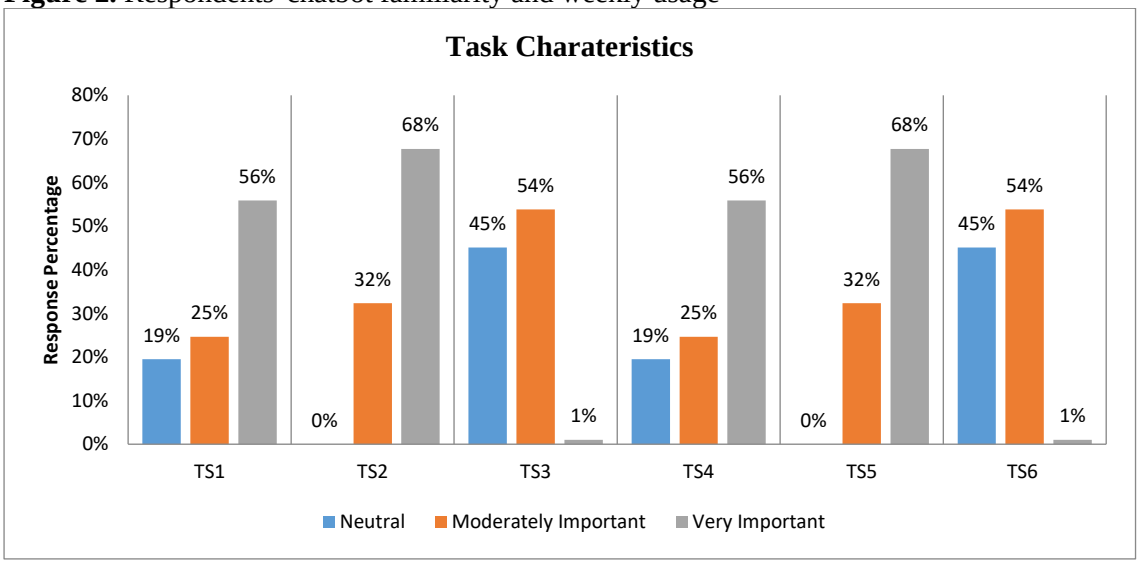

Figure 3. Task Characteristics Construct

Based on the questionnaire responses, the majority of the responses indicated that task characteristics are very important and crucial for conversational intelligence, as shown in Figure 3. Technology characteristics were also deemed very important, as shown in Figure 4, indicating that respondents perceive technology characteristics as key factors in determining the optimal task and technology fit and in the implementation of conversational intelligence characteristics in chatbots.

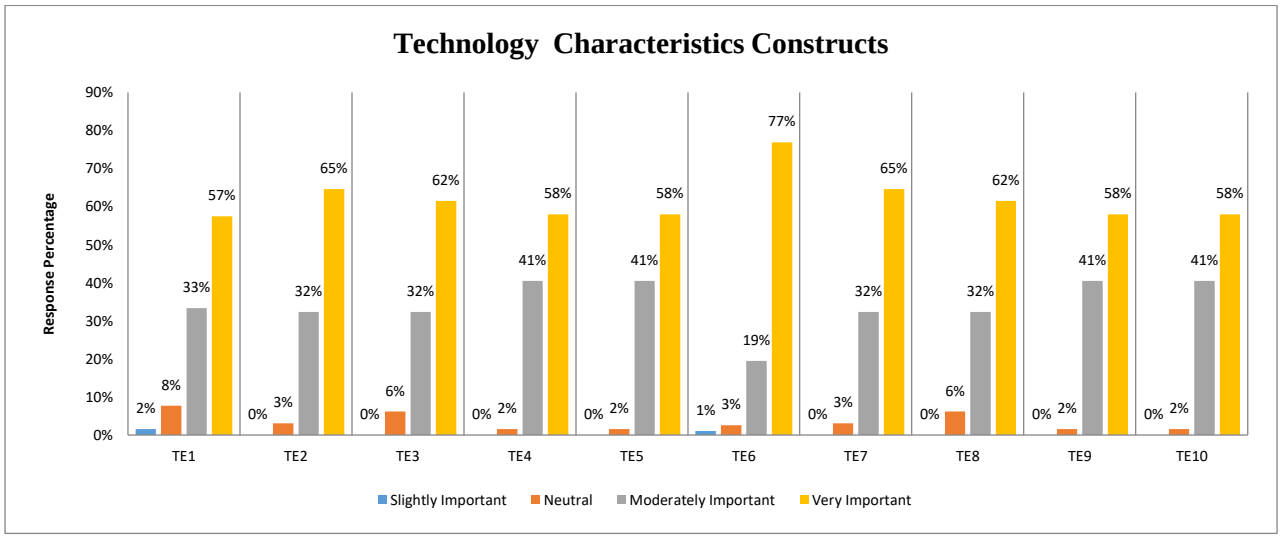

Figure 4. Technology characteristics construct

The majority of respondents agreed, though a significant segment neither agreed nor disagreed with the chatbot capabilities and functionality exhibited when a chatbot operates under the task-technology fit construct, as shown in Figure 5.

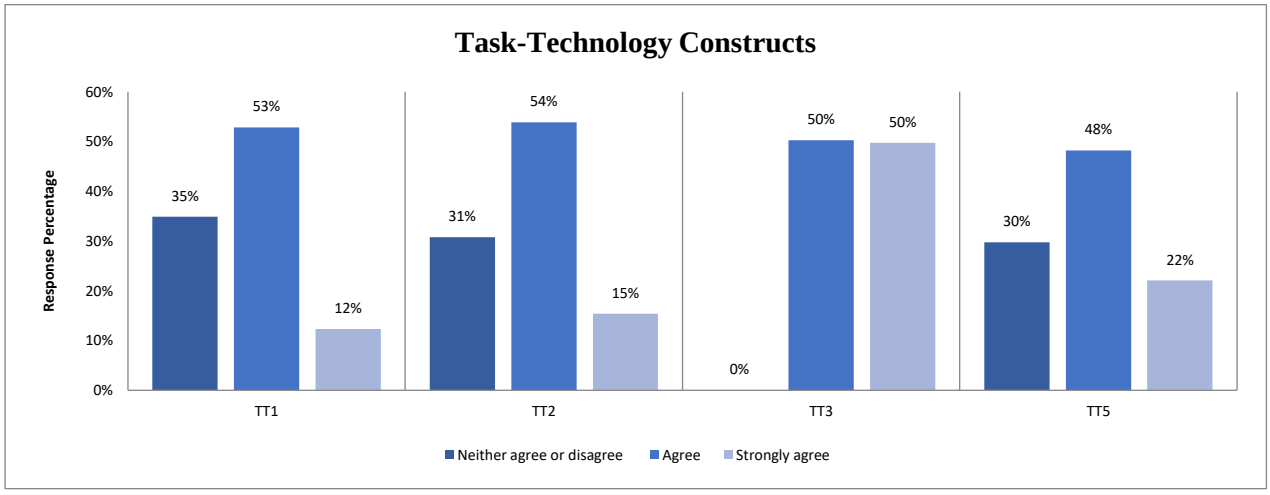

Figure 5. Task-Technology fit construct

Respondents generally agreed with several conversational intelligence characteristic constructs, as shown in Figures 6, 7, and 8. The mediation of conversational intelligence characteristics was perceived as an influential factor in customer service encounter satisfaction and task-technology fit, although the statistical significance of this notion has yet to be tested.

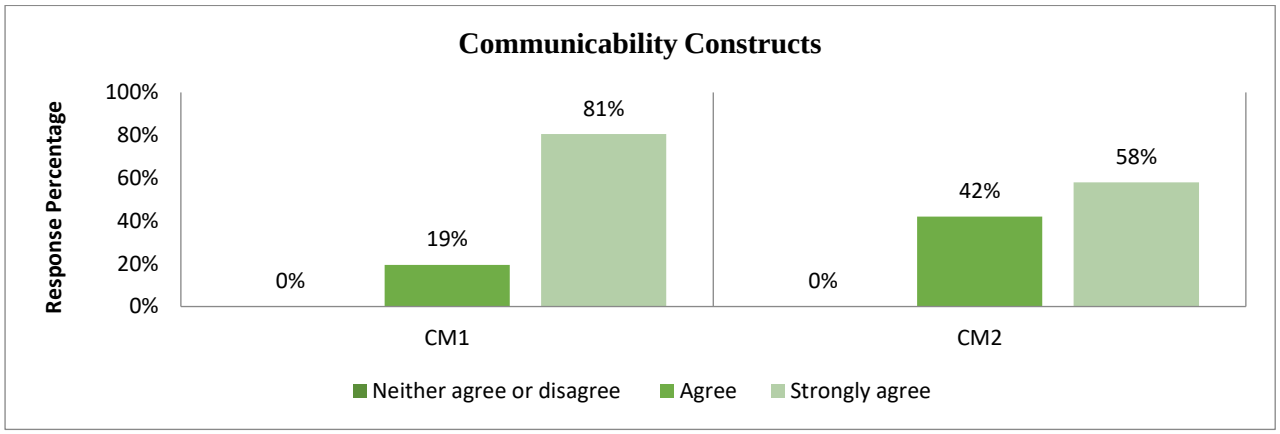

Figure 6. Communicability Constructs

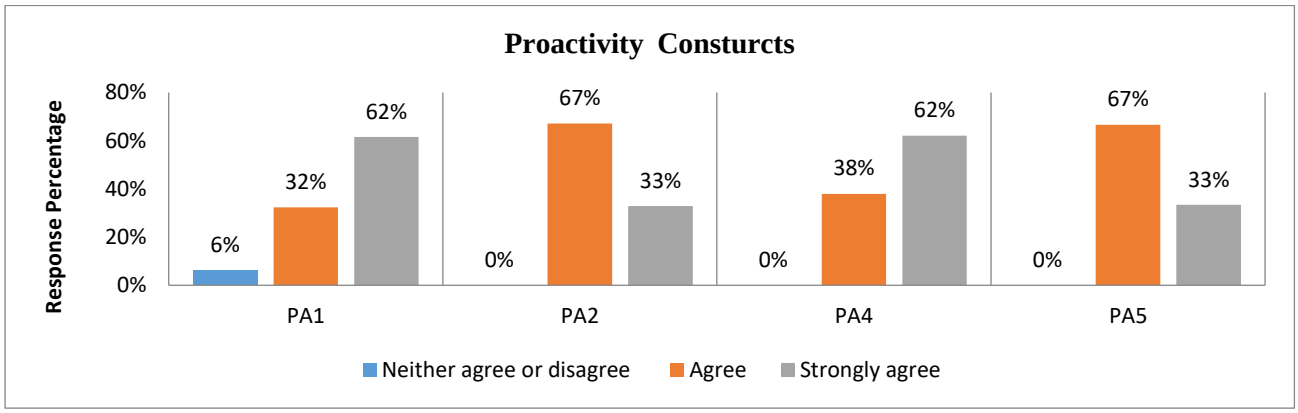

Figure 7. Proactivity Constructs

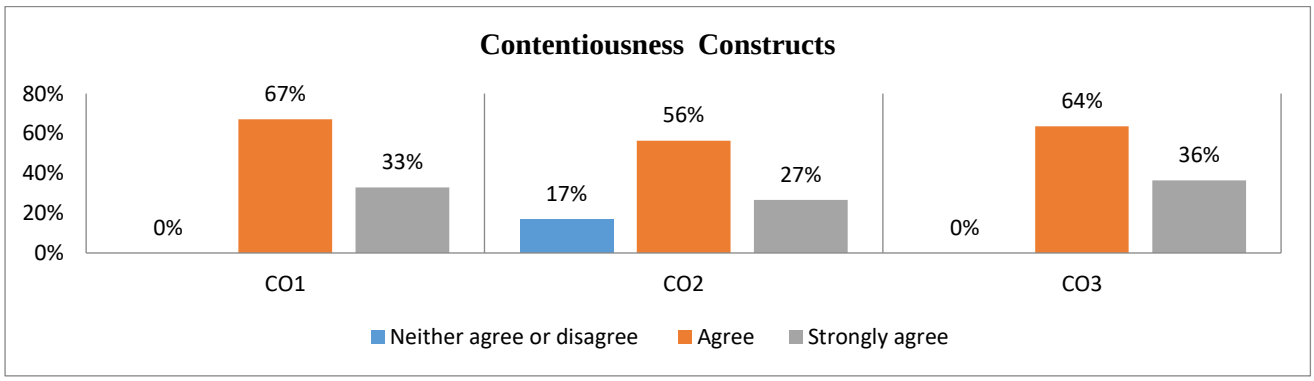

Figure 8. Contentiousness Constructs

Customer service encounter satisfaction constructs were related to the chatbot capabilities (task), functionality (technology), and operations (task-technology fit). The majority of respondents indicated that the perceived chatbot capabilities and functions provided a sense of satisfaction.

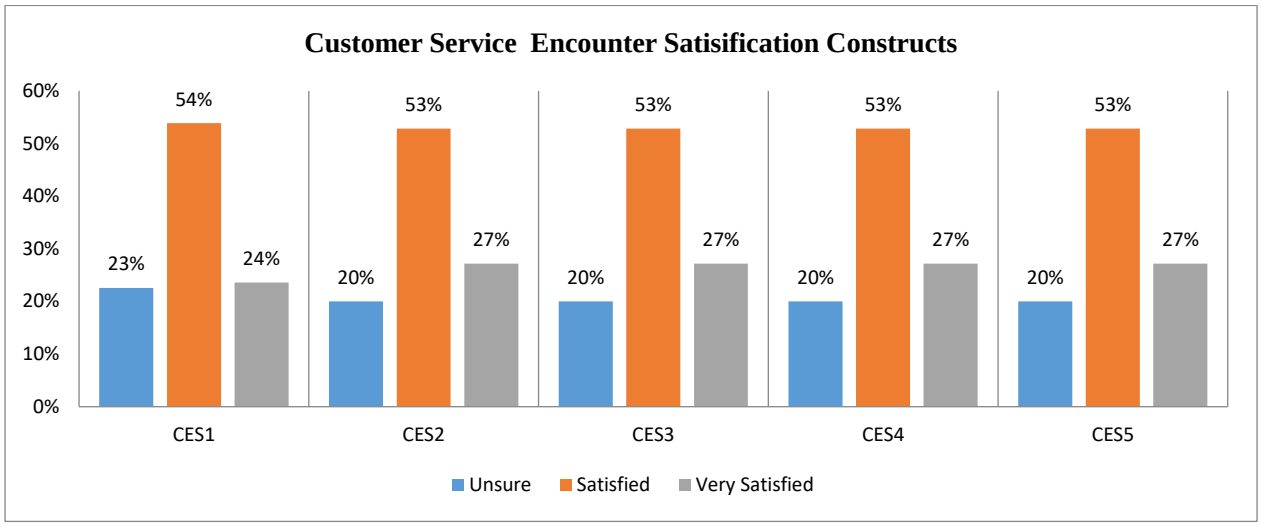

Figure 9. Customer service encounter satisfaction constructs

4.2 Measurement Model Assessment

Questionnaires from commercial bank employees and adult bank account holders provided quantitative data. The collected data was transcribed into a Microsoft Excel spreadsheet and then uploaded to Warp PLS 8.0. A partial least squares (PLS) technique was used, with PLS-SEM being suitable for the study since it has strong statistical power, which is significant in a less developed or nascent theory (Hair *et al.*, 2022; Ahmed *et al.*, 2024).

4.2.1 Indicator Loadings.

Table 1. Factor loadings (and cross-loadings) of all indicator items to their respective latent constructs

	Task	Tech	TaskTec	Comm	Con	Proc	CSES
TS1	**0.685**	-0.226	0.035	-0.183	-0.016	-0.163	-0.155
TS2	**0.519**	0.014	0.065	-0.057	0.016	0.051	-0.122
TS3	**0.641**	-0.048	0.036	0.061	-0.103	-0.122	0.006
TS4	**0.685**	-0.226	0.035	-0.183	-0.016	-0.163	-0.155
TS5	**0.519**	0.014	0.065	-0.057	0.016	0.051	-0.122
TS6	**0.641**	-0.048	0.036	0.061	-0.103	-0.122	0.006
TE1	-0.198	**0.769**	0.071	0.188	0.048	0.355	0.136
TE2	-0.074	**0.869**	0.063	-0.077	0.01	0.429	0.155
TE3	-0.175	**0.842**	0.021	0.05	0.12	0.624	0.161
TE4	-0.125	**0.692**	-0.019	0.099	0.044	0.293	0.121
TE5	-0.055	**0.812**	-0.01	-0.012	0.035	0.35	0.141
TE6	-0.198	**0.769**	0.071	0.188	0.048	0.355	0.136
TE7	-0.074	**0.869**	0.063	-0.077	0.01	0.429	0.155

	Task	Tech	TaskTec	Comm	Con	Proc	CSES
TE8	-0.175	**0.842**	0.021	0.05	0.12	0.624	0.161
TE9	-0.125	**0.692**	-0.019	0.099	0.044	0.293	0.121
TE10	-0.055	**0.812**	-0.01	-0.012	0.035	0.35	0.141
TT1	-0.022	-0.007	**0.233**	-0.082	-0.018	0.007	0.032
TT2	0.096	0.086	**0.782**	-0.038	0.04	0.081	-0.068
TT3	-0.014	0.102	**0.426**	-0.088	0.022	0.084	-0.077
TT5	0.04	-0.096	**0.679**	-0.065	-0.063	-0.106	-0.025
CM1	-0.001	0.013	-0.087	**0.803**	-0.014	-0.043	0.096
CM2	-0.161	0.077	-0.073	**0.803**	-0.139	-0.088	0.098
CO1	-0.1	0.105	0.017	-0.141	**0.84**	0.797	-0.013
CO2	0.063	-0.012	0.037	-0.066	**0.125**	0.055	-0.007
CO3	-0.011	0.006	-0.031	-0.012	**0.841**	0.287	-0.057
PA1	-0.175	0.842	0.021	0.05	0.12	**0.624**	0.161
PA2	-0.1	0.105	0.017	-0.141	0.84	**0.797**	-0.013
PA4	-0.037	0.551	0.084	-0.042	0.019	**0.537**	-0.028
PA5	-0.087	0.144	-0.035	-0.07	0.629	**0.809**	0.018
CES1	-0.136	0.153	-0.065	0.086	-0.07	0.046	**0.936**
CES2	-0.14	0.174	-0.092	0.108	-0.035	0.03	**0.987**
CES3	-0.144	0.184	-0.067	0.133	-0.034	0.05	**0.996**
CES4	-0.144	0.184	-0.067	0.133	-0.034	0.05	**0.996**
CES5	-0.144	0.184	-0.067	0.133	-0.034	0.05	**0.996**

*Task = Task characteristics; Tech = Technology characteristics; TaskTec = Task-Technology fit ;Comm = Communicability; Con = Contentiousness; Proc = Proactivity; CSES = Customer Service Encounter Satisfaction

Table 1 shows the factor loadings (and cross-loadings) of all indicator items to their respective latent constructs. When factor loadings exceed 0.70, the construct explains more than 50% of the variance in the indicator, demonstrating satisfactory item dependability (Hair *et al.*, 2019). The majority of the component loadings in Table 1 were greater than 0.70, suggesting that the constructs account for more than 50% of the variance in the indicators, indicating acceptable item dependability. However, TS1 (0.685), TS3 (0.641), TS4 (0.685), TS6 (0.641), TE4 (0.692), TE9 (0.692), and TT5 (0.679) loaded below 0.70 but were close, and hence acceptable in exploratory research (Mashingaidze, 2021). This was calculated based on the fact that TS1, TS3, TS4, TS6, TE4, TE9, and TT5 loaded higher on their own constructs than on any other construct, passing additional quality tests and thus being retained in the model.

4.2.2 Reliability Analysis

Composite reliability was used to examine internal consistency, as it is a more accurate indication of reliability; high scores imply high levels of reliability. Values between 0.60 and 0.70 are considered adequate, according to Hair *et al.*, (2022), as reported by Mashingaidze (2021), while values between 0.70 and 0.90 are considered acceptable to good. In contrast, values of 0.95 and higher are undesirable because they demonstrate item repetition, which weakens construct validity. The findings of the study's internal consistency reliability assessments are shown in Table 2.

Table 2: Composite Reliability, Correlations and Discriminant Validity

	Composite reliability coefficients	Average variances extracted	Full collinearity VIFs	Task	Tech	TaskTec	Comm	Con	Proc	CSES
Task	0.786	0.383	1.059	**0.619**						
Tech	0.946	0.639	1.711	-0.155	**0.799**					
TaskTec	0.625	0.327	1.021	0.07	0.033	**0.572**				
Comm	0.784	0.645	1.049	-0.101	0.056	-0.1	**0.803**			
Con	0.675	0.476	2.051	-0.06	0.064	-0.005	-0.095	**0.69**		
Proc	0.79	0.492	2.827	-0.142	0.519	0.022	-0.081	0.642	**0.701**	
CSES	0.993	0.965	1.067	-0.144	0.179	-0.073	0.121	-0.042	0.046	**0.982**

*Task = Task characteristics; Tech = Technology characteristics; TaskTec = Task-Technology fit ;Comm =Communicability; Con = Contentiousness; Proc = Proactivity; CSES = Customer Service Encounter Satisfaction

The composite reliability coefficients for all latent variables were acceptable, measuring between 0.60 and 0.95, which is above the acclaimed threshold value of 0.70, indicating high levels of reliability (Nunnally, 1994). However, the composite reliability coefficients for the contentiousness, task, and technology fit variables were below 0.7. As such, if the reliability is less than 0.7, the variables have less than 50% of their common variance attributed to the latent factor.

4.2.3 Convergent Validity

Convergent validity refers to the model's ability to explain the variance of the indicators. Conducting Average Variance Extracted (AVE) tests revealed evidence of convergent validity, indicated by an AVE threshold level of 0.5. This indicates that the construct accounts for at least 50% of the variance in its elements (Hair *et al.*, 2022; Ahmed *et al.*, 2024). As shown in Table 2, the measures of Tech, Comm, and CSES constructs have high levels of convergent validity, as their AVE values are higher than the threshold level of 0.5.

The AVE values for Con and Proc constructs are below the threshold of 0.5 but are close enough to establish convergent validity. The AVE value for the Task construct is below 0.5. According to Fornell and Larcker (1981), the construct's convergent validity is still acceptable even if the AVE is less than 0.5, provided the composite reliability is greater than 0.6. The derived AVE value for Task is 0.383, and when combined with composite reliability values greater than 0.6, the construct's convergent validity remains adequate.

4.2.4 Discriminant Validity

The discriminant validity results in Table 2 are consistent with Fornell and Larcker (1981) and Hair *et al.*, (2019) recommendations, which state that the AVE for each measure should be more than 0.50 to demonstrate discriminant validity. Furthermore, the square root values of all AVE measures are higher than their corresponding correlations, meeting the discriminant validity test of the Fornell-Larcker Criterion.

4.3 Structural Model Assessment

The following sections present the findings of the structural model assessment.

4.3.1 Collinearity Test

The Variable Inflation Factor (VIF) is used to measure variable collinearity (Mashingaidze, 2021). VIF values ranging from 3 to 5 may suggest collinearity concerns; thus, values of 3 or less are preferable (Mashingaidze, 2021). The results of the collinearity tests shown in Table 2, using the VIF criterion, indicated that Task, Tech, TaskTec, Comm, and CSES had VIF values less than 3, thereby satisfying the recommendations of Chatterjee and Hadi (2012) as cited by Mashingaidze (2021).

4.3.2 Coefficient of Determination (R^2)

The R^2 values of the endogenous constructs were analyzed. R^2 values range from 0 to 1, with higher values indicating greater explanatory power. Although R^2 interpretation is context-dependent, values of 0.75, 0.50, and 0.25 are considered substantial, moderate, and weak, respectively (Hair *et al.*, 2019). All constructs had R^2 values below 0.25, except for the proactivity construct, which had an R^2 value of 0.3 according to the findings.

The R^2 values below 0.25 indicate that these constructs accounted for less than 25% of the variance in the dependent variable. In contrast, the proactivity construct exhibited a notable R^2 value of 0.3, suggesting it accounted for 30% of the variance, which is comparatively higher than the other constructs. This finding implies that the proactivity construct may possess a more substantial correlation with the dependent variable than the other constructs analyzed.

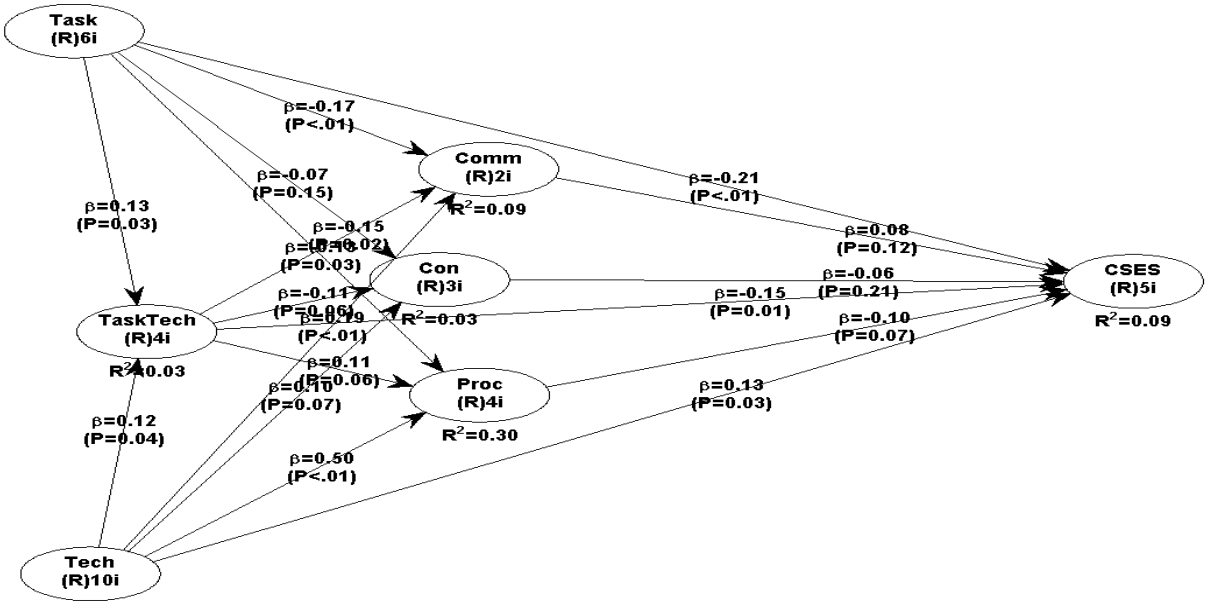

Figure 10: Study results **Source:** Warp PLS output

4.3.3 Hypotheses Testing: Statistical Significance

A hypothesis test compares p-values to a significance level of 0.05. The hypothesis is accepted if the p-value is less than 0.05; however, if the p-value is greater than 0.05, the hypothesis is rejected. Table 3 presents the results of the PLS-SEM analysis. The findings indicate that task characteristics and technology characteristics directly influence task-technology fit, customer service encounter satisfaction, proactivity, and communicability. The results show that task characteristics exhibited a statistically significant influence on task-technology fit ($t=1.891$, $p<0.03$), communicability ($t=-2.483$, $p<0.007$), proactivity ($t=-1.894$,

p<0.03), and customer service encounter satisfaction (t=-3.085, p<0.001). However, there was a statistically insignificant influence of task characteristics on contentiousness (t=-1.0292, p>0.152).

Technology characteristics also demonstrated a statistically significant influence on task-technology fit (t=1.783, p<0.038), communicability (t=2.734, p<0.003), proactivity (t=7.685, p<0.001), and customer service encounter satisfaction (t=1.832, p<0.034). Yet, there was a statistically insignificant influence of technology characteristics on contentiousness (t=1.47, p>0.072). Additionally, there was a statistically insignificant influence of task-technology fit on customer service encounter satisfaction through proactivity (t=-1.457, p>0.073), contentiousness (t=-0.803, p>0.212), and communicability (t=1.17, p>0.122). There was also a statistically insignificant effect of task-technology fit on proactivity (t=-1.583, p>0.057) and contentiousness (t=1.547, p>0.062). In contrast, there was a statistically significant direct influence of task-technology fit on communicability (t=-2.104, p<0.018) and customer service encounter satisfaction (t=-2.188, p<0.015). Therefore, the results show that only hypotheses H1, H2, H3, H4, H6, H7, H9, H15, H16, and H17 were accepted.

Table 3: Significance Testing Results of the Structural Model Path Coefficients.

Objectives	Hypothesis	Path	Path coefficients	t-value	P values	Significant Level	Decision
1	**H_1**	Task → TaskTec	0.131	1.891	0.03	Significant	Accepted
	H_2	Tech → TaskTec	0.124	1.783	0.038	Significant	Accepted
	H_3	Tech → Comm	0.187	2.734	0.003	Significant	Accepted
	H_4	Tech → Proc	0.496	7.685	<0.001	Significant	Accepted
	H_5	Tech → Con	0.102	1.47	0.072	No Significant	Rejected
2	**H_6**	Task → Comm	0.187	-2.483	0.007	Significant	Accepted
	H_7	Task → Proc	-0.131	-1.894	0.03	Significant	Accepted
	H_8	Task → Con	-0.072	-1.029	0.152	No Significant	Rejected
	H_9	TaskTec → Comm	-0.145	-2.104	0.018	Significant	Accepted
	H_{10}	TaskTec → Proc	0.11	1.583	0.057	No Significant	Rejected
	H_{11}	TaskTec → Con	-0.108	-1.547	0.062	No Significant	Rejected
3	**H_{12}**	TaskTec → Con → CSES	-0.056	-0.803	0.212	No Significant	Rejected
	H_{13}	TaskTec → Proc → CSES	-0.102	-1.457	0.073	No Significant	Rejected
	H_{14}	TaskTec → Comm → CSES	0.082	1.17	0.122	No Significant	Rejected
4	**H_{15}**	Task → CSES	-0.211	-3.085	0.001	Significant	Accepted
	H_{16}	TaskTec → CSES	-0.151	-2.188	0.015	Significant	Accepted
	H_{17}	Tech → CSES	0.127	1.832	0.034	Significant	Accepted

*Task = Task characteristics; Tech = Technology characteristics; TaskTec = Task-Technology fit ;Comm =Communicability; Con = Contentiousness; Proc = Proactivity; CSES = Customer Service Encounter Satisfaction

Respondents in Section E of the questionnaire supplied answers based on their personal thoughts rather than a rating scale or grade. The following themes were mapped based on the respondents' answers, which include a lack of resources, disregard for consumer needs and expectations, and lack of technological know-how. Most banks have found it difficult to integrate conversational intelligence into their customer care

chatbots. The majority of respondents stated that a lack of resources is the biggest barrier for commercial banks in Zimbabwe employing conversational intelligence chatbots. These resources include human capital with abilities in constructing conversational intelligence chatbots and insufficient finances for necessary technical infrastructure. Furthermore, numerous respondents claimed that the banking industry has a tendency to disregard consumer needs and expectations, making it more difficult for banks to set up and build conversational intelligence service chatbots.

The second question investigated whether conversational intelligence has improved customer service satisfaction. Some respondents stated that conversational intelligence has improved greatly but did not specify how much. The third question focused on the difficulties in determining the ideal chatbot task and technology match. Some of the respondents noted a number of issues, including the necessity to develop user-centric conversational platforms and a lack of technological know-how to match the desired task.

The respondents recommended several approaches for creating a chatbot with high conversational intelligence that improves customer service satisfaction. These include creating customer-centered designs based on their needs and the information they want to access. Additionally, after building a chatbot, it is necessary to repeatedly evaluate the content and language model, changing test groups to assess different material and questioning methods. Furthermore, when forming a chatbot development team, banks should hire employees with a variety of skills. Finally, banks should treat a chatbot as a long-term project that requires individual testing and continually shifting test groups, which necessitates several collaborators rather than being viewed as a simple technical project.

5. Discussion

The adoption of AI-based chatbot apps in the financial sector is revolutionizing communication between banks and customers. Many banks have started using chatbots to cut expenses and improve service quality. In order to boost consumer satisfaction in Zimbabwe's banking sector, banks must investigate the relationships between perceived user expectations and the chatbot system's functionality. The structural correlations hypothesized in the study model were tested using structural equation modeling with Warp PLS, and the specific findings of this study are reported.

H1 and H2 are statistically significant because chatbot task-technology fit is positively influenced by task and technology characteristics. The outcomes of this study confirm previous research by demonstrating a relationship between task and technological features and fit. Khan *et al.,* (2017) and Wu and Chen (2017) both found a positive correlation between task and technological features and fit. According to Carlos and Tiago (2016), task and technological characteristics are linked to the degree of fit in the online banking setting. As a result, a combination of relevant chatbot task features can be used to determine if the technological device-specific activity is a good fit (Valaie *et al.,* 2019).

The findings show that chatbot task and technological characteristics positively influence chatbot communicability and proactivity; thus, H3, H4, H6, and H7 are statistically significant. Chatbot task and technology attributes, on the contrary, have a negative effect on chatbot contentiousness (H5) and H8; however, these are statistically insignificant. Cheng *et al.,* (2021) found that task complexity and text-based chatbot disclosure moderate the association between chatbot characteristics and trust. Task difficulty negatively moderates the association between friendliness and consumer trust in chatbots, according to Cheng *et al.,* (2021), such that when the customer's task is complex, the beneficial effect of friendliness on consumer trust is reduced. As a result, task complexity has a negative impact on chatbot conscientiousness since consumers may be more concerned with the chatbot's professionalism and capacity to solve problems than with their attitudes or service manner.

Furthermore, task-technology fit had a negative influence on chatbot proactivity and conscientiousness but a positive effect on communicability; therefore, H9 and H10 are statistically insignificant, while H11 is significant. Prior research by Al-Rahmi *et al.,* (2020) utilizing the task-technology fit model to investigate

the factors impacting students' academic performance in higher education supports this argument. The researchers concluded that task-technology fit has a positive effect on social characteristics, meaning that task-technology fit has social characteristics that allow students to exchange information with peers during discussions. The ability to transmit information falls under the communicability scope of thought in the current study, which clearly supports and links to earlier findings.

Conversational intelligence characteristics (contentiousness, communicability, and proactivity) have a negative mediation effect on task-technology fit and chatbot customer service encounters, according to the findings; thus, H12, H13, and H14 are statistically insignificant. Anthropomorphism has been shown to have some detrimental consequences in specific instances in previous studies. Quintino (2019) examined the relationship between human-like design cues in chatbots and customer satisfaction. According to the regression-based model, there was no significant influence of human-like cues on the chatbot's perceived qualities and the customer experience. This suggests that when the chatbot had human-like traits, the perceived ease and utility did not lead to a better customer experience.

Crolic *et al.,* (2022) showed how anthropomorphism has a negative impact on customer service and linked the adoption of these human-like chatbots to unfavorable corporate outcomes. The bank took a deliberate and strategic decision to include conversational intelligence in its chatbots, effectively anthropomorphizing a chatbot. Though a task and technology match may exist, such a decision significantly impacts critical marketing outcomes for many consumers, particularly those who are dissatisfied during the service encounter (Crolic *et al.,* 2022). An expectancy violation caused by elevated pre-interaction efficacy expectations drives the negative effect. Han *et al.,* (2021) and Yen and Chiang (2021) previously documented the positive impacts of anthropomorphic chatbots. Banks should use a chatbot that has the appropriate balance of anthropomorphism, or none at all. As suggested by Crolic *et al.,* (2022), a less precise option would be to assign non-anthropomorphic banking chatbots to customer support tasks that frequently include irate consumers while continuing to use anthropomorphic banking chatbots in neutral or promotional settings.

The study's findings show that task and technology features, as well as task-technology fit, have a positive effect on customer service encounter satisfaction; thus, H15, H16, and H17 are statistically significant. Customer service satisfaction is improved by chatbot technology and task characteristics. It demonstrates the technology characteristics and tools that can be utilized to construct and design chatbots in the Zimbabwean banking sector. The outcomes of the study are consistent with earlier research. During the COVID-19 pandemic, Mulyono and Sfenrianto (2022) assessed customer satisfaction with Indonesian banking chatbot services. They found that the quality of the chatbot system, information, and service all improved consumer satisfaction. As a result, banking chatbots were able to deliver answers and information to consumers in a timely and accurate manner that was easy to understand. In the development and design of banking chatbots, employing complementary task and technological characteristics clearly increases customer service encounter satisfaction, thereby improving customer service. Because the degree of satisfaction with the chatbot is high, Quintino (2019) determined that the perceived technology attributes lead to a better customer experience. As the individual user interacts with technology through its use, the more usable the technology is, the more the individual will use it (Sitorus *et al.,* 2016).

6. Theoretical and Practical Implications

It's critical to evaluate multiple contact points and elements related to chatbots when it comes to mobile banking. Task-technology fit theory has made major contributions to research on online user and IT design, thanks to the appreciation of behavioral investigations (Aljukhadar *et al.,* 2014). There is a scarcity of research on chatbot-human interaction in the financial sector. The findings support the task-technology fit hypothesis by implying that performance characteristics should be aligned with technology and task characteristics when employing chatbots for online banking transactions and services, resulting in improved

service encounter satisfaction. Customer satisfaction can be achieved by combining important task features to create a proper fit for the technological device-specific activity with the appropriate balance of conversational intelligence in a chatbot.

Chatbots in banking serve as a customer service gateway, allowing customers to communicate and transact across many social media platforms or channels. The ongoing direct digital customer service revolution in the Zimbabwean banking sector in support of smart e-banking services requires both technological and human resources. Chatbot task and technology characteristics are imperative in the inclusion and development of banking chatbots that exhibit proactivity and communicability. Technologically savvy commercial banks in Zimbabwe must heavily invest in human capital that is highly skilled in machine learning, conversation design, and computing natural language. In addition, for banks to properly develop user-centric conversational platforms with communicability characteristics, technological know-how is required to match desired customer tasks. Commercial banks in Zimbabwe must repeatedly evaluate the content and language model, changing test groups to assess different material and questioning methods. Banks should treat a chatbot as a long-term project that requires extensive individual testing and continually shifting test groups, which necessitates several collaborators rather than viewing it as a simple technical project. The current study findings provide evidence that chatbot conversational intelligence negatively influences chatbot service encounter satisfaction. Managers dealing with the idea of technology taking over human-human service encounters must consider that this is not applicable in all aspects of customer service. Rather, they must re-strategize chatbots to be complementary to human customer service agents in order to improve customer service encounter satisfaction.

The study makes informed recommendations for an inclusive task-technology fit and conversational intelligence service chatbot design framework that could lead to improved customer service encounters in the Zimbabwean banking sector, as shown in Figure 10.

6.1 Feasibility Assessment for the Recommended Strategy

Most banks have found it difficult to integrate conversational intelligence into their customer care chatbots. This is due to the lack of resources in Zimbabwe for employing conversational intelligence chatbots. These resources include human capital with skills in constructing conversational intelligence chatbots and insufficient finances for necessary technical infrastructure. The inclusive task-technology fit and conversational intelligence service chatbot design framework will assist developers in creating customer-centered designs based on their needs and the information they want to access.

6.2 Implementation Guide: Inclusive Task-Technology Fit and Conversational Intelligence Service Chatbot Design Framework

1. *Identify tasks that are complementary/can be achieved by the present/available chatbot technology*: A combination of relevant chatbot task features can be used to determine if the technological device-specific activity is a good fit. The findings suggest that for a better fit when using chatbots for online banking transactions, performance parameters should be aligned with technology and task characteristics and services, resulting in improved customer satisfaction.
2. *Determine communicability and proactivity features applicable to the banking chatbot:* Chatbots are viewed as tools that allow users to receive information quickly and efficiently, and developers and marketers in the Zimbabwean banking business appear to place no emphasis on personality, emotions, or avatar features. These characteristics, however, frequently contribute to an increase in the costs associated with research and development and the time it takes to complete projects. A chatbot's communicability and proactiveness should not be overlooked. As a result, based on the understanding of the chatbot customer journey map, banks should consider including such conversational intelligence elements in banking chatbots.

3. *Align chatbot functionalities and capabilities with the appropriate communicability and proactivity features:* Though a task and technology match may exist, such a decision has a significant impact on critical marketing outcomes. An expectancy violation caused by elevated pre-interaction efficacy expectations drives the negative effect. Banks should use a chatbot that has the appropriate balance of anthropomorphism, or none at all. A less precise option would be to assign non-anthropomorphic banking chatbots to customer support tasks that frequently include irate consumers while continuing to use anthropomorphic banking chatbots in neutral or promotional settings.

6.3 General Recommendation

Customer service satisfaction is improved by chatbot technology and task characteristics. It demonstrates the technology characteristics and tools that can be utilized to construct and design chatbots in the Zimbabwean banking sector. The quality of the chatbot system, information, and service all improved consumer satisfaction. As a result, banking chatbots were able to deliver answers and information to consumers in a timely and accurate manner that was easy to understand. In the development and design of banking chatbots, employing complementary task and technological characteristics clearly increases customer service encounter satisfaction, thereby improving customer service.

Additionally, after building a chatbot, it is necessary to repeatedly evaluate the content and language model, changing test groups to assess different material and questioning methods. Furthermore, when forming a chatbot development team, banks should hire employees with a variety of skills. Finally, banks should treat a chatbot as a long-term project that requires extensive individual testing and continually shifting test groups, which necessitates several collaborators rather than viewing it as a simple technical project.

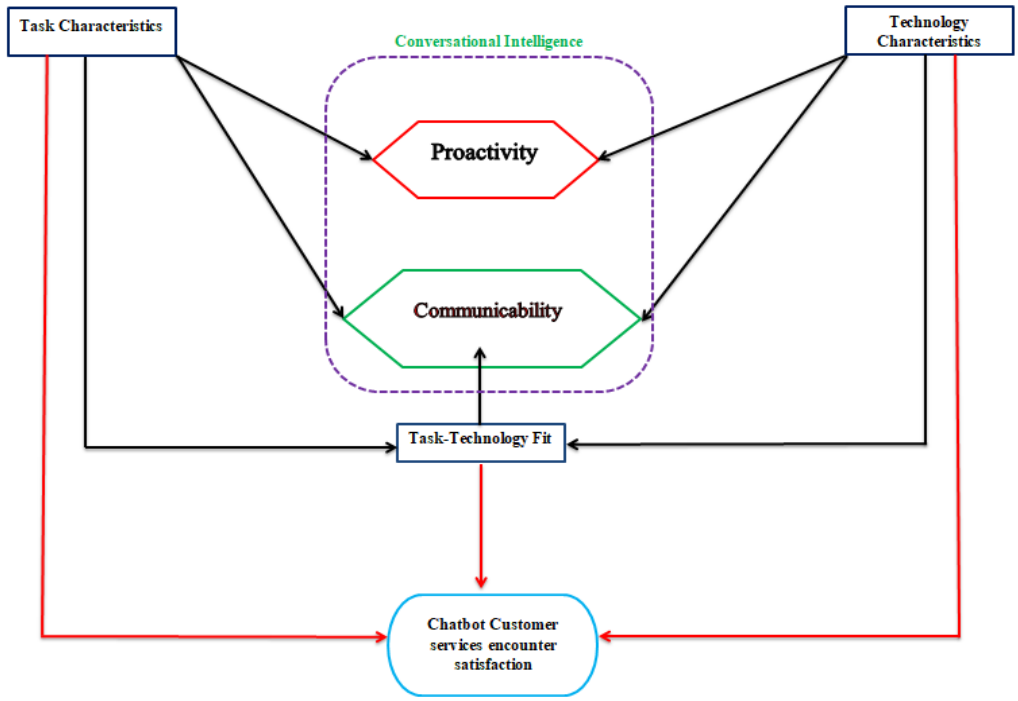

Figure 10. Inclusive task-technology fit and conversational intelligence service chatbot design framework

7. Conclusion

Chatbot task-technology fit is positively influenced by task and technology characteristics. Task and technological characteristics are linked to the degree of fit in the online banking setting. The findings show that chatbot task and technological characteristics influence chatbot communicability and proactivity positively. Chatbot task and technology attributes, on the contrary, have a negative effect on chatbot contentiousness. Task difficulty negatively moderates the association between friendliness and consumer trust in chatbots. The relationship between chatbot qualities and trust is moderated by task complexity and text-based chatbot disclosure, such that when the customer's task is difficult, the beneficial effect of friendliness on consumer trust is diminished. This is because customers may be more interested in the chatbot's professional competence and ability to handle problems than in their attitudes or customer service approach. Furthermore, task-technology fit had a negative influence on chatbot proactivity and conscientiousness, but a positive effect on communicability. Task-technology fit has a positive effect on social characteristics, meaning that it allows for the exchange of information during discussions. Conversational intelligence characteristics (contentiousness, communicability, and proactivity) have a negative mediation effect on task-technology fit and chatbot customer service encounters. Thus, banking chatbots with human-like traits may not lead to a better customer experience, as their perceived ease and utility are not necessarily enhanced. The study's findings show that task and technology features, as well as task-technology fit, have a positive effect on customer service encounter satisfaction. Because the individual user interacts with technology through its use, the more usable the technology is, the more the individual will use it. The perceived technology attributes contribute to a better customer experience, as the degree of satisfaction with the chatbot is high. Therefore, a solid task-technology-performance match improves customer service encounter satisfaction and chatbot conversational intelligence in Zimbabwe's banking sector.

8. Limitations

The study has limitations that may affect the generalizability of the results, as they can only be applied to the literature area studied. The study contextualized its framework in the banking sector in Zimbabwe, and the outlined research questions may apply to other service sectors where digitalization is occurring (e.g., health care).

9. Future Research

Additional research studies in different regions of the world might be conducted to provide cross-cultural comparability and empirical validation. Longitudinal empirical research investigations can be carried out in the future to assess variations in economic scenarios in other relevant studies and further evaluate other theoretical frameworks related to chatbots' customer service encounter satisfaction as an e-banking customer service theory.

10. Data Availability

The data used to support the findings of this study are available from the corresponding author upon reasonable request.

11. Conflict of Interest

The authors declare that they have no conflict of interest.

12. Acknowledgment

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Motor vehicle engine lubricants and their viscosity classes according to SAE, API and ACEA

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Abstract. The paper presents the author's own scientific representation and original point of view on the technical acceptability of lubricants for automotive thermal engines. In this way, those interested can become knowledgeable about the viscosity classes of engine lubricants according to the Society of Automotive Engineers (SAE), the American Petroleum Institute (API) and the European Automobile Manufacturers Association (ACEA). Readers can also learn about some aspects of lubricants for racing and military automobile engines. Finally, the paper deals with two case studies of lubricants used in BMV car engines using different fuels, gasoline and diesel. The conclusions related to the research are then drawn.
Keywords: *automotive, thermal engines, lubricants, viscosity class, racing cars, military vehicles*

Introduction

Lubricants have been in some use for thousands of years. Calcium soaps have been identified on the axles of chariots dated to 1400 BC. Building stones were slid on oil-impregnated lumber in the time of the pyramids. In the Roman era, lubricants were based on olive oil and rapeseed oil, as well as animal fats. The growth of lubrication accelerated in the Industrial Revolution with the accompanying use of metal-based machinery. Relying initially on natural oils, needs for such machinery shifted toward petroleum-based materials early in the 1900s. A breakthrough came with the development of vacuum distillation of petroleum, as described by the Vacuum Oil Company. This technology allowed the purification of very non-volatile substances, which are common in many lubricants [1]. Lubricants are liquid, semi-fluid or semi-solid substances, whose main characteristic is the ability to form a film between solid surfaces under friction [2, p. 5]. With this element, friction is relieved and its effects are much less destructive to solid parts. There is a wide range of substances that can be used in this case, all of which must, however, satisfy three basic functions. Firstly, the substance must adhere to the parts of the assembly, forming a film that does not allow the metal parts to come into direct contact. Secondly, lubricants also have a chemical function, protecting the metal parts from moisture or various acidic substances that could attack the metal structure. Thirdly, lubricants also have a thermal function, helping to remove the thermal energy resulting from friction. Recent studies have shown that about 70% of unplanned equipment downtime is caused by incorrect choice and use of lubricants. However, the studies also show that most fleet managers use any synthetic lubricants to lubricate their

fleets, without having a clear principle to follow for fleet management. This is not the right approach, leading over time to multiple and serious mechanical problems caused by serious defects.

1. Viscosity classes of engine lubricants according to Society of Automotive Engieers (SAE)

If the oil satisfies the requirements of only one viscosity grade, the oil is called monograde (e.g. SAE 30 or SAE 40 known in Romania as "M"). For example, a 15W-40 oil will provide a cold start similar to a 15W grade oil and will behave at high temperatures like a 40 grade oil. However viscosity grade tells us nothing about the quality of an engine oil. It depends on the composition of the oil. A car lubricant can be based on mineral, synthetic or semi-synthetic oil. Mineral oil can be obtained by physical or chemical processing (this process is called Hidrocrack). Synthetic oils can be obtained from synthetic esters or polyalphaolefins (PAO). A lubricant may also contain additives, such as anti-foaming agents, detergents, dispersants, antioxidants and anti-corrosives [2, pp. 469-489]. As a rule of thumb, synthetic oils can be said to be superior to mineral oils, but that doesn't mean it's the right one for your engine. The performance level tells us much more about the quality of a lubricant. An engine oil's viscosity grades are set by SAE - the Society of Automotive Engineers. In this case I explain what 5W-40 engine oil means:

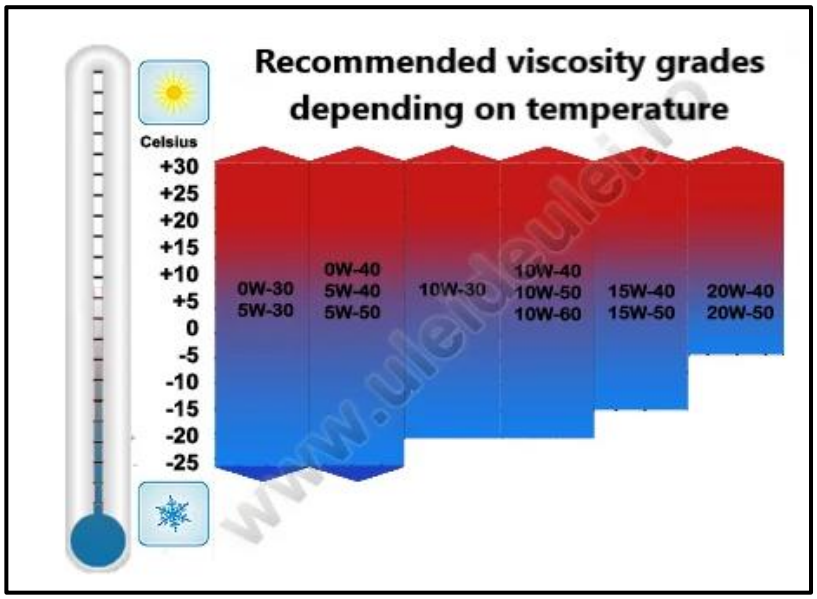

Figure 1. Recommended viscosity grades of thermal engine lubricants by temperature [3].

- "5" represents the degree of viscosity of the oil when cold;
- The letter "W" comes from the English "Winter" meaning "winter";
- "40" represents the degree of viscosity of the hot oil;

Figure 1 shows the recommended viscosity grades of thermal engine lubricants by temperature.

2. American Petroleum Institute (API) viscosity classes of warm engine lubricants

The American Petroleum Institute is the national association representing the U.S. oil and natural gas industry in all its aspects. API provides the Engine Oil Licensing and Certification System (EOLCS), a voluntary licensing and certification program that authorizes manufacturers and marketers of engine oils that meet the requirements to use the API quality marks. Here's how to evaluate an engine lubricant according to API [1]:

✓ The API classification system provides information about engine oil. The letter "S" followed by another letter (e.g. "SM") indicates that the oil is suitable for spark ignition (gasoline) engines;

✓ SL oils are superior to SF oils in several performance criteria including increased fuel efficiency, meeting the "energy conservation" classification and increased emissions protection system;

✓ The letter "C" followed by another letter or number (e.g. CI-4) indicates that this oil is suitable for diesel (compression ignition) engines;

✓ The second letter in the categories "C" and "S" is assigned in alphabetical order. The further up the alphabet we go, the more advanced the technology and the higher the quality of engine oils;

In our case Valvoline SynPower 5W40 meets API quality class: SM/CF and therefore benefits from the latest additive technology.

API classifies lubricants according to their performance in engines taking into account the type of service, operating conditions, change intervals, fuel used, etc. This classification comprises two categories: **SX** - for gasoline engines; **CY** - for diesel engines, where **X** and **Y** are consecutive letters in the alphabet indicating the updated subsequence.

The API classification of thermal engine lubricants, is as follows [4]:

a) Gasoline engines

SN: category introduced in October 2010 for engines produced from 2011 and older. These oils provide piston protection against deposits due to operation at very high temperatures, tighter deposit control and compatibility with sealing materials. These oils comply with ILSAC GF-5 requirements to provide fuel economy, turbocharger protection, compatibility with exhaust gas treatment systems, and protection for engines using ethanol fuel up to E85;

SM: grades introduced in November 2004 to provide increased resistance to oxidation, better protection against deposits and wear, and superior low-temperature performance throughout the life of the oil. These oils can be used where the old SL and SJ grades are recommended;

SL: The SL category was adopted in 2001 to meet the typical operating conditions of gasoline engines in cars, vans and light trucks. Oils of this type can also be used in place of SH or older oils;

SJ: Category SJ covers the requirements for oils for gasoline engines, produced since 1997, in passenger cars, vans and light trucks. Oils of this type can also be used in place of SH or older oils;

SH: out of use. For 1997 and older models;

SG: out of use. For 1993 and older models;

SF: out of use. For 1988 and older models;

SE, SD, SC, SB, SA: out of use categories. Warning: SE not recommended for engines built after 1979; SD not recommended for engines built after 1971 which may cause damage; SC not recommended for engines built after 1967 which may cause damage; SB not recommended for engines built after 1963 which may cause damage; SA not recommended for engines built after 1930 which may cause damage.

b) Diesel engines

CJ-4 (2007): high-rpm four-stroke engines with advanced exhaust treatment systems (DPF and EGR - Exhaust Gas Recirculation);

CI-4 Plus* (2004): high-rpm four-stroke engines and EGR. High dispersion properties.

* Superior dispersance characteristics and longer service life than those expected for CI-4;

CI-4 (2002): high-rpm four-stroke engines with/without EGR;

CH-4 (1998): high-rpm four-stroke engines (standard emissions - 1998);

CG-4 (1994): high-rpm four-stroke engines, severe service conditions;

CF (1994): indirect injection engines for off-road vehicles using high sulphur fuel. Replaces API category CD;

CF-2 (1992): two-stroke engines operated under severe conditions requiring increased performance. Replaces API category CD-II;

CF-4 (1990): out of use. Typical high-rpm four-stroke engines;

CE (1987): out of use. Naturally aspirated or turbocharged two-stroke engines operated in severe conditions;

CD-II (1987out of use. Two-stroke engines operated under severe conditions;

CD (1955): out of use. Naturally aspirated or turbocharged four-stroke engines operated under severe conditions;

CC (1961): out of use. Engines operated in moderate conditions;

CB (1949-1960): out of use. Engines operated in moderate conditions.

CA (1920-1930): out of use. Engines operated in easy conditions.

c) Auto gearing

API GL-4: oils intended for the lubrication of helical bevel helical and helical bevel gears operating at moderate speeds and loads. These oils may be used for certain manual gearboxes and transmission shafts;

API GL-5: oils for the lubrication of automotive gears, in particular hypoid gears operating at combinations of high/low speeds, high torque, shock loads. These oils must possess anti-rust, anti-foaming, pitting and scuffing characteristics, resistance to oxidative and thermal degradation;

API MT-1: lubricants intended for manual transmissions (without synchronizers) operating under severe conditions. Lubricants meeting the MT-1 specification shall provide good resistance to thermal degradation and be EP (extreme pressure) additive.

Note: In 1995, SAE Technical Committee 3, decided to drop the API categories: GL-1...3 and GL-6.

3. Viscosity classes of engine lubricants according to the European Automobile Manufacturers Association (ACEA)

The European Automobile Manufacturers Association (ACEA), founded in 1991, represents the interests of 13 car, truck and bus manufacturers at European level. The members of this association are major international companies in the automotive market, working together on legislative, commercial, technical, environmental, commercial and environmental protection issues. ACEA members are competitors on the car market but support free and fair competition.

ACEA has established a classification in 4 performance categories [4]:

- ✓ Category A - gasoline engines;
- ✓ Category B- diesel engines for passenger cars;
- ✓ Category C- catalyst compatible oils;

ategory E- diesel engines for heavy-duty vehicles;

ACEA main division [1]:

- ✓ ACEA A- gasoline engines;
- ✓ ACEA B- passenger car diesel engines;
- ✓ ACEA A/B- gasoline and light diesel engines;
- ✓ ACEA C- oils compatible with catalyst systems for gasoline and diesel engines with a secondary exhaust gas recirculation system with low sulphur, phosphorus and sulphurous ash content;
- ✓ ACEA E- diesel engines for heavy-duty vehicles.
- ✓ The ACEA classification of thermal engine lubricants, is as follows [1]:

ACEA A classification:

- ✓ ACEA A1- standard quality;
- ✓ ACEA A2 - the best quality standard;
- ✓ ACEA A3- best quality in relation to temperature and oxidation;
- ✓ ACEA A4- category retained for future gasoline engines to be equipped with direct injection system;
- ✓ ACEA A5- long-life oils that offer the possibility to reduce fuel consumption.

ACEA B classification:

- ✓ ACEA B1- basic quality;
- ✓ ACEA B2- best quality standard;
- ✓ ACEA B3- best protection against wear and ash formation;
- ✓ ACEA B4- for direct injection diesel engines;
- ✓ ACEA B5- best quality with maximum fuel economy.

ACEA A/B classification:

- ✓ ACEA A1/B1- for diesel and gasoline truck engines;
- ✓ ACEA A3/B3- very stable oils used in gasoline and diesel engines of trucks. This type of oil changes at longer intervals and is used in older cars;
- ✓ ACEA A3/B4- very stable high quality oils used in high performance gasoline and diesel engines with direct injection of recent production;

✓ ACEA A5/B5- low viscosity, high stability oils used in diesel and gasoline engines as well as in trucks.

- ***ACEA C classification:***

✓ ACEA C2- Stable oils used in engines with 3-way catalyst and particulate filter that have low viscosity at high temperatures. They increase the performance of the 3-way catalyst and particulate filter. If there is any uncertainty about the use of this type of oil, check the instructions in the vehicle manual;

✓ ACEA C3- oils used in diesel engines that are equipped with a particulate filter and 3-way catalytic converter as well as in high performance gasoline engines;

✓ ACEA C4- oils used in diesel and gasoline engines equipped with a particulate filter and 3-way catalyst and in which the SAPS (ash sulphate, phosphorus and sulphur) level is less than or equal to 0.5% and HTHS (high temperature viscosity) greater than 3.5MPa.s. If there is any uncertainty about the use of this type of oils, check the instructions in the vehicle manual.

- ***ACEA E classification:***

✓ ACEA E1- standard quality. It was retracted in 2000;

✓ ACEA E2- general use oil for naturally aspirated, turbocharged diesel engines with indirect or enhanced cycle and normal oil change intervals;

✓ ACEA E3- oils that provide protection against soot, prevent clogging of engine lubrication channels;

✓ ACEA E4- stable oil that maintains its properties, ensures ash removal and protection against piston wear and soiling. It is recommended for diesel engines that meet Euro1, Euro2, Euro3 and Euro4 emission requirements. It is also recommended for engines without particulate filters and for engines with exhaust gas recirculation or equipped with SCR NOx NOx reduction system;

✓ ACEA E5- meets the requirements of modern diesel engines with Euro1, Euro2, Euro3 and Euro4 European emission standards;

✓ ACEA E6- stable oil that maintains its properties, ensures ash removal and protection against piston wear and soiling. It is recommended for diesel engines meeting Euro1, Euro2, Euro3 and Euro4 emission requirements. It is also recommended for engines with exhaust gas recirculation or equipped with SCR NOx NOx reduction system. This type of oil is recommended for engines equipped with volatile particulate filters and those using fuel containing sulphur (maximum 50ppm);

✓ ACEA E7- stable oil that retains its properties, provides protection against wear and soiling of pistons, ensures polishing of cylindrical horns and ash removal. Provides good protection against normal wear and against debris accumulating in the turbocharger, removes soot and ensures grease stability. It is recommended for diesel engines with Euro1, Euro2, Euro3 and Euro4 emission requirements. It is also recommended for engines that do not have particulate filters, have emission gas recirculation systems (EGR) and are equipped with SCR NOx NOx reduction system.

4. A short characterization of racing engine lubricants

If a normal car is designed for everyday use, where benefits such as fuel economy and comfort are paramount, a racing car is designed to achieve maximum results with a very specific purpose in mind. That's why the chassis, tires, engine, suspension, interior and aerodynamics have been tuned to get the best results. A racing car's engine is under a lot of stress. These engines are often tuned and designed to deliver maximum power and torque at high revolutions per minute. They produce extreme heat and pressure that would not exist in a normal car. They are very taxing on the engine and so the oil must offer protection accordingly. Racing cars use powerful, modified engines with temperatures reaching over 120°C. Moreover, with every 10°C increase in temperature, the oxidation rate of the engine oil doubles and significantly reduces its lifetime. Racing engine oil must withstand massive shear forces. Such high pressure can damage the molecular structure of the engine oil, causing reduced viscosity and film strength. This is why racing cars require the use of an advanced racing engine oil, an oil that is produced differently from regular passenger car oil. Racing oil is designed to withstand the need for high speeds and to protect racing engines against wear.

A racing car engine lubricant must contain quality base oil. This is the first and most important requirement of a racing oil. Base oil accounts for 70-90% of any product. The base oil does not necessarily have to be synthetic, as is mistakenly believed about racing oils. Just like any other engine oil formulation, racing oils use different base stocks, ranging from mineral to synthetic. It's true, however, that - just like in regular cars - synthetic racing oils offer better performance because they go through complex refining and purification processes. As such, synthetic racing oils offer better properties than traditional mineral oils. Here are some of them: they resist oxidation at higher temperatures; they have longer drain intervals; they have superior anti-wear and lubrication properties; they have lower volatility, which means they evaporate more slowly when they are heated; they have greater deformation stability, which allows more accurate estimation of viscosity characteristics; they have superior air release capacity, which minimizes the risk of aeration.
The functional qualities of racing lubricants are demonstrated by [6]:

- *Strong additives.* The base oil needs to be enhanced by a powerful package of additives that provide superior lubricity, anti-wear and antioxidation properties. Some of them are corrosion inhibitors, anti-oxidants, anti-foaming products, detergents, viscosity index improvers and so on. But one additive that differentiates racing engine oils from regular oils is ZDDP. Racing oils contain high levels of ZDDP (Zinc Dialkyl Dithiophosphate), a powerful anti-wear and anti-friction additive. ZDDP is a combination of phosphorus and zinc, which creates a protective layer that minimizes metal-to-metal contact under pressure and at extreme speeds, adhering to metal surfaces and creating a thin film around them;
- *High viscosity*. When it comes to racing oils, viscosity depends on many factors, including ambient temperatures and engine rpm. Viscosities range from monograde oils (30, 40, 50 and 70) to multi-viscosity oils such as 0W-30, 5W-40, 20W-50, etc. The most common type of racing oil is 10W-60, with a fully synthetic PAO base oil;
- *Thermal stability.* When exposed to high temperatures, engine oil can degrade. Oil breakdown is accompanied by multiple performance problems, including reduced viscosity, increased oxidation, sludge formation and engine wear. Good thermal stability is therefore one of the essential properties of any quality racing oil. It represents the lubricant's ability to resist oxidation at high temperatures and determines how your vehicle behaves under such operating conditions;
- *Easy specific maintenance.* Usual engine oil generally lasts two years or more, depending on driving conditions. But for high performance oils these rules do not apply. As a rule of thumb, racing oil should be changed after one or more races, but the frequency of changes always depends on operating conditions. Dirt and contaminants are a major cause of frequent racing oil changes. One of the most common misconceptions is that low viscosity oils cannot protect racing engines. Thinner oils can flow faster and produce more horsepower. But thicker, higher viscosity oils can better meet the demands of racing vehicles, which operate at extremely high temperatures and extreme loads.

5. A short characterization of lubricants for military vehicles

Military vehicles, like racing cars, operate in the harshest and most demanding conditions. From extreme temperatures to rugged terrain, these vehicles require special maintenance to function optimally. An essential aspect of this maintenance is the use of military vehicle lubricants and oils. These products not only ensure the proper functioning of mechanical components, but also help extend the life of the vehicles, reducing wear and tear and preventing costly breakdowns. When it comes to fluids that come in contact with the metal parts of a car and engine oils specific to military vehicles, there are specific instructions on each type of industrial lubricant and where and when it should be used. When thinking about oil compatibility with military equipment and military oil specifications, there are a few things to keep in mind. Here they are. To choose the lubricant required for military vehicles it is important to always consult their maintenance manual. The manual for the military equipment or vehicle will always have the authorized lubricants clearly listed. If military oil is not available for any reason, it is advisable to find a suitable alternative. For example, when it comes to engine oils for turboprop airplanes, MIL-PRF-7808 and MLI-PRF-23699 are the only two acceptable

alternatives. MIL-PRF-7808 is a synthetic-based military oil specifically designed for aircraft turbine engines, helicopter transmissions and accessory equipment. This oil is designed for low temperature environments (such as Arctic and high altitude operations). The viscosity of this oil allows temperatures down to -51 degrees Celsius. The military oil for airplanes is MIL-PRF-23669. This oil offers the same properties as the first, although it only allows cold weather down to -40º Celsius. Due to the intense nature of many military operations, the use of standard oils is not acceptable. Both the extreme temperatures and the extreme stress on the engine require the use of a specific, superior quality oil.

The high operating qualities of lubricants for military vehicles are demonstrated by [7]:

- *High viscosity.* One of the most important factors related to military oil is viscosity. Viscosity is a measure of a fluid's resistance to flow. A thicker fluid is considered to have a high viscosity because it will flow more slowly. Thinner fluids will flow faster and thus have a lower viscosity. The viscosity of an oil varies with temperature. The viscosity grade shows the maximum flow rate of the oil at low temperatures. If temperatures become extreme, as they do in many military operations, the wrong type of oil or lubricant can stop the flow and cause catastrophic damage to equipment and vehicles;
- *Improved lubrication.* The main role of a lubricant is to prevent various forms of wear. By eliminating friction, the engine will run smoothly without the need for regular repairs and replacements. But there are also lubricants that are not good enough to improve a fleet's lubrication system. The specifications for military oils meet all the requirements for quality oils. They reduce wear by over 90%, which is difficult to achieve with other forms of lubricants in the industry;
- *Cleaner engines.* Every fleet manager and mechanic should turn to a heavy-duty lubricant that will not only lubricate the engine system, but will also keep the various parts of the engine clean. Most engines are characterized by sludge, grease and other oils. However, the majority of oils on the market contribute to dirt rather than cleaning and removing all debris and foreign matter. Military oils, on the other hand, play an essential role in cleaning the entire engine, especially by removing all traces of dirt and debris from moving parts;
- *Improved engine cooling.* Most heavy vehicles need to cool their engines during long journeys. Water and air are the main cooling mechanisms in most engines. However, the finer parts of these vehicles can only be cooled with special lubricants. The specifications of military oils are essential in cooling all engine parts due to their extreme penetration. The fact that military oils have very high boiling points makes them the ideal alternative for cooling parts;
- *Superior engine efficiency.* Mechanical and physical deficiencies and vulnerabilities in the engine lead to a situation where most of the system is weak and does not allow the engine to perform its role optimally. This situation is very inefficient due to weak parts and sometimes poorly sealed engine and cylinder pistons. This can lead to poor engine performance. Military vehicle oils are essential to fill all the holes and voids left by poor mechanical workmanship, which helps to increase engine efficiency and performance;
- *Increased engine durability.* Most manufacturers of standard lubricants talk about the benefits of using their oils, but none of them emphasize that their oil will increase engine life. The explanation is that most standard oils are not of the highest quality and play a major role in reducing engine life. But military oils have long-term lubricity capabilities not found in other lubricants;
- *Reduced environmental pollution.* In recent years there has been a whole series of rules and regulations governing the environmental impact of different oils. Most construction lubricants, as well as most regular oils, are currently struggling to meet these standards, which often makes them inadequate. On the other hand, the oils used in military applications meet all the necessary environmental standards, making them the ideal choice of oil in terms of environmental protection.
- *Easy maintenance and operation.* Maintenance of military vehicles requires attention to detail and rigorous planning. Essential conditions for the lubricants of military vehicle engines to meet the above requirements: regular oil changes. Follow manufacturer-recommended change intervals to maintain optimal engine performance; monitor oil and fluid levels-check oil and other fluid levels

frequently to prevent deficiencies that can lead to failure; use quality products-invest in high-quality oils and lubricants designed specifically for the harsh operating conditions of military vehicles; clean and inspect systems-keep filtration systems clean and inspect components regularly for signs of wear or leaks.

Figure 2. Original Twin Power Turbo lubricant for BMW engines.

6. Thermal engine lubricants for BMW cars. Case study

When a BMW engine malfunctions due to the use of improper lubricants, users blame them. Hence the myth that "original BMW oil does not damage the engine if it is replaced in accordance with the requirements of the vehicle's technical note".

- The **first case study** is a BMW M 135i supercharged (turbocharged) gasoline fueled BMW M 135i, whose original Twin Power Turbo lubricant (Figure 2) in the engine was used 30,939 actual km, well above the norm specified in the technical note of the vehicle, i.e. 9,830 actual km, lubricant replaced at the term specified by the manufacturer in the technical note of the car. Analyzing the data with a dedicated software on a PC gives disastrous data (Figure 3).

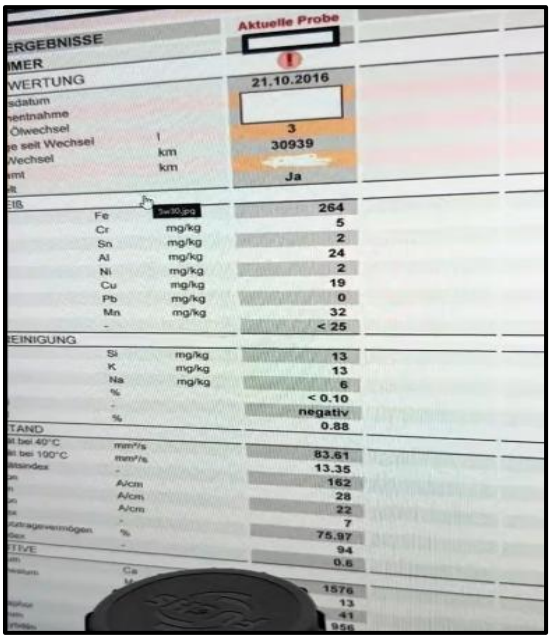

Figure 3. Results obtained with the software for the original BMW M 135i engine oil, at an actual mileage of 30,939 km.

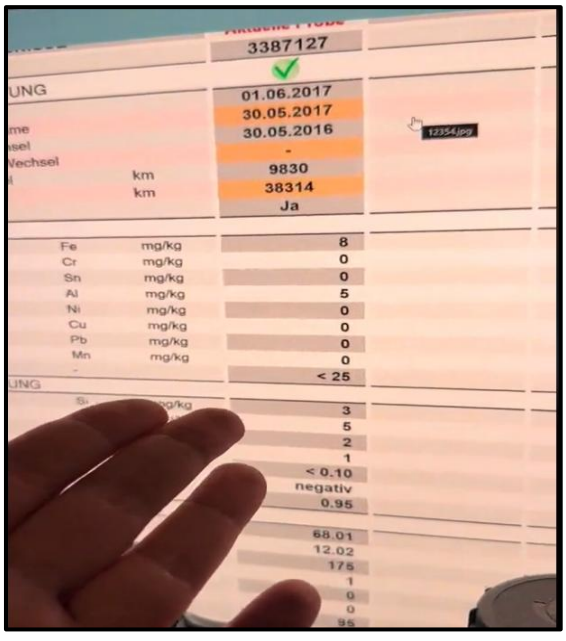

Figure 4. Software results for the original BMW M 135i engine oil at an actual mileage of 9,830 km.

Analysis of the data presented in Figure 3 shows 348 parts per million wear at an actual over-run of 30,939 km, compared with the same engine, whose lubricant was changed on schedule, i.e. at 9,830 km (Figure 4), where 13 parts per million wear was found. In order to understand what 348 and 13 parts/million attrition, respectively, means, we have to think of the aspect where a sample of lubricant is extracted from the engine and sent to a specialized laboratory for analysis. Here, the amount of

microscopic particles in the lubricant's composition is analyzed, particles in the form of particles in the order of microns.

The more microscopic deposits there are in the lubricant, the more wear on the engine. The appearance of the lubricant in the engine was also analyzed by color spectrum analysis. Figure 4 shows the color spectrum analysis of the replaced engine lubricant at 30,939 km and Figure 5 shows the color spectrum analysis of the replaced engine lubricant at 9,830 km. Analysis of the data presented in the two figures shows that the lubricant replaced at 30,939 km has a dark color spectrum (black), identical to diesel engines, while the lubricant replaced at 9,830 km has a light color spectrum (brown), specific to gasoline engines.

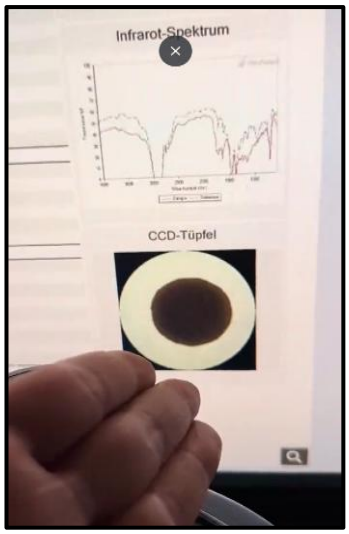

Figure 5. Color spectral results for the original BMW M 135i engine oil after 30,939 km.

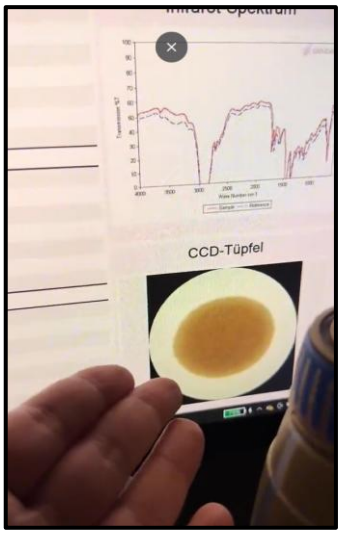

Figure 6. Color spectral results for the original BMW M 135i engine oil after 9,830 km.

In comparison with another type of lubricant, e.g. Castrol Edge LL 5W30 5W30 15666D (Figure 7), let's suppose we buy a BMW 320 diesel-engined car, bought second-hand from the West, with 250,000 km on board and serviced according to the manufacturer's technical specifications ("by the book") at the BMW dealership.

Like any bona fide user, in order to perform to the srtabilized deadline, I purchase for maintenance the MAN oil filter and Castrol engine lubricant, shown above. At some point, the lubricant pressure in the engine drops dramatically, the warning lights on the dashboard come on, and the engine stops due to a technical fault in the lubrication system. The user's mind starts to think that he has put a counterfeit lubricant into the engine, because this type of lubricant is counterfeit in Romania. The real problem is that we bought a car with a lot of wear and tear, with revisions carried out at 30,000 km and not at 10,000 km. To illustrate how serious the situation is, the engine of the supercharged BMW M 135i (Figure 8), at over 200,000 km, with subsequent overhauls at 10,000 km, will have about the same engine wear as one that has had a single overhaul at 30,000 km. However, great care should be taken with Castrol lubricants in Romania. If purchased from a reliable source, they are not so counterfeit that they can damage our engines. If you look on Romanian websites (e.g. OLX, or private individuals), it is quite easy to see that the engine lubricants are bottled and labeled improperly, which shows that they are counterfeit. Therefore, beware of counterfeit lubricants, which are qualitatively inadequate, as

Figure 7. Castrol Edge LL 5W-30 15666D.

Figure 8. BMW M 135i car with supercharged engine.

they lead to rapid wear of rotating or translating parts in the engines of road vehicles, further ac centuating wear.

The **second case study** is that of a BMW 520d, engine code LCI B47D20 (Figure 9). In this case, if the engine lubricant is not changed at a maximum of 10,000 actual kilometers, the wear increases exponentially. In Figure 10 I show the case of a counterfeit lubricant, which was not changed within the prescribed period. Analysis of the data shows high amounts of: diesel oil (4.1 ppm) and ash (4.5 ppm) in the lubricant, which resulted in excessive wear (see data in Figure 10, top right).

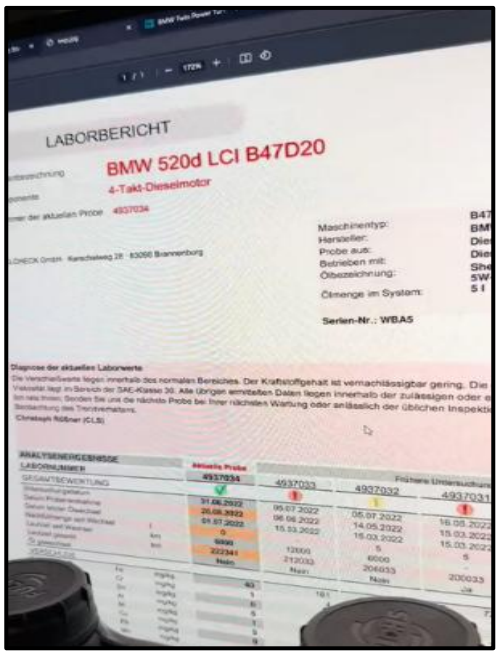

Figure 9. Lubricant testing for BMW 520d LCI B47D20 engine B47D20.

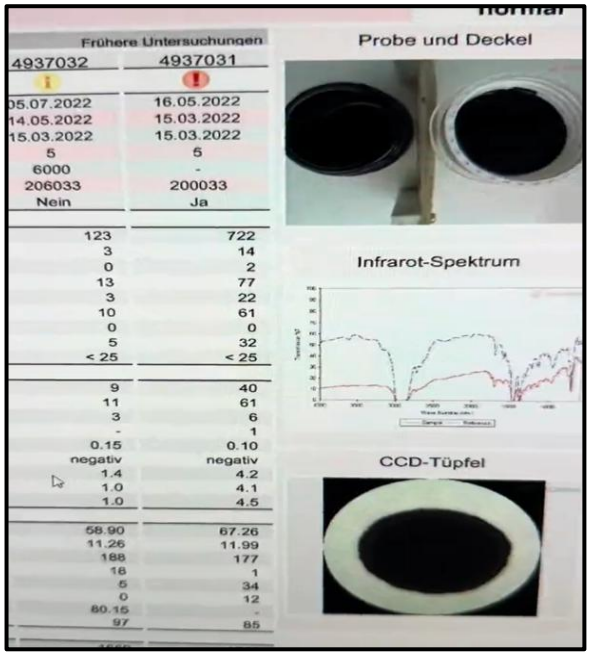

Figure 10. Results obtained with counterfeit lubricants.

If we compare these results with those obtained on a BMV 3-series, 320d engine, engine code LCI B47D20, using Fuchs lubricants (Figure 11), which were changed at 10,000 actual km, and with the same type of engine on a BMW 5-Series (Figure 12), which uses a different type of lubricant at different change intervals, we observe much lower engine wear values.

This is also due to the fact that, unlike gasoline BMW engines, diesel engines are more tolerant of more viscous lubricants. The results of the friction by measurement of particles in the lubricant composition are shown in Table 1.

Table 1. The results of particle friction measurements in the composition of Fuchs lubricants used in BMW car engines.

The resulting composite material mixed with the lubricant	**U/M**	**Lubricant analysis results Fuchs Titan GT1 PRO C-3 5W-30/10,000 km.**	**Lubricant analysis results Fuchs Titan GT1 FLEX 3, 5W-40/10,000 km.**
Fe	mg/kg	23	17
Cr	mg/kg	1	1
Sn	mg/kg	0	0
Al	mg/kg	13	7
Ni	mg/kg	1	1

The resulting composite material mixed with the lubricant	U/M	Lubricant analysis results Fuchs Titan GT1 PRO C-3 5W-30/10,000 km.	Lubricant analysis results Fuchs Titan GT1 FLEX 3, 5W-40/10,000 km.
Cu	mg/kg	5	4
Pb	mg/kg	0	0
Mn	mg/kg	1	1
Degree of wear	-	< 25	< 25

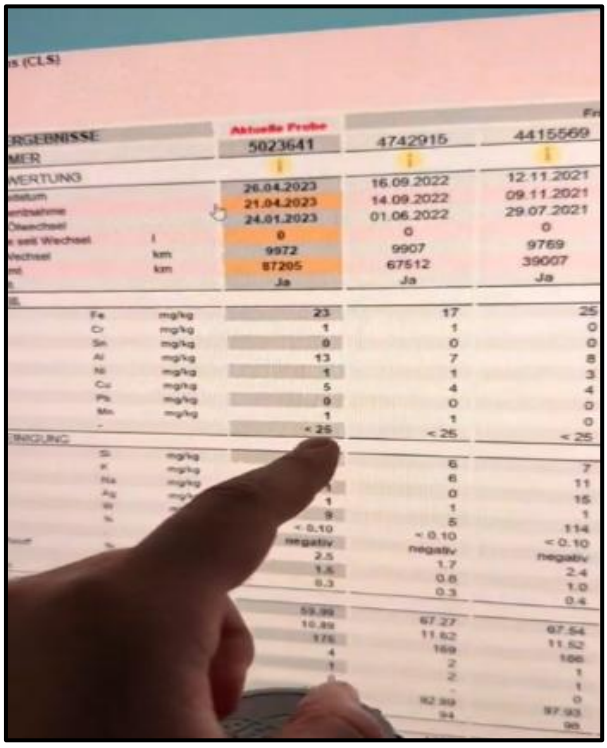

Figure 11. Wear values of a BMV 3-series 320d car engine, engine code LCI B47D20 at 10,000 km using a Fuchs lubricant.

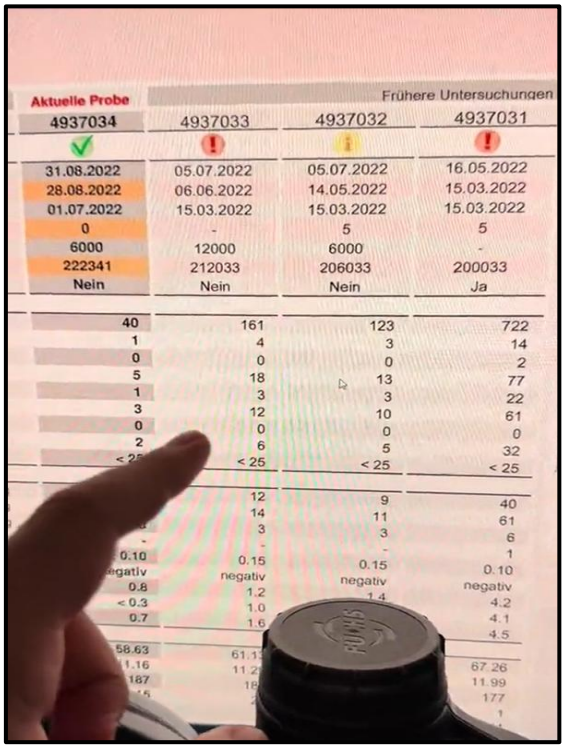

Figure 12. Wear values of a BMV 5-series 520d car engine, engine code LCI B47D20 at 10,000 actual km using a Fuchs lubricant.

Analysis of the data presented in figure 11 and Table 1 shows that Fuchs 5W-40 lubricant has lower engine wear values. This is due to the high viscosity and is the main reason for recommending Fuchs Titan GT1 Flex 3, 5W-40 for BMW engines (Figure 13).

For the famous N47 series diesel engines in BMW cars, engines with an enviable reliability, a number of precautions must be taken to prevent technical problems that could be caused by the lubricants used. The N47 is a four-cylinder diesel engine produced by BMW. It was first introduced in 2007 and has been used in a variety of BMW models. These models include: BMW 1 Series (116d, 118d, 120d); BMW 3 Series (316d, 318d, 320d); BMW 5 Series (520d); BMW X1 Series (sDrive 18d, xDrive 18d, xDrive 20d); BMW X3 Series (xDrive 18d, xDrive 20d, xDrive 30d).

This engine was designed to provide a balance between performance and fuel efficiency. Notwithstanding the above, there are some known problems with the gas timing chain of this engine which, due to technical maintenance issues, including the use of improper engine oils, lead to premature wear.

For these reasons, in order to keep the N47 engine in optimal operating condition, regular maintenance practices are recommended by the BMW manufacturer. In the following, we present some of these:

- Regularly replace the engine lubricant and filter according to the recommended maintenance schedule: This promotes proper, efficient and effective lubrication of the motor mechanism or other parts in the gearing;
- Check and replace air and fuel filters on time to ensure proper air-fuel mixture. This keeps fuel consumption low and avoids hydrocarbon contamination of lubricants;
- Inspection and maintenance of the cooling system, including regular checks of coolant level and quality. This keeps the engine running at optimum engine speed, avoids overheating and eliminates coolant mixing with lubricant;
- Timely inspection and replacement of the timing chain and associated components to prevent wear and impregnation of the wear particles resulting from wear and tear with engine lubricant;

Figure 13. Fuchs Titan GT1 PRO C-3, 5W30 and Fuchs Titan GT1 Flex 3, 5 W-40 engine lubricants.

- Avoid engine overheating and rough acceleration that could affect the lubricating quality of the engine oil.

Schedule regular check-ups with an authorized service to identify and fix any potential problems before they become serious (preventive maintenance).

Following all of these maintenance requirements and practices will help to maintain the performance and reliability of the N47 engine over the long term. It is therefore recommended to use only dedicated engine lubricants approved by BMW.

Lubricants such as LIQUI MOLY 5W-30 TOP TEC 4200, MOTUL X-clean+ 8100, SAE 5W-30 Sinthetic can also be used. However, I do not agree with the labeling of the lubricant MOTUL X-clean+ 8100, SAE 5W-30 100% Synthetic in Europe and HC Synthetic in Germany, or that in Germany it has one code and in Romania it has another code, this does not indicate that we are dealing with a low quality lubricant. The lubricant has all the necessary approvals for BMW engines and is in accordance with the manufacturer's specifications. Accordingly, it has been submitted to them, tested and approved for use. It is certified for use in engines that require the viscosity (5W -30 100% Synthetic) and specifications listed on the packaging (BMW LL-04; MB- Approval 229.51; Porsche C30; VW 504 00/507.

7. Conclusions

Engine problems in the car you drive are preventable. One study shows that 90% of them would not have reached critical condition if they had been discovered early. In conclusion, prevention is always cheaper than repair.

All the information of a car engine is in the lubricant. Whether it is working perfectly, has incipient wear, or faults that reach the critical level, all this is shown by the lubricant. They are discovered when lubricants are analyzed in laboratory tests.

If a vehicle consumes engine oil in excess of the manufacturer's prescribed norms, there can be many causes. Some engine components may be excessively worn, seals may be ageing, and through loss of elasticity or deterioration, lubricant may be leaking (leaking) through surfaces, or the driver may be driving the car aggressively.

The difference between a mineral and a synthetic engine lubricant is as follows: mineral oil is made from refined crude oil and synthetic oil is made in the laboratory using chemical processes and offers

better performance, longer life and the ability to adapt to severe operating conditions, of course at a much higher price compared to mineral oil.
If certain noises are coming from the engine area, it is important to be able to expect that a possible cause could be the use of the wrong engine lubricant. For example, if it is too thin, the lubrication will not be the right one, which will damage the engine technically.
The most commonly used types of lubricants for automotive thermal engines are 5W-30 and 10W-40. The difference is that 5W-30 is a thinner oil compared to 10W-40. This distinguishes them in the balance between performance and protection. For this reason, 10W-40 oil is dedicated to engine protection but can have difficulties at very low temperatures.
When it comes to 5W-30 versus 5W-40 engine oils, the most important similarity between these types of lubricants is the way they both perform in winter. In summer, however, the differences arise. A 5W-40 lubricant has better lubricity at high temperatures, and the increase in temperature from summer to summer will at some point force us to replace 5W-30 with 5W-40. Another extremely important aspect is the resistance to overheating, where 5W-40 motor oil is clearly superior to 5W-30.
As far as 0-W20 and 0-W30 lubricants are concerned, these two types of engine oil behave identically in winter and differently in summer. Both provide adequate lubrication at low temperatures, cold temperatures do not thicken them and lubrication at critical points in the engine is fast. It also has the advantage of lower fuel consumption. In summer this phenomenon is reversed. A 0W-20 oil will be more prone to thinning than a 0W-30 oil, increasing the risk of friction between engine parts.
A car with a diesel engine does not do well if it is used more in the city, over short distances. It also needs to run long distances. It is recommended that a car should be purchased according to the needs of the user. Short-distance use of the car in an urban environment leads to failed regeneration of the particulate filter (DPF), which will eventually clog. This will contaminate the engine lubricant with fuel.
It is recommended to avoid bottlenecks in busy road traffic. The reason for this is as follows: failed passive regenerations of the particulate filter (DPF) can lead to clogging. The lubrication lubricant in the engine will never reach its optimum operating temperature, which will lead to wear of the engine's parts and mechanisms and, of course, insufficient charging of the battery.
The lower the cold or hot viscosity index, the lower the viscosity of the oil and vice versa.
Not all engine oils are equally effective and not every lubricant on the market can be beneficial to military vehicle fleets. To extend the life of engines, to have clean engines, to improve engine performance and to reduce environmental emissions, you must always choose the right oils.
The right oils and lubricants play an essential role in maintaining the reliability and performance of military vehicles. The correct choice and use of these products can make the difference between a vehicle that is running optimally and one that experiences frequent problems and breakdowns. Following maintenance recommendations and using the right products can ensure that military vehicles are ready to meet the most demanding challenges.
As long as the engine shows no wear, and the overhauls are carried out within the time limit set by the manufacturer for each individual vehicle, only recommended lubricants that are not counterfeit can be used, and the engine life is substantially extended.
Carrying out overhauls beyond the time prescribed by the BMW automobile manufacturer will certainly lead to premature engine wear. Add to all these non-conformities a faulty EGR system or a worn and tired gasoline or diesel fuel injection system, and problems are imminent.
ROVE 5W-30 MULTI SYNT DPF, KRON OIL HELAR SP LL - 03, 5W-30, or RAVENOL range engine lubricants are all lubricants that, in a well maintained and properly operated engine, will give excellent results.
It is not the lubricants that destroy engines, it is the failure to change the lubricant within the time prescribed by the car manufacturer.
Each major oil brand has its own contracts with different car manufacturers sponsoring the latter to put the brand name in advertisements or in the technical book. For example, some BMW cars have the Castrol logo on the oil filler cap.

There are vehicles that consume a larger amount of lubricant per 10,000 km from the factory (from new), or between changes, and others that do not consume lubricant from one engine oil change to another. In short, any road vehicle engine consumes oil to a greater or lesser extent, but if you find yourself in the situation where your vehicle's engine consumes too much oil, then this could indicate a serious problem that can only be solved in the service department.
Lubricants with inadequate viscosity for their intended use may cause:

- Greater metal-to-metal contact, excessive friction and increased wear;
- Higher oil consumption;
- Gasket leaks.

Lubricants with too high a viscosity for the intended use may cause:

- Higher fluid friction and higher operating temperatures;
- Poor low temperature fluidity and lubrication;
- Reduced energy efficiency.

Understanding viscosity and its different aspects, such as the viscosity index and the concepts of dynamic and kinematic viscosity, is essential in many applications in various industries. From ensuring the smooth flow of oil in an engine to guaranteeing the desired consistency of a sauce, viscosity plays a vital role in our daily lives, influencing the quality and functionality of numerous products and processes. The viscosity index (VI) of a lubricating fluid refers to how much the viscosity of the fluid changes due to temperature. A high VI (above 95) indicates that the fluid undergoes a small change in viscosity due to temperature fluctuations, while a low VI indicates a relatively large change in viscosity. Fluids with a high viscosity index provide more protection for critical components over a wide temperature range, maintaining fluid thickness and the necessary fluid barrier between parts. The viscosity index test (ASTM D2270) is based on the kinematic viscosity of the fluid at 40°C and 100°C. Synthetic fluids typically have much higher viscosity index figures compared to conventional fluids, which means they offer improved protection of critical components over a wider temperature range.
Dynamic viscosity is measured by CCS - Cold Crank Simulator (ASTM D5293). The dynamic viscosity determines the oil's viscosity at low temperature (winter or "W" - "5W" in 5W-30 motor oil). The lower the "W" value, the faster the oil will flow when cold. The CCS viscosity test evaluates the amount of energy required to start an engine at a specific temperature; the lower the viscosity, the lower the temperature at which the test is performed. The test assigns a value in centipoise (cP), which is used to determine the viscosity.
The kinematic viscosity, measured using ASTM D445 methodology, determines the viscosity at the elevated temperature or operating temperature of an SAE - 30 SAE 5W-30 engine oil.
The kinematic viscosity test attempts to simulate the viscosity under normal operating conditions for a passenger car or light truck. The test is performed at 100°C and/or 40°C, depending on the classification system used. The value at 100°C is used to determine the SAE viscosity grade by measuring the time taken for the oil to flow completely from a vascosimeter heated to 100°C. The elapsed time in seconds is converted to centistokes (cSt). Lower values reflect lighter viscosity oils.
Always stop the engine from running if you notice low lubricant pressure in the engine or if you hear abnormal noises in the engine area. If you continue to run the vehicle you will accelerate the wear of parts which will lead to costly repairs.
If you are buying a second-hand car and need to top up the engine with oil, first find out the brand and type of engine oil previously used. For example, it is not enough to know that a 5W-30 lubricant was used. Oils differ. Depending on the brand, the additive package is different, and this can create a non-homogeneous mixture, with the risk of non-conforming lubrication, which can cause wear on engine parts.
Vehicle engines can block in a short period of time if the concentration of metals in the lubricant is high. The change in viscosity, caused by a high amount of metal particles mixed with the oil, leads to lubrication problems at certain points in the engine. This leads to high friction forces between the parts in the gearing.

10-W60 is a special racing engine lubricant. It has superior lubrication at very high temperatures and is designed for extreme operating conditions and overload. When used in engines running under normal, under-torqued conditions, it does more harm than good, because the lubricant is so thick that it won't reach all the critical points of the engine, resulting in damage to the parts in contact. The damage is created by the high frictional forces of poorly lubricated uprakes.
In aviation, many of these non-conformities in aircraft control system lubricants would keep them grounded until industry specialists replace them completely.
A very important aspect regarding service intervals when talking about engine oil is: how frequent do we change our oil. The repair manual for every car tells us to have the oil checked every 15,000 km or every calendar year for normal use. If the vehicle has been operated in a heavy-duty regime, the intervals for overhauling and replacing engine lubricants are halved. Let me show you what intensive vehicle operation means. A vehicle that is used for short distances (e.g. police, ambulance, fire engines, taxi vehicles, goods delivery vehicles, vehicles for driving training, buses for short route runs, etc.), under 8 km and in conditions of low ambient temperature, all these aspects are intensive use. In all these cases, the engine lubricant should be replaced every six months, as the lubricant will lose its lubricating properties due to the vehicle having been operated in adverse conditions.

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Brief overview of evolution of the bone cements

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Abstract. Bone cements have undergone significant evolution in recent decades, adapting to clinical and technological needs. From the simple use of polymethyl methacrylate (PMMA) cement in the mid-20th century, there has been the development of advanced materials that combine mechanical functionality with biological benefits and sustainability.
Keywords: *bone cements, biocompatibility, properties, prostheses*

Introduction

Nowadays, numerous studies are being conducted to obtain new materials with superior properties, which can replace the use of classic materials, which can also lead to avoiding excessive consumption of raw materials and materials. These new materials, which can be used in different fields of activity, have improved properties, easier and faster methods of obtaining and can also be economically efficient. In this regard, such a material, used in the field of orthopedic and dental surgery, is known as bone cements. [1-3].

Bone cements are biocompatible materials found in orthopedic interventions and implantology techniques. These materials are used to load small bone defects, to fix prostheses and to reconstruct bone, having an important role in restoring the functions of the musculoskeletal system.

Before the discovery of bone cements, the technique of replacing joints, especially the hip, had great difficulties. Implants made of metallic or other rigid materials were difficult to fix in the bone and weakened over time, which caused patients to have very severe pain and most often required several orthopedic interventions to correct the problem. For this reason, attempts were made to solve these problems by making the implants more stable and resistant over time and at the same time aiming to reduce pain and eliminate postoperative complications.

Around 1950, when the orthopedic field was gaining momentum, a new type of material appeared, namely bone cement, which had methyl methacrylate as its basic element. And so, the most widely used bone cement used in joint replacement techniques (in hip and knee arthroplasty) was acrylic cement. Because this type of bone cement set quickly and had good biocompatibility, it became the most widely used material ("gold standard") in orthopedic interventions.

In the 60′s, Sir John Charnley, at the Wrightington Clinic in England, performed hip arthroplasty interventions for the first time using cement based on polymethyl methacrylate.

PMMA-use and application

Polymethyl methacrylate is a hard plastic, obtained by the chemical reaction of polymerization of the monomer methyl methacrylate and when mixed it turns into a viscous paste. This paste is embedded in the space between the bone and the implant, and after hardening it is extremely solid, and makes a strong bond between the implant and the bone. Sir Charnley realized that the material polymethylene methacrylate could act as a stable fixator for orthopedic implants, providing the prosthesis with great stability in the bone, which reduced patient pain and decreased the rate of implant failure.

This was the first major clinical application of bone cements and marked the beginning of their use in orthopedics, and they were created to help fix orthopedic prostheses, such as hip and knee replacements, and have become a staple in orthopedics due to their ability to stabilize implants in the bone.

Due to the success of this technique, PMMA-based bone cement began to be widely used worldwide, becoming the standard in joint replacement surgery.

Starting with the 1970s, bone cements began to be used more widely in Europe and the United States for hip and knee prostheses, once Charnley's positive results were confirmed, and several orthopedic surgeons played an important role in the development and refinement of these techniques.

Dr. Heinz Wagner, is a German surgeon who used bone cements in hip arthroplasty. He developed a femoral prosthesis that influenced subsequent hip replacement techniques. This femoral prosthesis replaced the upper part of the femur in patients with severe osteoarthritis or who had other conditions that required hip replacement surgery; it provided a superior and more stable fixation than the prostheses available at the time.

Another influential German surgeon of the time, Otto Käfer, worked with cemented hip prostheses and contributed to the improvement of the cemented arthroplasty technique.

Maurice Müller, a Swiss surgeon, played a major role in standardizing the use of bone cements in hip prostheses and was the founder of the Swiss Orthopedic Society. His implant systems and guidelines for cement fixation had an international influence.

From the USA, physician William Harris contributed to the development and refinement of cemented hip prosthesis techniques and studied the materials used in joint prostheses, and was also involved in research on cement wear and how to improve the durability of hip prostheses.

In the 1980s and 1990s, bone cements underwent significant development, leading to their wider use in orthopedic and reconstructive surgery, and they offered greater safety and better integration into the body. This remarkable development was due to both advances in materials science and new production technologies. At the same time, the properties of polymethylmethacrylate-based cements were improved by modifying their chemical composition, which resulted in superior mechanical properties and better biocompatibility.

A major impact on the use of bone cements was the introduction of antibiotics such as gentamicin directly into their composition, which led to a reduction or even elimination of the risk of postoperative infections and reduced anti-inflammatory or allergic reactions. The new composition of bone cements led to the reduction of the heat released from the exothermic reactions that occur during the polymerization process, thus, the tissues in the vicinity of the cements being protected.

In their evolution, cements were developed in whose chemical composition bioactive nanoparticles were placed that accelerated the healing and integration of natural bone with an implant or a reconstructed bone, a process also called stimulation of bone integration, and also silver nanoparticles with an antibacterial role that were used to prevent the formation of bacterial biofilm [4].

This bone integration is essential for the success of many medical procedures such as joint prostheses, bone grafts or other orthopedic interventions.

Following changes in chemical composition and improvements in mechanical properties and biocompatibility, the range of uses of bone cements has broadened, being used not only in total hip or knee arthroplasties, but also in more complex procedures such as stabilizing osteoporotic fractures and vertebrae.

Since bone cements were porous and there was a risk of cracking, after the 1990s cements appeared in whose composition much finer particles and more homogeneous mixtures were introduced, which led to a decrease in the number of pores.
Between 1990 and 2000, the composition of bone cements was improved by finding an optimal ratio between the proportion of PMMA powder and the liquid monomer, so that the bone cement obtained was even more resistant and flexible, thus reducing the risk of fractures and better resisting high mechanical stresses in the hip or knee.
The 2000s were innovative in terms of the controlled release of antibiotics in bone cements, both in the introduction of antibiotics to reduce the risk of infection that could occur immediately after the intervention, or the antibiotics could be released in a controlled manner, over a longer period, ensuring long-term protection for weeks or even months.
Another important stage was that in which other types of antibiotics such as vancomycin or tobramycin were introduced into the composition of bone cements for patients who had high resistance to several types of bacteria.
Chemical compounds such as calcium phosphate, whose composition is close to the mineral structure of bone, and the hydroxyapatite compound, which directly stimulates bone cells and causes them to deposit bone matrix, were also introduced.
These important innovations had the role of forcing natural bone to deposit on the surface of the cement or, in some cases, the bone to gradually replace the cement. This has led to bone cements having other uses such as complex bone reconstructions applied after tumor interventions or bone grafts in spinal surgery.
The bone cements existing in the 2000s were characterized by increased safety, which resulted in a decrease in infections and toxicity and stimulated bone integration and made them customizable by being adapted to the patient's needs and giving them increased applicability.
Currently, cements have been developed that have additives in their composition that increase resistance to compressive stress and determine that bone cements are used in higher biomechanical loads.
Another type of bone cements are injectable cements that are used in minimally invasive interventions and have a variable and much better viscosity that allows easier and more precise application in problem areas or in areas that are difficult to access. These cements harden quickly and cause immediate fixation of the bone structure.
Biodegradable bone cements are also currently in use and are gradually reabsorbed by the body as they are replaced by natural bone tissue. Modern composition formulas reduce the heat released during hardening and thus protect sensitive tissues, nerves and blood vessels.
The era of digitalization is also having a major impact on the field of bone cements, which are integrated with advanced technologies (3D printing) through which, depending on the needs of patients, the composition can be personalized.
Since there is currently an increasing emphasis on sustainable development, sustainability and ecology, bone cements also align with the requirements of these imperatives and are designed to minimize their impact on the environment and increase patient safety. Thus, technologies and processes that try not to pollute the environment are used in the medical industry, using polymers that are biodegradable. Another way bone cement technologies are aiming to be environmentally friendly is by replacing synthetic components like polymethylmethacrylate with natural, less toxic alternatives or by using manufacturing processes that consume renewable energy, thus eliminating greenhouse gas emissions. These types of eco-friendly bone cements are safer to handle and dispose of post-operative waste, resulting in a reduced environmental impact.

Conclusions

Bone cements have adapted to clinical requirements and emerging technologies. From simple polymethylmethacrylate (PMMA) formulations used for prosthetic fixation, there has been a shift to advanced compositions that combine superior mechanical characteristics with biological stimulation of the bone.

Modern bone cements have high mechanical strength, which determines a longer lifespan, they contain antibiotics to prevent infections, and the heat generated during hardening is low, which prevents tissue and nerve damage.
Ecological cements, which contain biodegradable materials or are obtained through technologies that have low carbon emissions, reflect a commitment to non-polluting practices. These aspects align with global trends for sustainability.
Nanoparticles introduced into the bone cement formula have improved the characteristics of the cements, ensuring good antibacterial protection and good mechanical and biological interaction with the bone.
Digitalization and 3D printing techniques allow bone cements to be adapted to the anatomy and requirements of each patient, which contributes to a better adaptation of implants and to improved clinical outcomes.
The evolution of bone cements continues towards intelligent, sustainable and customizable materials, which determine a better quality of life for patients and the efficiency of orthopedic interventions. These directions make the transition from passive solutions to technologies that determine active bone regeneration and reduce postoperative risks.

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Street lighting a basic component of modern road infrastructure and traffic

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Abstract. Road safety is now a priority for all international bodies, and reducing road fatalities has been accepted as a key objective by both the United Nations and the European Union. In its essence, road traffic safety refers to the methods and measures used to prevent road or street users from being killed or injured. The issue of road safety is a solid topic of debate and action in most countries of the world, irrespective of geographical area, degree of motorization or quality of infrastructure. This scientific research presents the authors own representation and original point of view on the technical acceptance of street lighting as a basic component of modern road traffic. In this way, those interested can get informed about the current criteria and requirements for the appreciation of public street lighting and about the number of road accidents occurring at night on public roads in Romania. Presented below is a case study analyzing some IIHS (Insurance Institute for Highway Safety) research on pedestrian detection safety systems that are ineffective in low light conditions and at speeds above 50 mph, and an evaluation of driver assistance systems in modern road vehicles to date. The analysis was performed on a Toyota RAV 4 passenger car manufactured in 2019. At the end of the research the conclusions in the addressed area are presented.

Keywords: *lighting, street, pedestrians, intersection, lighting, luminance, pedestrian crossing*

Introduction

Road safety is a concept that expresses a wish of the overall society, infrastructure and road traffic is an important part of the daily life of each one of us, given that a large part of our daily journeys take place on the road network of streets, roads or highways both in Europe and in Romania. Infrastructure and road traffic are complex systems in which several factors, at different levels, are permanently interdependent. Whether we are talking about the road network, vehicles and their drivers, or about the legislation in this area and the measures taken by the various institutions or organizations responsible for this field, all these elements are interconnected by a constantly dynamic whole which affects both the safety and comfort of road users [1]. It is unanimously recognized that good road lighting contributes substantially to increasing road traffic safety at night. More than 30% of the number of accidents that occur at night can be prevented by using road surface illumination techniques. Good street lighting is that which allows traffic to move safely and comfortably at night, in conditions as close as possible to those during the day. The comfort provided by a lighting system reduces nervous

tension and driver fatigue. These and other aspects make street lighting systems particularly important for the smooth running of road traffic at night. Roadway lighting, the most important type of outdoor lighting, has its own particular characteristics because of the relatively high speed of road vehicles. In order to drive a road motor vehicle on a public road, in conditions of acceptable safety, at a given speed, the driver must visually determine that the road ahead of him is free of bumps or obstacles for a reasonable distance, lane or roadside markings, the location and meaning of road signs, the location and direction of movement of objects on or near the roadway, and last but not least, the position of his own vehicle in relation to the immediate destination of other objects. The additional road safety benefits of street lighting are: prevention and reduction of road motor vehicle accidents; reduction of community costs (including those caused by material losses due to damage caused by road accidents); saving of travel time; reduction of noise, as a street or road properly lit at night leads to a high flow of road traffic and, consequently, to a correct use of road vehicles and of the operating regime of internal combustion engines. These conditions result in reduced stationary times which generate less chemical and noise emissions from vehicles in operation. The lighting of public roads is provided by means of a technological and functional ensemble of specific constructions, installations and equipment, collectively referred to as a lighting system. The architecture of these systems depends to a large extent on the mode of operation of the lighting equipment, i.e. connection to the national electricity grid, or the use of renewable or conventional energy sources (solar, wind, hydro, nuclear) [2, p. 5].

1. Literature review

A Directive of the European Parliament and of the European Council (2009/125/EC) in this area sets ecodesign requirements for energy-using products, focusing on energy consumption throughout the life-cycle of the product, including production, transportation, scrapping and recycling. One aspect of the directive is the phasing out of high-pressure mercury vapor lamps by 2015 and of medium-efficiency high-pressure sodium lamps by 2017. The regulation of street lighting in Europe is done through the quality standard EN 13201 (2,3,4), but most of the EU Member States have their own rules adapted, inspired or corrected by this standard.

Older technologies do not match the capabilities of LEDs (Lighting Emitting Diode) or other more advanced technologies. In the case of incandescent lamps, 90% of the energy consumed generates heat and only 10% is converted into light. An incandescent lamp generates light at approx. 17 lm/W while compact fluorescent lamps (CFLs) can generate 60-75 lm/W and LED lamps over 100 lm/W. LED luminaires can be controlled by dimming/telemanagement systems, resulting in substantial savings.

The public street lighting system shall comply with the lighting standards provided in the standards:

- SR CEN-TR 13201-1 Street lighting. Part 1: Selection of lighting classes;
- SR EN 13201-2 Street lighting. Luminaires - Part 2: Performance requirements;
- SR EN 13201-3 Street lighting. Part 3: Performance calculation;
- SR EN 13201-4 Street lighting. Luminaires - Lighting - Part 4: Photometric performance measurement methods;
- SR EN 13201-5 Street lighting. Lighting - Part 5: Energy performance indicators.
- Road Technical Bulletin - Monthly publication published by the National Company of Highways and National Roads of Romania (CNADNR).

In Romania, ASRO (Romanian Standards Accreditation) specialists initially adopted the Romanian standard SR 13433/1999 for street lighting, and then the Romanian standard SR 13201/2015 in correlation with the development and modernization of the national network of public roads, which generated the need for a Guide on the conditions under which the lighting conditions of roads/highways in Romania should be achieved. In this context, since "artificial" lighting tries to compensate for the lack of natural light, we observe its perception, i.e. vision, which is influenced by certain factors related to human nature [2, p. 7]:

- age, gender and health status;
- occupations and level of information/culture;
- rhythm of life, etc.

In another context, public road lighting must also take into account its impact on the environment not only by reducing the emissions of chemical pollutants emitted by road vehicle engines but also by understanding the life cycle and behavior of flora and fauna of human habitats. For these reasons, the need for street lighting can be defined by the following considerations [2]:

- the policy of the governments of the EU member states to reduce chemical emissions from road vehicles (in particular CO_2), in general to protect the environment;
- reducing investment (capital costs), energy, maintenance, infrastructure, etc;
- daytime visual impact of the implemented lighting system on the natural landscape;
- problems arising from human adaptability to darkness or light;
- occupational health and safety issues arising from street lighting;
- "right to the stars" versus light pollution;
- protect biodiversity as a component of animals (especially birds) and life cycles.
- The influence that various factors have on the luminance on the road surface are:
- the reflectance characteristics on the road are between the observer and the luminaire;
- the average luminance of the road is directly proportional to the flux/m2 provided by the luminaire distribution unless the road type is changed;
- changes in average luminance resulting from changes in the spacing between the luminaires can easily be predicted by using a proportional ratio;
- reducing the mounting height reduces the light spread outside the road and increases the luminous flux/m2 and the luminance of the road/street. The effect of decreasing the mounting height cannot be predicted using a ratio;
- by increasing the length of the arm we will increase the average luminance of the road as long as the increase in the amount of light spreading on the road edge is less than the reduction in the amount of light behind the luminaire;
- the improvement in luminance uniformity is much more difficult to predict and there is no method using ratios to predict it.

The national roads (DN) and highways passing through localities will be illuminated according to the technical provisions according to the Guide on lighting conditions on national roads and highways in Romania. In rural areas (between localities), only those stretches of road that are dangerous in operation, present a high risk or on which a high number of road accidents have been recorded that have been favored by the lack of light, namely; crossings at the railroad junction; pedestrian crossings, roundabouts; intersections; motorway junctions; tunnels; parking areas; underpasses and overpasses; bridges and viaducts over 100 m in length; public transport stations; service areas, parking areas and areas with pedestrian facilities.

It is also recommended, according to the Guide on Lighting Conditions on National Roads and Highways in Romania, to illuminate national roads and highways as follows [2]: road sections with a high number of road events (car accidents); on road sections with difficult geometry and/or special traffic conditions (near forests, lakes or rivers; at intersections where lane separation is necessary for turning or turning of road vehicles; lighting of all national roads crossing inhabited areas; in all areas with a high risk of road accidents.

Specialists building streets, roads or highways must take certain criteria into account when designing them, such as [2]:

- average travel speed, traffic volume, road configuration and the presence of hazardous areas, which dictate how to assess the need for street lighting;
- possible estimates of savings in road use savings as benefits for this purpose (the most important savings achieved by decreasing/eliminating accidents or road events of any type);
- the basis for calculating the benefits resulting from street lighting, justified by the volume of traffic, taking into account the average number of persons injured and the fatality rate for each type or category of road (on highways and national roads, savings from reduced travel time are taken into account);

- the cost effectiveness of road lighting as a component of the overall traffic economy achieved by comparing the average annual savings in the total costs of each roadway with the total annual costs of the lighting system and the costs resulting from collisions with the supporting elements of road lighting;
- where the volume of traffic is low, which does not justify road lighting simply to reduce the number of road events, lighting can be justified on the basis of: the inhomogeneity of the road traffic environment; the alignment of the road being inadequate for correct orientation; the short distance between intersections; the greater than normal number of pedestrian crossings or stops for public transport; the lack of pedestrian pavements, even in cases where, in the cost effectiveness calculation, street lighting would not be cost effective in terms of road traffic.

Directive 2006/32/EC on energy end-use efficiency, which became binding for Romania in 2008, stipulates that EU Member States commit to reduce final energy consumption by at least 9% over a 9 year period (2008-2016) compared to the average consumption in the last five years for which data are available (2001-2005).

2. Criteria and requirements for the assessment of public street lighting

Public street lighting is provided for the illumination of public roads and their elements (streets, sidewalks, squares, intersections, pedestrian crossings, bridges, passages, underpasses, overpasses, alleys and pedestrian areas, vehicle stops, parking lots), as well as for the enhancement of monuments, statues, architectural ensembles, buildings and constructions and/or public spaces of monumental value and of heritage interest.

Saving electricity is becoming more and more common parlance, so much so that it has already become an "ingrained" word of everyday life because today, with the price of electricity getting higher and higher every day, we need to save energy in all our activities. The solution is to use energy-efficient installations and equipment. In the case of public lighting, energy savings cannot be made at the expense of public safety and traffic by partially or totally interrupting its operation.

Energy savings can be achieved by:

- lighting systems design;
- optimization of the contracted tariff;
- implementation of a command and control system for the installation;
- optimization of the operating times of the installation.

According to the new requirements the most demanded and utilized types of lighting fixtures are LED technology. LED is an optoelectronic device capable of emitting light when an electric current is passed through it. An LED luminaire has a high efficiency unlike other technologies such as halogen lamps or incandescent lamps which have very low efficiencies. LED systems produce more light per watt consumed than conventional lamps. Strict control of light dispersion achieved by the optical system with lenses for focusing the rectangular light beam ensures protection against light pollution. The lens has a very important role because, in addition to reducing light loss, it also eliminates the risk of glare caused by shining lights, and for street lighting it is located at 120 degrees to produce light dissipation in street lighting. Classical LED devices have a lifetime of 100,000 hours for a dimming down to 80%, and for LED modules embedded in luminaires, a minimum of 50,000 hours is guaranteed. This very high lifetime of LED luminaires leads to reduced maintenance costs of the lighting system, offering the feasibility of reducing real investment costs.

In order to achieve adequate lighting, streets need to be divided into road classes, which is done taking into account the size of the traffic, the type of traffic participants, the speed of traffic, etc. The following requirements apply when designing a street lighting system [3]:

- standardized values of quantitative and qualitative indicators of lighting systems;
- economy of installations, rational use of electricity;
- reliability of lighting systems;
- safety of service personnel and road users;
- ease of maintenance and management of lighting systems.

In the design and realization of a functional street lighting system, it is very important how it is calculated and its quantitative and qualitative evaluation. The development of this sector is defined by the following criteria for assessing the street lighting system: illuminance criterion, luminance criterion, illuminance and visibility of objects criterion.

Luminance is the light intensity measured per unit area of light In other words, it is the light perceived by the human eye relative to an illuminated surface Therefore, in the case of street lighting, all quantities are measured relative to an "observer". This "observer" is, in fact, the driver who is in the lane 60 m ahead of the illuminated area (Figure 1) The measured magnitudes represent his perception of the illumination of the roadway and its surroundings For a correct assessment, the measurements are made with the *luminance meter* positioned in the driver's seat, who is the human perceiver of this phenomenon.

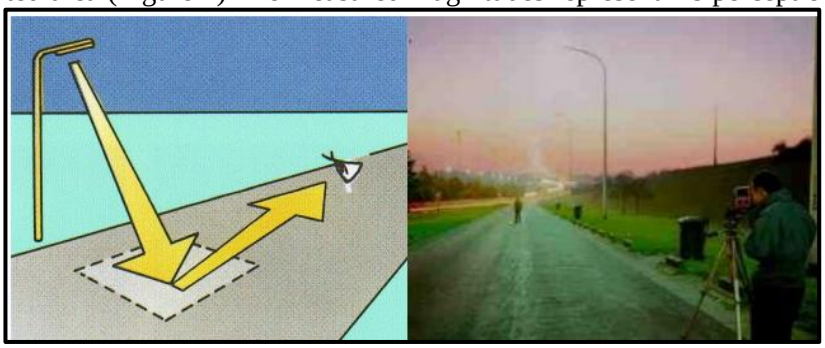


Figure 1. Luminance measurement [4].

For risk areas: intersections, pedestrian crossings, etc, the class is chosen one level above the maximum street level entering that area and must meet the conditions below. This is done because by increasing the level of lighting on certain areas there is also an increase in the visual acuity of drivers. In addition there is a psychological phenomenon, as it has been shown that there is a tendency to instinctively apply the brakes when there is a sudden change from one level to another. In Table 1 we shows the lighting classes for risk zones.

Table 1. Lighting classes for risk areas [4]**.**

Lighting class	Horizontal lighting	
	$E_{med.}$ (lux)	U_0 (%)
C0	**50**	**0.4**
C1	**30**	**0.4**
C2	**20**	**0.4**
C3	**15**	**0.4**
C4	**10**	**0.4**
C5	**7.5**	**0.4**

Illuminance is the luminous flux falling on a surface (e.g. the road surface). In this case we no longer refer to an "observer", because it is assumed that the "observer" is also at the intersection and in addition there are other traffic participants (pedestrians). As presented above, another important factor is the complexity of the field of vision and the possibility of orientation. This is why the type of measurements at the intersection differs from those on the road/street. For intersections or hazardous areas, the measurements are made with a *lux meter*, because in this case the important measurement is the illuminance and not the luminance.

For pedestrian zones, bicycle paths or rural side streets the road classes have to comply with the following minimum conditions (Table 2).

Table 2. Lighting classes for pedestrian areas [4].

Lighting class	Horizontal lighting	
	$E_{med.}$ (lux)	$E_{min.}$ (lux)
P1	15	3
P2	10	2
P3	7.5	1.5
P4	5	1
P5	3	0.6
P6	2	0.4
P7	undetermined performance	

In addition, to ensure proper uniformity for these classes, it is recommended that: the average illuminance (E_{med}) should not exceed the minimum illuminance level (E_{min}) of the lighting class by more than 1.5 times. This means that if the imposed E_{med} is 10 lux, we cannot have an E_{med} of more than 15 lux. There is a link between the lighting classes, the imposed levels are comparable as can be seen in Table 3.

Table 3. Comparison between lighting classes [4].

	M1	**M2**	**M3**	**M4**	**M5**	**M6**		
C0	C1	C2	C3	C4	C5			
			P1	P2	P3	P4	P5	P6

Note: M, C and P represents lighting class.

Comparing the current classification with the existing one in the standard CIE 13433/1999, it can be seen that in addition to the subdivision of classes M3 and M4, there is a development of criteria and in addition certain recommendations that lead to increased traffic and citizen safety.

Recommendations such as [4]:

- the area with the highest recommended illuminance level is the reference area;
- it is desirable to avoid a difference of more than two comparable classes between two adjacent zones;
- where necessary, consideration should be given to semi-cylindrical illuminance (to be calculated in particular for spaces where there is a risk of serious road traffic accidents) or vertical illuminance (to be calculated in particular for spaces where vertical surfaces need to be visible).

For the appreciation of street lighting in the urban environment or road lighting in the extra-urban environment, studies have been carried out and are still being carried out on the uniformity of lighting on the road surface and the avoidance of blinding road users.

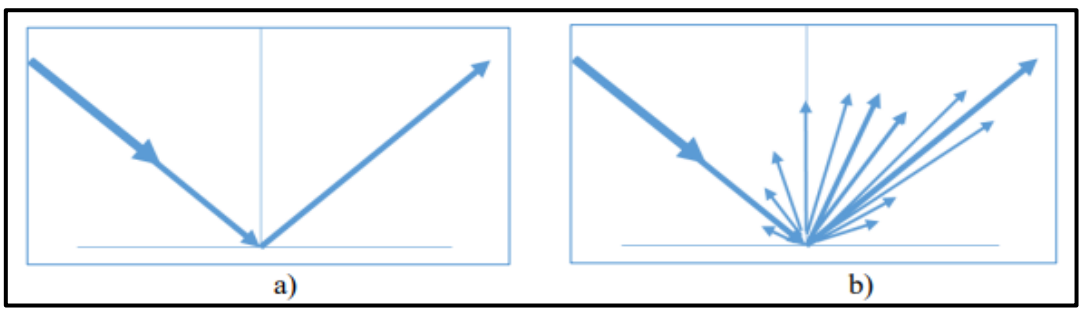


Figure 2. a) ideal reflection - b) true reflection [3, p. 427].

Compared to the lighting of indoor areas, the calculation of the illuminance of streets, roads or intersections is much more unpretentious, since the reflected component is zero. The visibility conditions at the same illuminance values of road arteries are different and depend on the reflective properties of their surface. This is the reason why the original illuminance criterion was replaced by the luminance criterion (Figure 2 a and 2 b).Analysis of the data shown in figure 2 shows that in the case of ideal reflection, the light beam is totally reflected at an angle equal to the angle of incidence.
In figure 3 a we show the reflection from absorbing materials, and in Figure 3 b we show the reflection in the same direction as the incident light beam

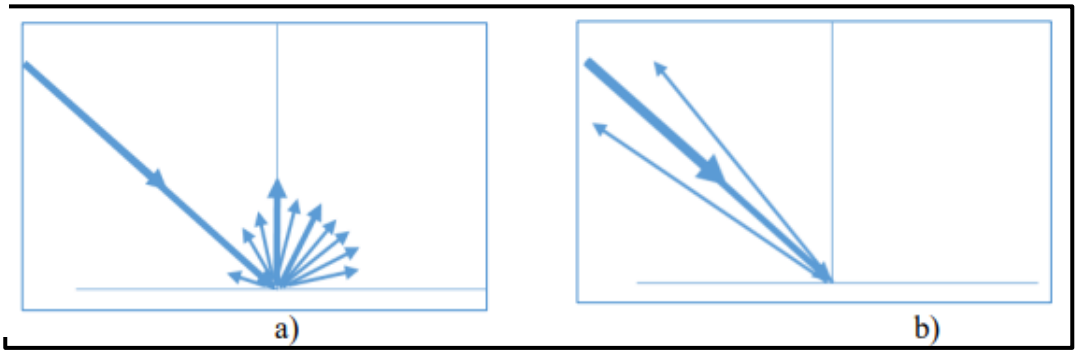


Figure 3. a) Reflection from absorbing materials; b) Reflection in the same direction as the incident light beam [3, p. 427]**.**

Analysis of the data presented in figure 3 shows that in the case of reflections from absorbing materials most of the light is absorbed, making road illumination poor.
The illuminance of the road surface is influenced by the contrast sensitivity of the driver's eye and the contrast of the obstacles on the road relative to the field of view, which directly influence the driver's visual performance [5, p. 237].

The following criteria should be taken into account when choosing poles and luminaires for street lighting:

- architectural characteristics of the area;
- planning of the illuminated area;
- user perception of the area during daylight;
- user perception of the area in low visibility conditions;
- the arrangement of street luminaires at a height between 6.5-13 m, depending on their type and the width of the street, road or intersection;
- the height at which the luminaires are placed shall be assigned in such a way as to exclude glare or impairment of visibility of users by excess light (the higher the luminance of the street lighting system, the higher the height at which the luminaire is suspended).

In the following I will analyze from a technical point of view the criteria and requirements for public street lighting of different areas that are extremely dangerous for the safety of road traffic participants. Street lighting criteria and requirements for: ***public roads and streets, intersections and roundabout intersections, pedestrian crossings*** will be analyzed in turn.
a) Lighting of public roads (streets). In the case of roads delineated with striping, visual guidance can be achieved by installing lighting on the striping. This method of street lighting has some advantages over face-to-face (opposite) street lighting. These advantages are: low investment and low maintenance costs. In this case the placement of the lighting system will be on the central side, one-sided with an external or internal layout (Figure 4a and 4b).

a) b)

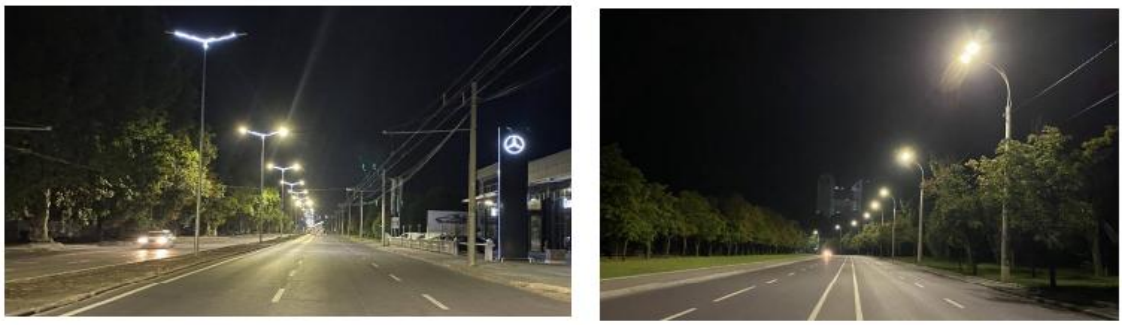
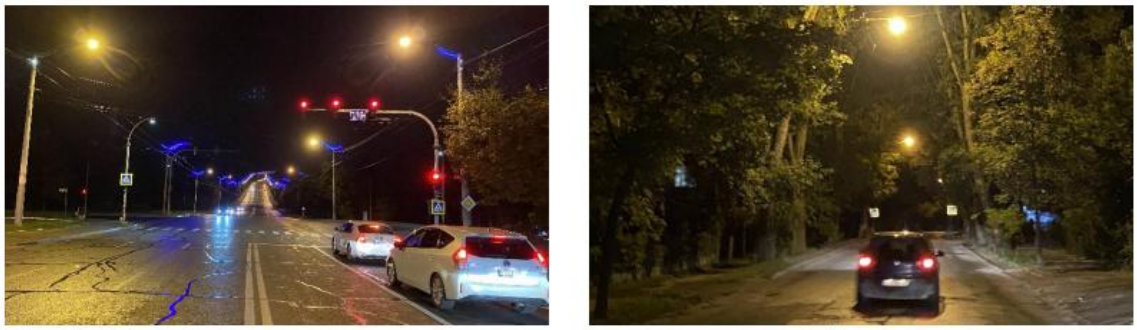


Figure 4. a) Location of the lighting system on the central part; b) Placement of one-sided lighting on the exterior/interior side [3, p. 427]**.**

For roads of greater width, where space and location permit, it is advisable that street lighting pillars are arranged face to face. In this case the reflection characteristics become weak for light beams forming large angles with the line of sight (horizon) of the drivers of road vehicles. In this case, the positioning of the lighting system will be done bilaterally with the luminaires in suspended/central position (Figure 5a and 5b).



a) b)

Figure 5. a) Location of bilateral lighting system; b) Location of suspended/central lighting system [3, p. 427]**.**

b) Lighting of intersections/roundabouts. From a road traffic safety point of view intersections are defined as the area where the most frequent serious road traffic events/accidents are likely to occur.
The methods by which the attention of drivers of road vehicles is drawn are as follows [3, p. 429]:

- increasing the level of illumination by 50% in relation to the arteries entering the intersection;
- different lighting colors may be used for orientation;
- the lighting levels to be achieved shall be expressed in the standards in force.

In the case of road or street intersection lighting, the pillars must be placed as close as possible to the corners. In the case of one-sided installation of lighting columns, they shall be placed on the right-hand side of the road or street at the entrance to the intersection. Roads entering or exiting the intersection shall be illuminated for a minimum distance of 150 m from the entrance/exit of the intersection. This is shown in Figure 6.

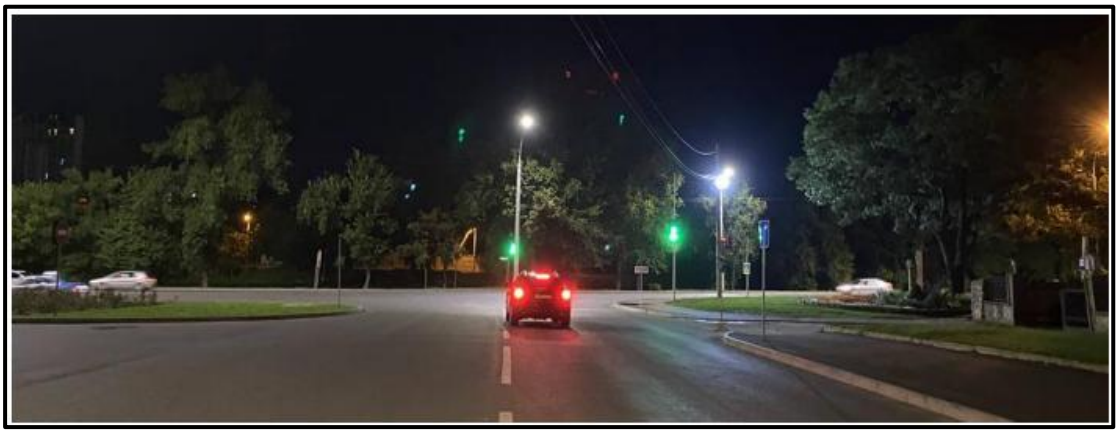


Figure 6. Location of lighting at intersections [3, p. 427]**.**

The street lighting system at intersections shall, as far as practicable, both in conditions of reduced visibility and in heavy traffic, provide a visual orientation which clearly shows the route of the intersection to be followed by the road vehicle driven by the driver in the following successive situations:

- on entering the intersection from a distance of 150-250 m;
- when entering the intersection and throughout the crossing;
- have a bright environment by eliminating glare;
- not have a high number of illuminating devices which could induce visual errors;
- not have luminaires located in dangerous places or in places where their location may create obstacles in the path of road vehicle flows;
- have an aesthetic execution, appropriate to the architectural scheme of the locality.

The installation of a street lighting system for a roundabout intersection presents some technical difficulties. In this case, each roundabout has to be analyzed individually. This is a general rule which is also valid for other types of intersections.

Some recommendations on how to deal with a lighting system at roundabout intersections can be made as follows:

- if the diameter of the roundabout is small, the luminaires should be placed peripherally. The central area can be used for floral arrangements (Figure 7 a);
- if the diameter of the roundabout is large, the luminaires shall be placed on the outside diameter of the roundabout in the direction of the roads entering the roundabout (Figure 7 b);
- it is not recommended to install lighting columns only inside the roundabout. The lighting of the intersection should also be provided with poles installed on the outside of the roundabout. In this case, the installation of the poles supporting the street lighting shall be carried out in such a way that, through the guidance created, drivers entering the roundabout can easily drive into the roundabout. The installation of poles in line must be completely excluded here. This could create errors on the part of the driver who would think that the road continues straight. Luminaires must be installed in such a way that they are in front of the driver when he intends to exit the roundabout [3, p. 430].

a) b)

Figure 7. Location of lighting at roundabout intersections. a) small roundabout; b) large roundabout [3, p. 427]**.**

c) Lighting pedestrian crossings. Pedestrian crossings should be illuminated at night to increase the safety of pedestrians crossing the road.
Crosswalk lighting requirements are as follows:

- the road/street intersecting the pedestrian crossing shall be illuminated/illuminated for a minimum distance of 150 m before and after the pedestrian crossing point;
- pedestrian crossings shall be illuminated at 50% more than the normal illumination level of a road or street;
- the direction of luminous flux should be such that pedestrians are easily observed by drivers of road vehicles;
- it is advisable to change the color of the light emitted by the luminaires provided that this does not cause confusion in traffic;
- it is recommended that flashing warning signs be installed in the immediate vicinity of pedestrian crossings to warn drivers;
- the installation of luminaires should be carried out in accordance with current standards so as to ensure that the imminence of obstacles can be observed.

If the luminance level at pedestrian crossings is high, the positioning of the crosswalk luminaires is necessary to ensure excellent negative contrast. In this case pedestrians will be visibly distinguishable to drivers in road traffic as dark silhouettes against a bright background. To directly illuminate pedestrians crossing the road/street at pedestrian crossings, who are directly on or near the crossing, and at the same time to increase the attention of drivers to the presence of the pedestrian crossing, local lighting with luminaires in addition to the warning signs may be used (Figure 8a and 8b).

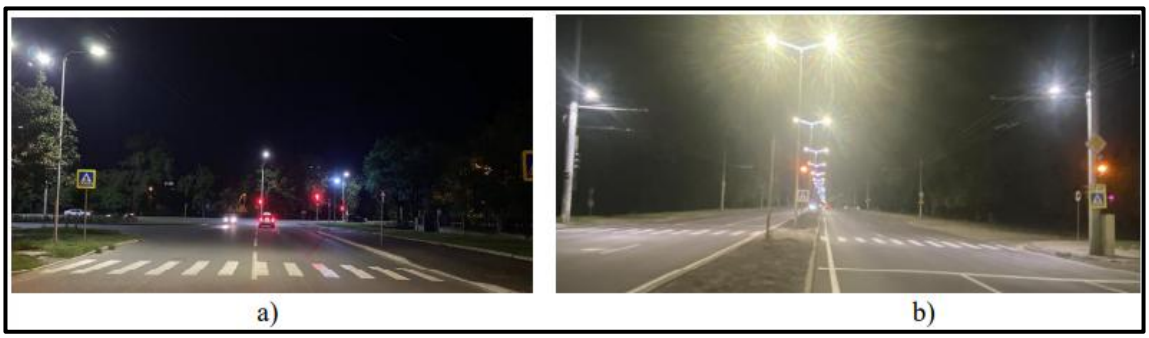


Figure 8. Location of lighting at pedestrian crossings, a) at intersections, b) outside the intersection [3, p. 427]**.**

Their type, installation and orientation in relation to the pedestrian crossing should be done in such a way as to achieve a positive contrast and not to cause undue glare for drivers. One option would be to install the luminaires at a short distance in front of the pedestrian crossing and in the direction of the vehicular flow, with the light directed towards the pedestrian crossing. For two way public roads it is necessary to install one luminaire in front of the pedestrian crossing in each direction of the street/road.

Of course, road infrastructure lighting is done according to the legislation in force and other places where the need for safety, confidence, comfort and orientation while traveling on public roads, national roads or highways increasingly congested, is a reality that calls for the emergence and development of public street lighting at night, but in another scientific paper we will address the mode and technique of street lighting on the following elements of road infrastructure not yet addressed:

- national roads and highways in populated areas;
- railroad crossings;
- highway junctions;
- parking lots;
- tunnels;
- overpasses;
- bridges and viaducts over 100 m in length;
- stops for public transport (buses and maxi-taxis, taxis);
- service areas, parking lots and areas with pedestrian facilities.

3. Road accidents caused by inadequate lighting of public roads/streets

a) Current situation regarding the road network in Romania. For the analysis, the reference values of road events recorded in 2022 and 2023 will be taken as the only true data according to the Road Safety Bulletin issued by the General Inspectorate of Police of the Ministry of Internal Affairs of Romania and National Statistical Institute of Romania (NSI).

So, worldwide, 1.35 million people lose their lives in road accidents, according to the World Health Organization. In addition, 50 million people are seriously injured in motor vehicle accidents [1, p. 7]. 93% of road fatalities worldwide occur in low and middle income countries. The European Union has the safest roads in the world. In 2022 it recorded 46 deaths/1 million inhabitants. In 2022, 20,678 road users lost their lives on EU roads, an increase of 4% compared to 2021 [1, p. 7].

On December 31, 2023, the length of the public road network totaled 86,388 km, of which 17,677 km (20.4%) were national roads, 35046 km (40.6%) county roads and 33,665 km (39.0%) municipal roads. Figure 9 show the structure of the length of the public road network, by development region, on December 31, 2023 in Romania.

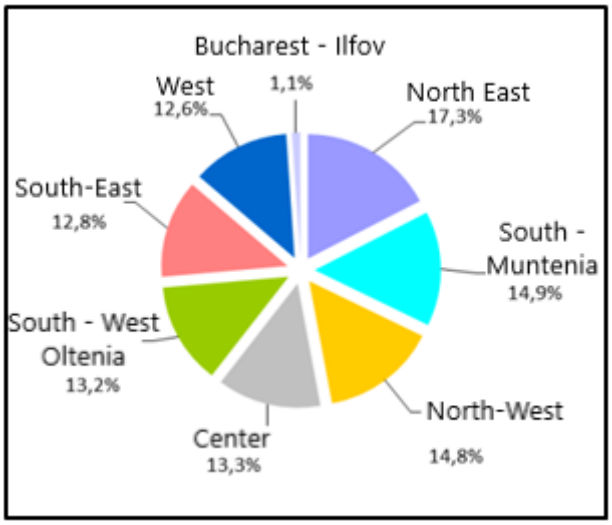


Figure 9. Structure of the length of the public road network, by development region, on December 31, 2023 in Romania [6, p. 2]**.**

In terms of type of pavement, the structure of the public road network recorded: 49.4% (42,692 km) modernized roads (94.2% modernized roads with asphalt pavements of heavy and medium asphalt type), 23.9% (2,0671 km) roads with light road pavements and 26.7% (23,025 km) gravel and dirt roads. As regards the technical condition of public roads, 27.5% of the length of upgraded roads and 39.4% of the length of roads with light surfacing had their service life exceeded. Out of the length of national roads, 6189

km (35.0%) were international roads, 997 km (5.6%) were motorways and 70 km (0.4%) were express roads, and in terms of the number of lanes, 2,161 km (12.2%) were 4-lane roads, 311 km (1.8%) were three lane roads and 37 km (0.2%) were six lane roads. The length of county roads included 51.5% modernized roads and 35.1% of municipal roads were paved roads. At the end of 2023 the length of highways in Romania increased by 48 km [6, p. 1].

b) Current situation regarding road traffic accidents and their victims at night or after dark. Following the bibliographical research carried out by us authors, in specialized literature and WEB site, we did not find data on the influence of street lighting on road accidents, but we consider that on the data we will present, street lighting had some influence. We also believe that if the streets, pedestrian crossings, and intersections had been illuminated, or adequately illuminated, the number of accidents, or their victims, would have been much reduced.

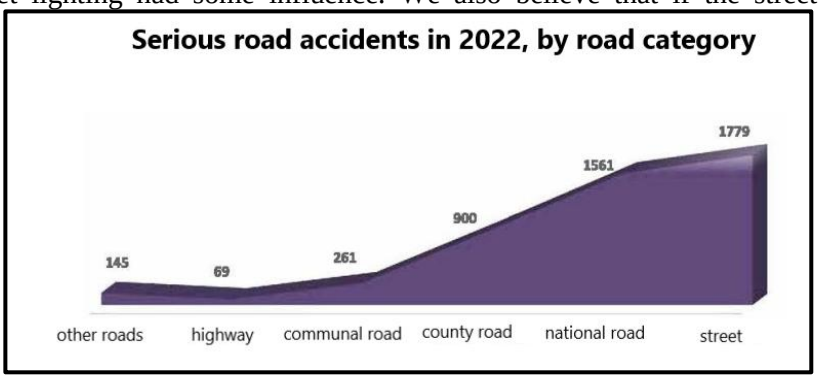


Figure 10. Serious road accidents in 2022, by road category in Romania [1, p. 40]**.**

In Romania, 4,715 serious road accidents occurred on public roads in 2022. These road events caused the death of 1,633 people, 3,695 people were injured and another 2,076 people were slightly injured. On average, every day in 2022, there were 13 serious road crashes, in which 4 people lost their lives and 10 others were injured [1, p. 10]. There was a death rate of 86/1 million inhabitants, with the death rate falling from 36.2% in 2021 to 34.6% in 2022. The highest number of serious road crashes occurred in 2022 in rural areas (1,831 events), accounting for 39% of the annual total. Rural areas had a fatality rate of 37%, while urban areas had a fatality rate of 18.6% in 2022. On the other hand, although less numerous, serious road traffic events occurring on roads outside settlements register the highest fatality rate (57.1%) [1, p. 10].

The distribution of serious road events produced in 2022 in relation to the category of road on which they occurred indicates that the most numerous accidents occurred as a result of factors related to road safety such as: the safety elements present on the public road (these elements include street lighting, taken as part of the road safety system), the density of road traffic recorded on the many existing roads, the limitations imposed on road traffic and the state of the road infrastructure existing at that date in Romania. Similar to previous years, with the exception of 2021 when the road sector with the most significant serious road events was the trunk road, in 2022 the road remains the road category with the most road accidents. There were 1,779 serious road crashes on the road, 3% more than the previous year. National roads are the second most

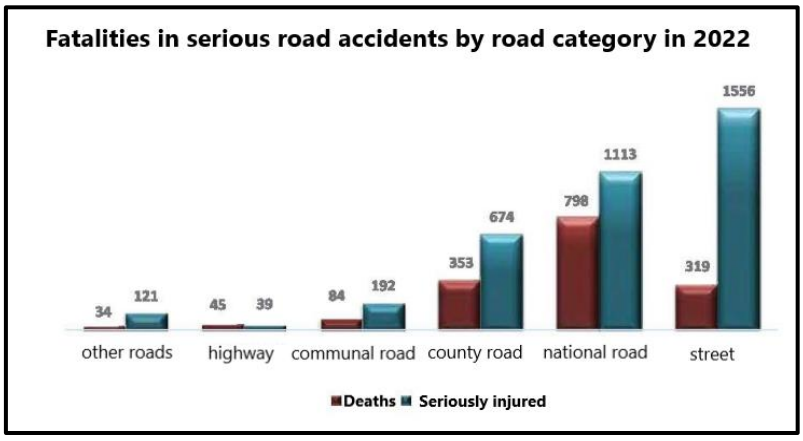


Figure 11. Fatalities in serious road accidents by road category in 2022 in Romania [1, p. 41]**.**

serious road accident category (33.1%) [1, p. 40] (Figure 10). Referring to road fatalities, we state that 48.9% of all people killed in serious road crashes in 2022 lost their lives, more than twice as many as in road traffic events on the streets. This is similar to 2021 (Figure 11). An analysis of some of the data presented in the literature shows that a significant number of serious road accidents occur at night. Inadequate street or intersection lighting contributes substantially to these serious road accidents. The graph in Figure 12 shows the number of serious road accidents at different times of the day. Serious road accidents occur between 0:00-0:07 in the morning and 21:00-24:00 at night. Road accidents are more frequent in the cold winter season, when the day decreases and night sets in more quickly, the brightness and visibility of the road also decrease substantially, favoring the occurrence of undesirable events by drivers. This is also shown in the graph in Figure 12. It can be observed that between 6-7 in the morning, the number of serious road accidents increases significantly, with a value about twice as high as one hour ago. The maximum values of the day are recorded between 17:00-18:00, when 349 serious road events occurred, especially in winter, when at this time of the day night sets in and visibility decreases substantially. In addition, the busiest time of day in terms of the number of serious road accidents is between 16:00 and 19:00 (especially in winter), when 1 in 5 serious accidents is recorded during the 24 hours of the day. More than a quarter (26.8%) of those killed in serious road accidents lost their lives in such events between 17:00-21:00 [1, p. 53].

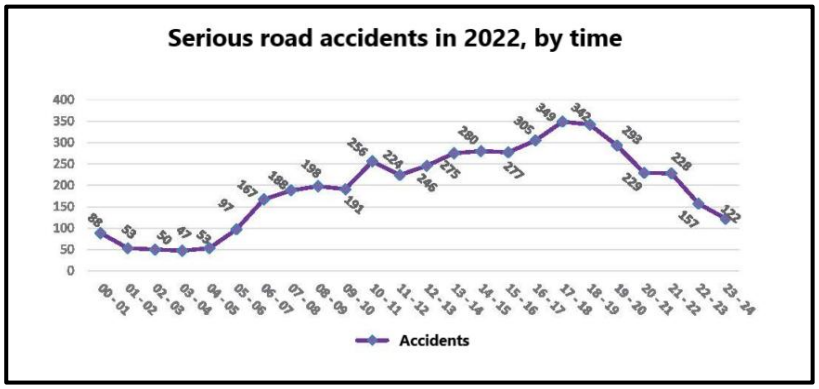


Figure 12. Serious road accident in 2022 in Romania, by times [1, p. 52]**.**

Road accidents at night have the most serious consequences. This is shown in the graph in Figure 13 showing the fatality rate. Analysis of the data in Figure 13 shows that high fatality rates are recorded between 01:00-02:00 and 04:00-06:00, when traffic is lower, but also between 06:00-07:00 shortly before daylight. High values were also recorded between 20:00 and 21:00 after dusk, periods when visibility conditions are particularly specific (visibility in road traffic decreases substantially and increased attention to the road is required from drivers).

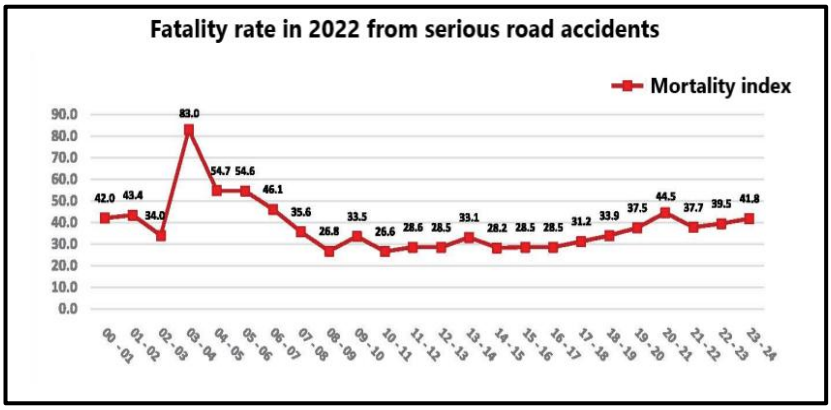


Figure 13. Fatality index in 2022 from serious accidents in Romania [1, p. 54]**.**

The data presented above highlight the seriousness of road events at night, which are exponentially amplified with the degree of lighting of the street, intersection or road on which they occurred. Probably, if there had been adequate lighting systems on those road sections, the number of serious road events resulting in fatalities would have been substantially reduced. Hence the importance of street lighting.

At European level, according to a proposed draft for regulating road traffic on public roads in EU countries, more measures are needed to reduce the number of road accidents. As a result, a number of restrictions are being introduced aimed at novice drivers. If the draft becomes a reality, as it is currently at the proposal stage, drivers who have obtained their license within the last three years will no longer be allowed to drive at night. The ban will apply for beginners between 24:00 and 6:00. Only experienced drivers will be allowed to drive during this time. The proposed ban is based on several statistics which show that less experienced drivers are responsible for many of the road events that occur at night. These statistics show that novice drivers are at the highest risk of being involved in accidents at night, or of causing serious road accidents at night.

4. The effectiveness of low light pedestrian detection safety systems and driver assistance systems on modern vehicles. Case study

According to research by the Insurance Institute for Highway Safety (IIHS), safety systems with pedestrian detection are not effective in low-light conditions and at speeds above 80 km/h. Today, however, we know that today's road vehicles are safer than ever, equipped with a wide range of technologies that protect both passengers and other road users. A good example is the automatic braking system with pedestrian detection. Like any other technology, however, this system has certain limitations. According to a study by the IIHS, the system is not very effective in low light conditions or at speeds above 50 mph.

The experts carried out a series of tests in real traffic conditions at night and on poorly lit or unlit streets and concluded that in these cases the automatic braking system with pedestrian detection has no effect, with pedestrians being hit head-on by the experimental vehicle.

This is the first case study covering a wide range of manufacturers and demonstrating efficiency and effectiveness in daylight only. In this case it can be claimed that the technology substantially reduces the number of vehicle crashes. Unfortunately, it also shows that these systems are less effective at night, in the dark, where three-quarters of fatal crashes involving pedestrians occur, the IIHS release said. Over the past 13 years, the number of pedestrian fatalities has increased by 51%, the study says [7].

Figure 14 shows a grouping of images from IIHS research into pedestrian detection safety systems at night, when visibility is low at speeds above 80 km/h.

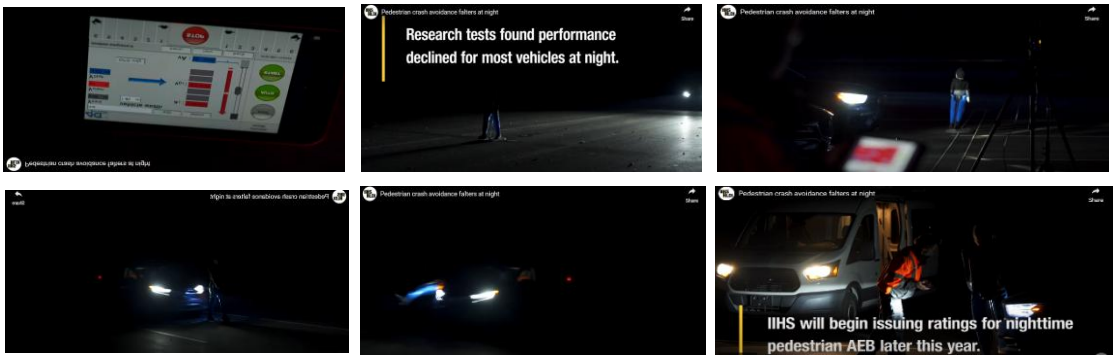


Figure 14. IIHS research on pedestrian detection safety systems [7]**.**

Regarding these aspects, similarities were also noticed by one of the authors of the present scientific research, Gheorghe Neamțu, who in his doctoral thesis publicly defended at the National University of Science and Technology Politehnica Bucharest, entitled *"Contributions on the integration of knowledge management in the sustainable development of automotive transportation"*. Thus, in chapter 7 entitled *"Road safety and its management in the context of sustainable development of the road transportation system"* [8, p. 106], the author presented an assessment of the existing driver

assistance systems on Toyota vehicles. The shortcomings/ malfunctions/ non-conformities presented reinforce the claims of this case study.
To confirm this, in Table 4 we present this assessment of the driver assistance systems existing to date on Toyota cars. Some of the systems analyzed in Table 4 have become mandatory and are included in the configuration of the Basic Road Safety Packages for every motor vehicle built in EU countries from January January, 2022, in accordance with the Regulation of the European Parliament and of the Council (PE-CONS 82 of October 18, 2019) amending Regulation (EU) 858 of May 30, 2018.
The assessment represents a personal view of the authors, is based on a passenger car on public roads around the world, and is made with the purpose of arguing that the current driver assistance systems of today's modern, modern motor vehicles are not fully safe, reinforcing the non-conformities in this case study.

Table 4. Assessment of existing driver assistance systems on Toyota cars [8, pp. 123-127]**.**

Vehicle driver assistance system name	**System/ mechanism where it operates, acts, or intervenes on the motor vehicle**	**The receiver on which the operation is based**	**Function/ Level of automation**	**Functions performed**	**Shortcomings/incorrect operations/nonconformities**
1. Pre-collision safety system (PCS)	Apply the brakes	Radar sensor 1; Front video camera in radiator grille	A/4	**1. Optical and acoustic warning** Veh.= 10-180 km/h; Bicyclists and pedestrians = 10-80 km/h; **2. Automatic Brake Assist** Veh.= 30-180 km/h; Bicyclists and pedestrians = 30-80 km/h; **3. Automatic braking** Veh.= 10-180 km/h; Bicyclists and pedestrians = 10-80 km/h;	When the vehicle or detectable object is moving unevenly;
					When the detectable object is near a wall, fence, pillar, tree;
					If VSC is disabled;
					When the detectable object is under another structure;
					When a part of the detectable object is masked by an umbrella, flask, luggage;
					When the detectable object is white or glows brightly;
					If the vehicle in front has: very high ground clearance; reduced width; low rear window; over gauge at the rear;
					When the detectable object cuts the path or suddenly appears in front of the vehicle;
					When visibility is reduced; at dusk, in daylight or in a tunnel;
					If the front of the vehicle is covered in water, snow or mud;
					If the height of the pedestrian is less than 1 m or more than 2 m;
					If heavy rain or snow;
					If the front of the car is raised

Vehicle driver assistance system name	System/ mechanism where it operates, acts, or intervenes on the motor vehicle	The receiver on which the operation is based	Function/ Level of automation	Functions performed	Shortcomings/incorrect operations/nonconformities
					or lowered;
					If the pedestrian or cyclist is wearing bulky clothing.
2. Lane following assist system (LTA)	Acts on the steering mechanism	Front video camera in the radiator grille; Front No. 1 radar sensor.	B/2	1. **Give optical and acoustic** warnings when leaving the driving lane and when the vehicle is side swerving; **2. Automatic steering assist** by gradually operating the steering wheel and briefly maintaining the vehicle's direction of travel; **3. Automatically operates the steering wheel** and centers the vehicle in the driving lane.	If the road is under construction and the lines are colored yellow (temporary markings), the road is covered with snow, dust, dirt or mud and the longitudinal markings are faded, undefined, illegible, or missing;
					When the cruise adaptive cruise control display is shown and the vehicle in front: changes lane; swings; is driven close to the left/right lane departure line; moves out of the front camera field of view.
					When there are other objects on the edge of the carriageway (reflecting pillars, kerbs, railings);
					If there are shadows parallel to the longitudinal markings or if the asphalt shines brightly;
					If the longitudinal markings are cracked, raised, have stones, wet asphalt, or puddles;
					If the road slopes steeply to the left/right or has serpentines;
					If the road is paved/ gravel.
3. Adaptive cruise control across the speed range	Acts on: - the engine during acceleration and deceleration; - the braking system at stops.	Front No. 1 radar sensor; Front video camera in radiator grille	C/4	**1. Accelerates, decelerates and brakes automatically,** depending on the speed of the vehicle in front, even without applying the brake/ accelerator pedal;	It does not correctly detect the speed of the vehicle in front when: another vehicle suddenly pulls in front; the vehicle in front is moving at low speed; the vehicle in front has a reduced rear surface area (e.g. unloaded trailers); two-wheeled vehicles moving in the same direction and lane; when the sensor is blocked by water or snow; when the front

Vehicle driver assistance system name	System/ mechanism where it operates, acts, or intervenes on the motor vehicle	The receiver on which the operation is based	Function/ Level of automation	Functions performed	Shortcomings/incorrect operations/nonconformities
				2. Automatically sets the distance between cars, depending on the speed of the car in front (high = 50 m; medium = 40 m; low = 30 m); **3. Automatically maintains constant speed**, depending on the speed of the vehicle in front; **4. Warns visually and audibly** when the distance between vehicles is less than the set distance; **5. It warns the driver visually and audibly** to intervene if the system doesn't reduce speed on its own; **6. Keep the vehicle within a preset maximum speed limit.**	of the vehicle is lifted by the load on the luggage carrier; when the vehicle in front has a high ground clearance. After braking and stopping for more than 5 seconds, the vehicle in the queue does not move off on its own unless the accelerator pedal is depressed by the driver. Does not correctly control the distance between vehicles: when cornering, when the vehicle in front disappears from the camera's field of view; when the road is narrow; when the vehicle's steering or position on the road is not stable (side-slipping, vehicle swaying); when the vehicle in front suddenly decelerates; while the vehicle's speed is decreasing towards a set speed after the driver has intervened by pressing the accelerator pedal.
4. Cruise control with traffic sign recognition	Acts on: - the engine during acceleration and deceleration; - the braking	Front No. 1 radar sensor; Front video	C/4	**1. Recognizes traffic signs** (speed limit and no overtaking), displays them	The system does not warn correctly: when the vehicle in front is traveling at the same or higher speed; when the vehicle in front is traveling at reduced

Vehicle driver assistance system name	System/ mechanism where it operates, acts, or intervenes on the motor vehicle	The receiver on which the operation is based	Function/ Level of automation	Functions performed	Shortcomings/incorrect operations/nonconformities
(RSA)	system at stops.	camera in radiator grille.		on the dashboard and gives visual and acoustic signals when the speed limit is exceeded; **2. It displays on board and visually informs the driver of the areas where the traffic sign is operating** (the area where it has legal effect).	speed; immediately after the speed has been entered and set; when the driver steps on the accelerator pedal.
					It does not correctly detect if the traffic sign is dirty, obliterated, obscured or partially obscured by vegetation or other obstruction;
					It does not correctly detect if the camera is out of adjustment, dirty or covered in mud, snow, etc;
					It does not correctly detect heavy rain, snow, fog or sand storm;
					It doesn't correctly detect if oncoming light "blinds" the front camera;
					It does not detect correctly if the traffic sign appears briefly and quickly in front of the recognition camera (usually if it appears immediately at high speeds);
					It does not correctly detect if the traffic situation (turn approach, lane change in overtaking) is incorrectly appreciated by the system;
					It does not correctly detect if the vehicle in front has stickers stuck to the rear;
					Does not detect correctly in case of a traffic sign incompatible with the system;
					Does not detect correctly if other road signs on side roads etc. are detected.
					Does not correctly detect if the front of the car is too high or too low;

Vehicle driver assistance system name	System/ mechanism where it operates, acts, or intervenes on the motor vehicle	The receiver on which the operation is based	Function/ Level of automation	Functions performed	Shortcomings/incorrect operations/nonconformities
5. Blind Spot Surveillance (Monitoring) System (BSM and RCTA)	Do not operate the vehicle's control or driving systems; Warns optically in the left/right side mirrors and acoustically inside the passenger compartment (BSM system). Warns optically on the display and acoustically inside the passenger compartment (RCTA system).	Rear No. 2 radar sensor	B/2	**Assists the driver when changing direction -** Blind Spot Monitoring (BSM); **2. Assists the driver when reversing -** rear and cross-traffic warning function (RCTA).	In bright sunlight, the BSM system's optical indicator in the outside rear-view mirrors (left-right) may not be visible to the driver;
					The RCTA audible warning may not be heard by the driver if the volume of the car's audio system is loud or outside noises are loud;
					The system does not warn correctly when the sensors are blocked or obscured by mud, snow, ice or if the towed trailer load exceeds the side gauge;
					The system does not correctly warn when hot or freezing weather may affect the proper functioning of the sensors;
					The system does not correctly warn when the sensors are out of adjustment due to mechanical actions;
					The system does not warn correctly when several vehicles are approaching and the distance between them is small;
					The system does not warn correctly when the traveling speed of the approaching vehicle is equal to that of the vehicle on which the sensors are operating;
					The system does not warn correctly on steep slopes or ramps, sharp bends or uneven surfaces;
					The system does not warn correctly when there is a significant height difference between the vehicle on which the sensors are operating and the vehicle approaching from

Vehicle driver assistance system name	System/ mechanism where it operates, acts, or intervenes on the motor vehicle	The receiver on which the operation is based	Function/ Level of automation	Functions performed	Shortcomings/incorrect operations/nonconformities
					behind;
					The system does not correctly warn when the vehicle is parked or moving backwards on an incline;
					The system does not correctly warn when the vehicle on which the sensors are operating creates water vapor or snow behind it.
6. Parking assistance system	It warns the driver optically and acoustically; Acts on the automobile's braking system (PKSB system).	Ultrasonic radar sensors in the front grille and front and rear bumper; Video cameras in the front and rear bumpers; Video cameras in the side exterior mirrors.	A/4	**1. Audible and visual (on display) warning the driver** of the position of the car, the distance between the car and nearby objects during parking; **2. Brakes the vehicle when the system estimates the risk of collision with nearby objects during parking maneuvers -** parking brake assist for static or dynamic objects (PKSB)	The system does not work or works incorrectly when sensors or cameras have poor detection visibility, are covered with snow, ice, mud, etc.
					The system does not work or works incorrectly if the ambient temperature is too high in summer or too low in winter;
					The system doesn't work or works incorrectly when the vehicle is on a bumpy road, there is tall vegetation or gravel;
					The system malfunctions or malfunctions incorrectly when there is excessive noise nearby, heavy rain, heavy snow, or if the car is tilted excessively;
					The system does not work, or works incorrectly, when the car is making a downhill turn or oversteer;
					The system does not detect: wires, cables, strings, ropes, sharp-angled objects, water, snow, other low objects or objects that absorb sound waves (e.g. cotton).

Vehicle driver assistance system name	System/ mechanism where it operates, acts, or intervenes on the motor vehicle	The receiver on which the operation is based	Function/ Level of automation	Functions performed	Shortcomings/incorrect operations/nonconformities
7. Automatic long phase	Acts on the car's lighting system	Windshield mounted camera sensor	C/4	**1. Assess the brightness** of the street lighting system and oncoming vehicles; **2. Automatically activates or deactivates** the long phase (as needed).	The headlamps (high beam) may not be switched off automatically: when vehicles ahead appear suddenly from behind a hill, bend or obstacle; when the vehicle is overtaken by another vehicle; when vehicles ahead have their headlamps switched off, only the headlamps on or have low headlamp brightness; when vehicles ahead disappear from the range of vision.
					The system malfunctions or does not function at all when: heavy rain; heavy snow; dense fog or smoke; or when encountering highly reflective objects;
					The system doesn't work properly when the vehicle is tilted forward, backwards or sideways.

The assessment is based on research on a Toyota RAV 4 hybrid car in Romania with state-of-the-art automation and is the author's own, original contribution. It presents here all the shortcomings that have been found by users during operation, showing the stage/level of development, how the automation intervenes on the car's behavior in traffic.

We have shown the deficiencies/incorrect operations/non-compliances in Table 4, which can occur both day and night. They are designed and installed on today's road vehicles, and through incorrect operation can lead to incidents or accidents in road traffic. For this reason, in order to prevent all of this, the human factor is still necessary for driving. In accordance with the provisions and requirements of the European Union, these systems in the form of basic packages have become mandatory and are installed on all new motor vehicles manufactured in EU countries, starting in January 2022.

The functions specific to each level of automation for autonomous vehicles (Column *"Function/Automation Level"* in Table 4), which are the following [8, p. 121]:

A. For the level of automation related to assisted driving: automatic parking pilot function; remote parking assist function; evasive steering support function; automatic emergency braking function;

B. For partial vehicle automation level: roadside assistance function; integrated cruise assist function (cruise control, lane departure warning); lane departure warning; traffic jam assist function;

C. For the full and high level of vehicle automation: urban pilot function; on-road/highway pilot function (lane keeping, traffic sign recognition, automatic high beam); autopilot function when stuck in traffic.

Specific features are found on most new cars today. They form the base level of all vehicle ranges, including series production, and are fitted with the aim of raising the level of ergonomics, comfort, safety and range offered by the vehicle [8, p. 121].

To clarify what the degrees of automation refer to, I present the six levels of road vehicle automation (column *"Function/ Level of automation"* in Table 4) as follows [8, p. 120]:

- **level zero,** without automation, where the driver is entirely responsible for moving the car on public roads;
- **level 1** or the assisted driving level, where only a system (e.g. cruise control function) supports the driver;
- **level 2** or the level of partial automation, where other systems intervene and ensure the safe movement of the car on public roads (e.g. steering control system). In this case the driver continuously monitors and intervenes on the vehicle's movement;
- **level 3** or the level of conditional automation, where the vehicle travels most of the time on its own, driven by automated systems, which perceive traffic elements, analyze them, make decisions and implement them. However, the driver must be at the driving seat to take control of the vehicle when needed;
- **level 4** or the high level of automation, where the car is almost entirely driven by the systems and installations fitted to it. The driver intervenes only occasionally;
- **level 5** or the autonomous level, where the car is completely autonomous, driven solely by the systems and installations fitted to it. In this case, the driver is no longer needed in this role, becoming a mere passenger.

5. Conclusions

By decreasing the distance between two fixtures and increasing the mounting height we improve uniformity. It is advisable to analyze the luminance distribution at all points of the grid to determine the position of the minimum and maximum with their help you can estimate the effects of changes.

In general, if the lowest value is between luminaires this can be improved by choosing a luminaire whose angle in the vertical plane for the maximum intensity is greater. If the lowest value is at a point on the roadside the situation can be improved by choosing a luminaire with a wider distribution or by changing the length of the mounting bracket. For very wide streets it is better to use the front-facing arrangement because the reflectance characteristics are poor for light forming large angles with the observer's line of sight.

The Guide on lighting conditions on national roads and highways in Romania is a working tool both for CNADNR (National Roads and Highways Company), as administrator of the road network, and for the designers who will dimension and elaborate the technical prescriptions regarding the lighting on the respective road traffic routes

The rehabilitation or refurbishment of physically or morally ageing lighting installations is of particular significance, as higher luminance results can be achieved with lower energy consumption if state-of-the-art design or technologies (e.g. LED - Light Emitting Diode) are used. Improved lighting and lighting control systems typically give superior cost-benefit ratios with rapid payback periods.

When designing a lighting system it is necessary to pay attention to visual guidance to avoid misguidance. Visual guidance is a concept covering measures to be taken into account in order for the driver to easily identify the roadway configuration according to the maximum permissible speed for the particular road section. For unlit public roads, visual guidance is restricted to the area illuminated by the headlights of the car. A lighting layout designed to follow the road layout improves visual guidance and contributes to road traffic safety. This applies to roads with many small radius curves and multiple intersections. A serious traffic problem on public roads is blinding. This is determined by the luminance, size, position of sources in the field of vision, and the ratio of the luminance of the

source to the average luminance of the background. There are other factors that influence glare, such as the presence in cities of large, highly reflective surfaces, high luminance road signs and road markings, which affect the safety of drivers.
High quality street lighting should ensure safe and comfortable traffic at night, in conditions as close as possible to those during the day, which would help to reduce driver nervousness and fatigue. For this reason lighting installations that do not meet current requirements should be restored/renovated. Correctly installed street lighting helps to reduce the number of road traffic accidents at night. At the same time, it is much easier for the traffic police, who monitor the order on public roads or streets, to identify the causes and culprits of road accidents.
Each modern luminaire continuously illuminates exactly that portion of the road that is extremely important to be visible at night. Designers pay particular attention to the spacing of street lighting for public roads, strictly following the recommendations of specialists who have made preliminary calculations. Of course, we cannot say that it is only the lack of street lighting on a particular stretch of road that causes road traffic accidents. The human factor has the greatest influence on road traffic safety, but with high-quality street lighting every driver has the chance to avoid making mistakes, obeying traffic rules and, as a result, not being involved in road accidents.
It is recommended that in today's street lighting to use LED lighting elements as luminaires. They emit a strong neutral-white light, are more reliable and have a much lower energy consumption compared to traditional incandescent bulbs.
In Romania, most serious road accidents occurred between 0:00-07:00 in the morning and 21:00-24:00 at night. They have multiplied in the cold winter season, when the day gets shorter and night sets in more quickly, and road brightness and visibility also decrease substantially. This favors such undesirable events for drivers. Between 6:00-7:00 in the morning, the number of serious road accidents increases exponentially, with about twice as many as an hour ago. Peak values/day are recorded between 17:00 and 180:00 (349 serious road traffic events), especially in winter, when night falls and visibility decreases substantially. In addition, the busiest time of the day in terms of the number of serious road accidents is 16:00-19:00 (winter), when 1 in 5 serious accidents is recorded during the 24 hours of the day. More than a quarter (26.8%) of the people killed in serious road accidents lost their lives in such events between 17:00 and 21:00. These issues are substantially amplified when drivers' visibility is low due to poorly lit roads, streets, intersections or pedestrian crossings.
From the investigations of the systems presented in Table 4, more than 50 nonconformities have been found, demonstrating a low level of autonomy of the analyzed vehicle in road traffic. Human intervention in the vehicle's controls is still necessarily necessary. While some systems, by the way they operate, are limited to warning only (Lane Keep Assist - LTA, Blind Spot Monitoring - BSM and RCTA and Radar Dynamic Cruise Control with Traffic Sign Recognition - RSA) and do not operate mechanisms such as steering or brakes, others have a higher level of automation (Radar Dynamic Cruise Control with full speed range and automatic high beam). These are not, of course, maximums that completely take over functions from the driver. It has not been possible to establish a maximum level of autonomy, even for the last two systems mentioned, which are much more advanced and much more advanced. The fact that all these systems are installed in new, modern cars nevertheless ensures a higher degree of safety, giving us hope that in the near future they will evolve in such a way that the driver can be a mere passenger in the autonomous vehicle. At the moment, they support the driver and intervene when necessary depending on the situation, but they cannot totally eliminate unpleasant road events. For this reason, it is very important to specify that the vehicle must be driven with caution.
From January 01, 2022, in accordance with the Regulation of the European Parliament and of the Council (PE-CONS 82 of October18, 2019) amending Regulation (EU) 858 of May 30, 2018, the European Union through its policies obliges all European manufacturers of road vehicles to fit/install on new vehicles safety packages for both road vehicles and their users and vulnerable road users, with the aim to increase safety on public roads and to substantially reduce the number of serious road traffic accidents.

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Welding considerations for duplex steel sluice gates in water pipelines

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Abstract. The article presents the finding of an optimal technology for welding an oversized construction, from an LDX 2101 duplex steel. The biggest problems are related to the occurrence of stresses and deformations after welding. Also, depending on the parameters of the welding regime, the structure of the material, and the amount of ferrite/austenite can also be modified. These changes will also lead to changes in mechanical properties and corrosion resistance. The article also presents the problems that can arise from the inadequate choice of the filler material, cracks in the weld seam, for a heterogeneous joint, and how to make the optimal choice.
Keywords: *welding, duplex steel, crack*

Introduction

High-alloy steels, as defined by the European standard EN10200, are iron-chromium-carbon alloys containing more than 10.5% Cr and less than 1.2% C [1], [2]. Based on their chemical composition, they can be classified as chromium steels or chromium-nickel steels. According totheir crystalline structure, high-alloy steels can be categorized into martensitic, ferritic, austenitic, duplex, and precipitation-hardening steels.

The main categories of high-alloy steels are as follows:

- martensitic steels: Characterized by a chromium content of approximately 13% and a high carbon concentration (exceeding 1% in some cases). These steels exhibit high mechanical strength but are difficult to weld and deform.
- ferritic steels: Contain approximately 10–18% Cr and a very low carbon content (around 0.05%).
- austenitic steels: Contain at least 16% Cr, with Ni and/or Mn as alloying elements to stabilize the austenitic phase. The addition of nickel enhances formability and weldability; a nickel content between 8% and 12% allows stainless steel to undergo rolling, pressing, and deep drawing while also improving its corrosion resistance.
- duplex steels: Contain more than 22% Cr, Ni, and approximately 3% Mo. These steels exhibit superior resistance to highly corrosive environments.
- precipitation-hardening steels: Alloyed with copper, which enhances acid resistance, and niobium, which mitigates corrosion in welded areas. These stainless steels have high processing costs but combine the exceptional corrosion resistance of austenitic steels with the superior mechanical properties of martensitic steels.

There are numerous applications in hydro construction where such materials are used. Although initially perceived as an expensive option due to the cost of materials, in the long term, maintenance costs are significantly reduced, and repairs are almost eliminated compared to conventional steel.

Oversized components refer to parts with large-scale dimensions and weights. Their manufacturing involves multiple considerations related to the associated technological processes, required equipment, and logistics.

The first challenges arise during the manufacturing process, as it requires specialized logistics, lifting equipment such as cranes, overhead bridges, and slings, as well as skilled personnel. Additionally, machining such components demands large-scale equipment, ranging from 5 to 30 meters in size, with extremely tight tolerances in the order of hundredths of a millimeter or even microns.

Individual components can weigh between 5 and 20 tons, while assembled structures can reach weights of 200–300 tons and lengths between 15 and 100 meters. The most significant challenges are related to stresses and deformations that occur after welding.

The assembly is a vertical sluice gate, a plate valve with approximate dimensions of 10 x 3.5 x 0.5 m, manufactured from thick steel plates of 20–30 mm, reinforced with various stiffening ribs made of 15 mm thick unalloyed steel plates (see Figure 1 – final assembly). The total weight of the structure is approximately 20 tons.

Figure. 1 – Final assembly

The welding process was divided into two main stages:

- manufacturing and positioning of the components
- welding of the individual parts

The assembly was made up of several components. The base materials used were high-alloy duplex steel LDX 2101 and S355JO. The chemical composition of LDX 2101 is presented in the table below:

Elem	C	Cr	Mn	Ni	Mo	Nb	Fe
%	0 – 0.03	21.5	5	1.5	0.3	0.22	rest

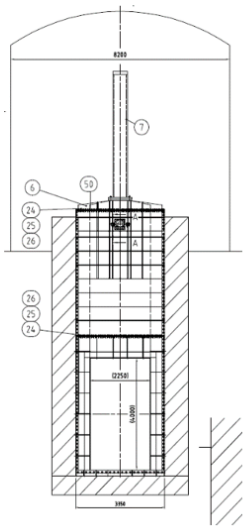


Figure 2 – Assembly drawing – view A

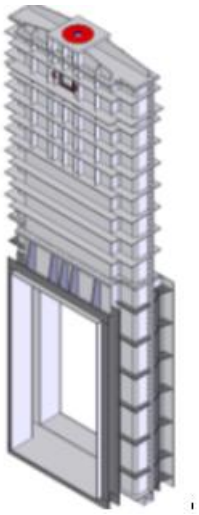


Figure 3 – Assembly drawing – isometric view

2. Manufacturing the Components and Their Positioning:

The "Gate" assembly consists of three subassemblies, which will be mechanically assembled using bolts.

The semi-finished products were in the form of flat plates, with thicknesses ranging from 20 to 30 mm, depending on the part. The components were cut using water jet/plasma methods.

The plastic deformation was carried out using different presses, but freely, not in molds, which led to differences between components. Some mechanical processing was done manually, without precise control.

This resulted in deviations ranging from 5 to 20 mm, deviations that negatively affected the deformation values of the welded product.

High-alloy steel deforms extensively and uncontrollably during welding. If the joints are large and there is no mechanical restraint, the deformations can only be compensated by cutting and rewelding.

On the other hand, after welding, thermal treatment for stress relief must be performed so that the areas under stress due to restraint can release their internal stresses. If this is not done, after the mechanical restraint is removed, the part/assembly will deform, less than if it was not constrained, but it will still deform.

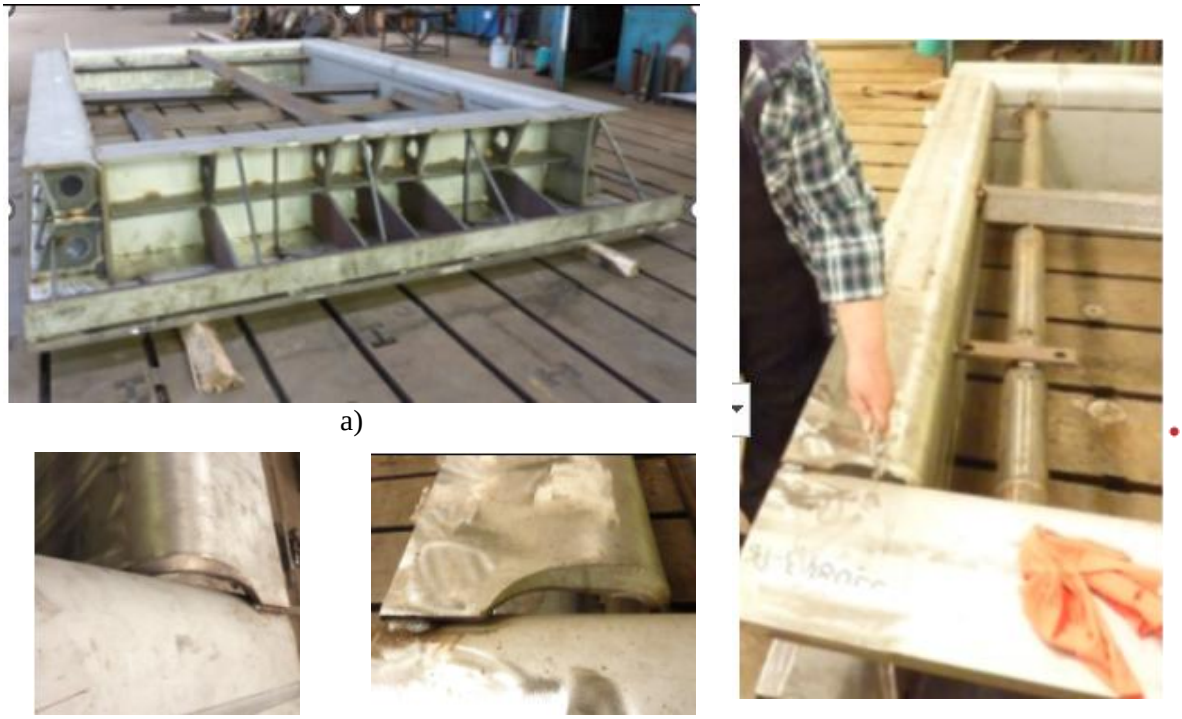
The welding sequence is equally important as it ensures the balancing of the residual stresses/deformations during welding. Since oversized components are involved, the tolerances for the material resulting from mechanical processing or welding must fall within the values presented in the table below.

General Tolerances				General Tolerances			
Welding	EN ISO 13920 B			Mechanical Processing	ISO 2768 – 1m		
	Dimensions		Tolerance		Dimensions		Tolerance
	From	To	±		From	To	±
	0	30	1		0.5	3	0.1
	30	400	2		3	6	0.1
	400	1000	3		6	30	0.2
	1000	2000	4		30	120	0.3
	2000	4000	6		120	400	0.5
	4000	8000	8		400	1000	0.8
	8000	12000	10		1000	2000	1.2
	12000	16000	12		2000	4000	2
	16000	2000	14				
	20000		16				

The positioning of the components must be executed on a flat reference plane. Flat tables are used for machining, or rectangular/circular platforms.

In this case, some components were not properly machined, and the deviations did not conform to the standard. The positioning and fixing of the elements were carried out with difficulty.

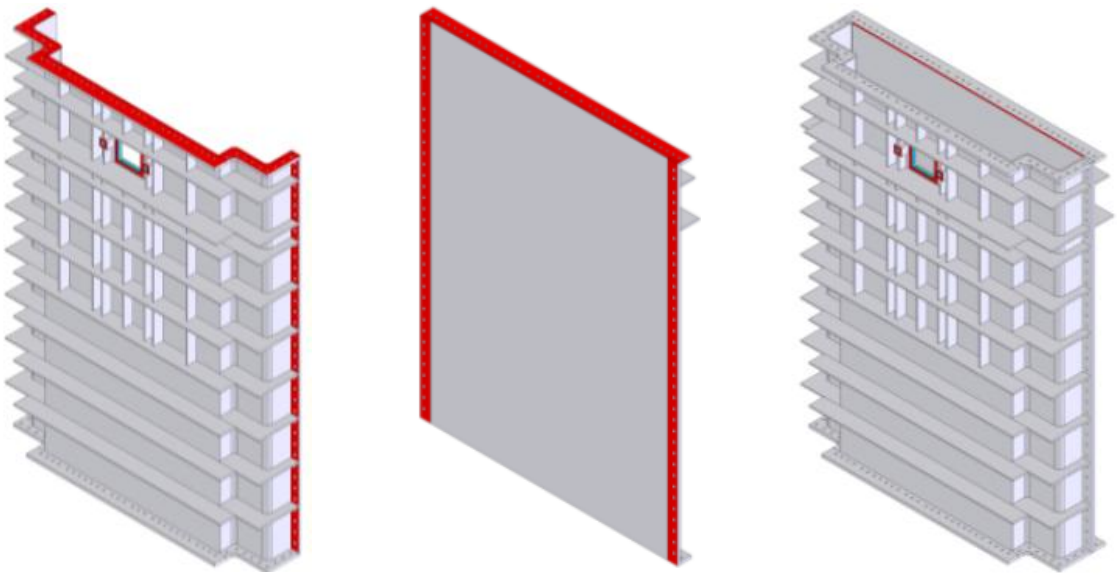
The table below shows some images of "Subassembly 2" and some deviations from the mechanical processing. Each subassembly came with various deviations and deformations. Subassembly 1, as seen in Figure 5, consists of two parts: the upper cap (CS1) and the lower flat cap (CS2). The dimensions are approximately 5.5 x 3.2 x 0.7 m.



a) c) d) b)

Figure 4 – Mechanical processing deviations

The closing plate slides inside this subassembly. Due to the high forces exerted by water pressure and to allow it to be fixed into concrete, stiffeners in the form of plates made from carbon steel were mounted on both caps.



a) b) c)

Figure 5 – Subassembly 1; a) upper cap CS1, b) lower flat cap CS2; c) mounted subassembly

Figure 6 – Images from the execution of this subassembly

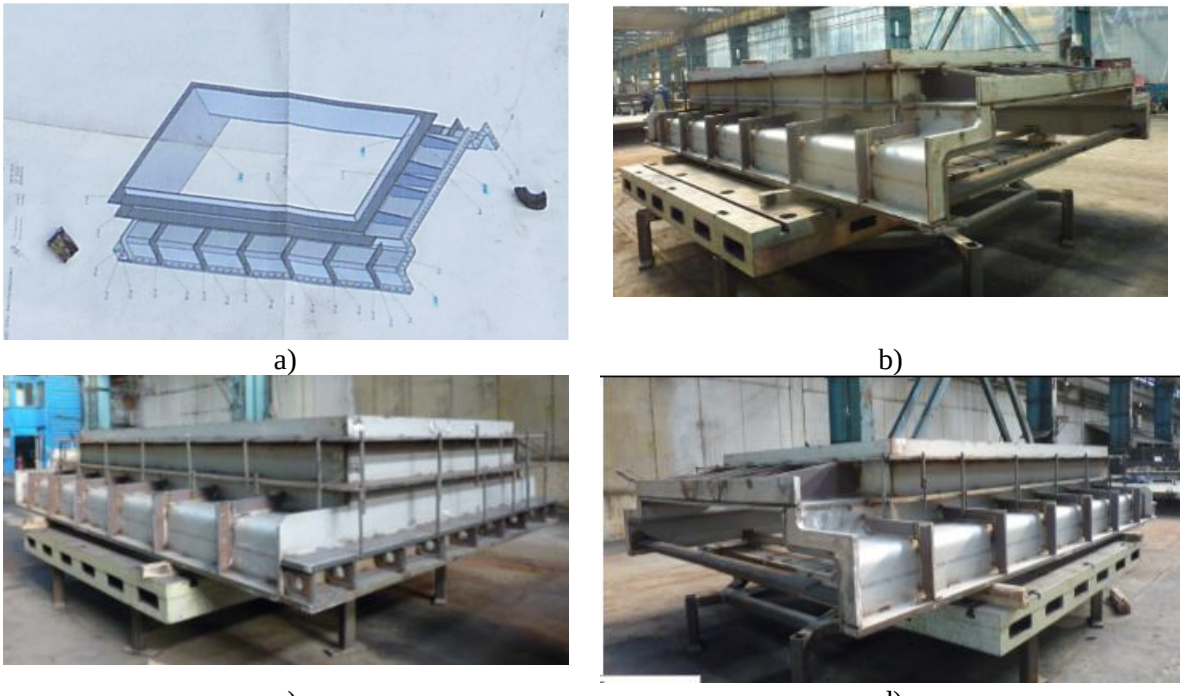
Figure 6 – View of subassembly 1

There were also significantly larger deviations during the manufacturing of the parts. For positioning and fixing the components, various profiles were used to secure the elements both internally and externally. During welding, it was found that these temporary fixations were insufficient, and additional ones were added. Most of the stiffeners were placed inside the subassembly.

The weight of the assembly, according to the drawing, was 9070 kg, and with the positioning and fixation elements, it reached 11,000 kg (11 tons). The logistics for handling the product had to be suitable for both the weight and material. In order to be welded, the assembly was rotated several times.

For subassembly 3, see Figure 7, the same issues related to the dimensional precision of the parts occurred. In joints made from the same material, the deformations were almost evenly distributed; however, in heterogeneous joints (stainless steel + unalloyed steel), the deformations were different due to the varying stresses in the material, see Figure 8. The dimensions are approximately 4.7 x 3.2 x 0.7 m, and the weight is approximately 4,200 kg.

In the specialized literature, there is no guide for the positioning or sizing of stiffeners to prevent deformation during welding. This can only be approximated from accumulated experience and computer simulations using FEM software.



a) b)

c) d)

Figure 8 – Subassembly 3

The stiffeners were positioned in such a way as to allow the welder access and to facilitate the handling of the component. Since carbon steel stiffeners were used in the design, all temporary fixations could also be made from carbon steel, avoiding issues with stainless steel contamination.

The large deviations from the mechanical processing, which were present from the beginning, turned into significant deformations after welding. During welding, additional fixing elements were added, depending on the deformations that occurred.

a) b)

Figure 9 – Position deviations/from the plastic deformation technological process

3. Welding of Components.

The proposed welding process was MIG [4] with solid wire, with a difference in the chemical composition of the material depending on the base material, as follows:

a) The filler material for duplex–duplex welding was according to AWS ER 2209 [78], a solid wire with a diameter of 1.2. The chemical composition is presented in the table below:

Chemical Element	C	Si	Mn	Cr	Ni	Mo	N
%	0.01	0.5	1.6	23	9	3	0.15

Mechanical Properties:

	σ_c N/mm^2	σ_r N/mm^2	A %	KCU J
Val	600	765	28	100

b) The filler material for heterogeneous joints – stainless steel + unalloyed steel was according to AWS ER 309Si, a solid wire with a diameter of 1.2.

Chemical Element	C	Si	Mn	Cr	Ni
%	0.02	0.9	1.7	23.5	13.5

Mechanical Properties:

	σ_c N/mm^2	σ_r N/mm^2	A %	KCU J
Val	440	600	41	160

a) Duplex – Duplex Welding

The samples for process qualification were successful, see Figure 10. The base joint was a corner joint. The welding parameters were: I = 210 A; U = 22 V; Welding speed = 35 cm/min.

Welding was done with the gun held back (dragged bath) – due to the thick plates.

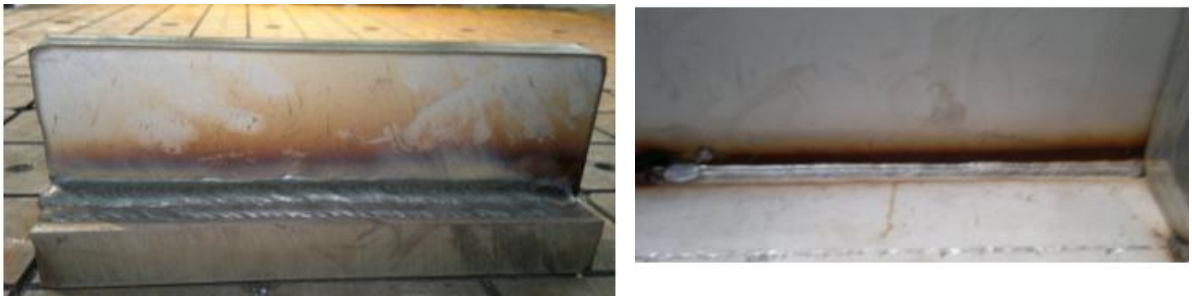


Figure 10 – Welding samples

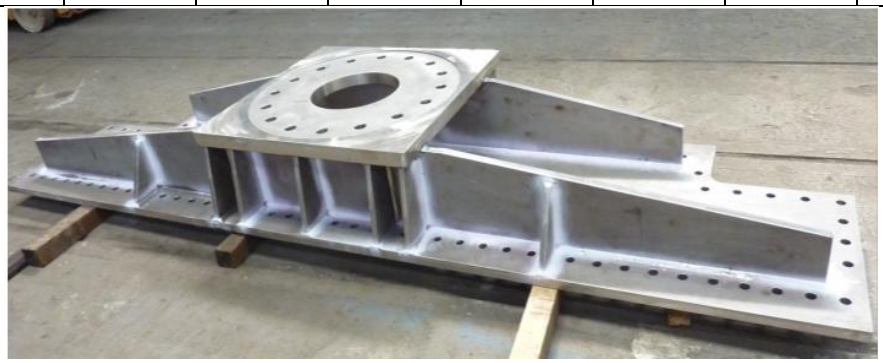
For good results, the temperature between layers did not exceed 120°C.

Given the large amount of filler material that needed to be deposited, and to allow the piece to cool, various technological welding options were tested, including welding in different locations or pulsed current welding. The results were better but still not satisfactory. Therefore, tests were conducted with tubular wire.

The MAG process was used, utilizing a tubular wire E2209TO – 1, with shielding gas Ar+20%CO2. The results were very good. Spatter was reduced, penetration was good, and for various welding positions, using tubular wire, there were no further issues. Figure 11 shows the "Cap" piece welded with tubular wire.

Chemical composition:

Chemical element	C	Si	Mn	Cr	Ni	Mo	N
%	0.03	0.6	0.9	22	9	3.4	0.12



a)

b) c)

Figure 11 – Cap welded with duplex tubular wire

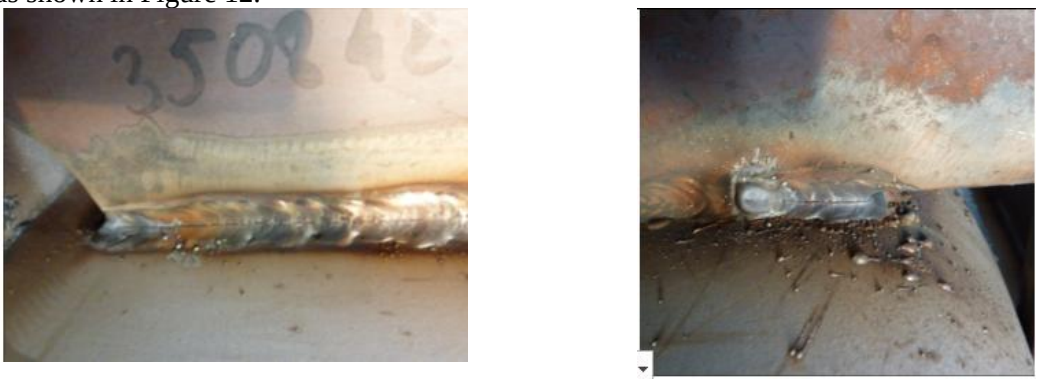
Mechanical Properties:

	σ_c N/mm^2	σ_r N/mm^2	A %	KCU J
Val	633	768	31	120

I = 190 A; U = 26 V; Welding speed = 40 cm/min; Welding with the gun ahead

b) Heterogeneous joint, duplex–carbon steel welding

For the heterogeneous joint, the use of a solid wire, 309Si with a diameter of 1.2 mm, was chosen. Laboratory samples for qualification were good, but in practice, numerous cracks appeared in the weld bead, as shown in Figure 12.



a) b)

Figure 12 – Cracks in the weld bead

The Schaeffler diagram, Figure 13, allows for the determination of the structure in the case of heterogeneous joints.

Because numerous cracks appeared in this type of joint, solutions were sought. The research began by approximating the weld structure through the calculation of two indicators, Cr equivalent and Ni equivalent.

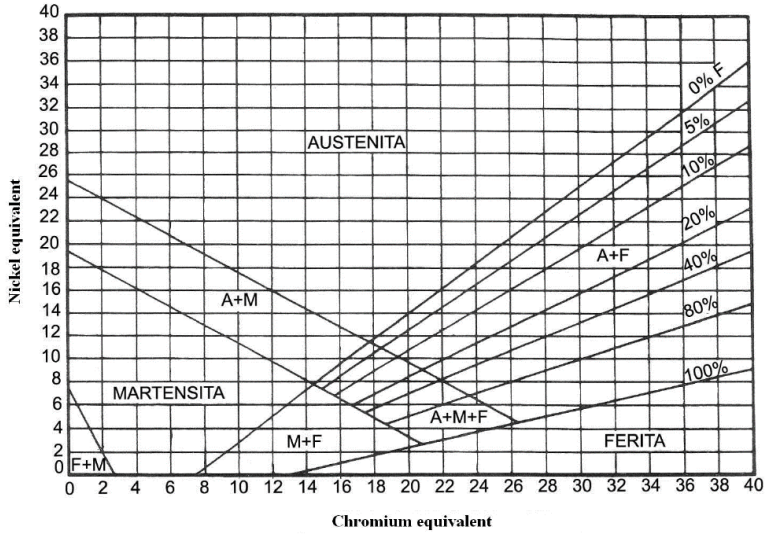


Figure 13. The Schaeffler diagram

Several filler materials recommended for heterogeneous joints were selected, namely: 307, 309, 309Mo, and 312. The Cr equivalent and Ni equivalent were calculated.

Material	307	309	309Mo	312
Cr equivalent	18.7	24.6	26.7	30.3
Ni equivalent	14.2	13.3	13.5	12.7

By drawing dilution lines, the best material that would reduce the amount of martensite in the weld was 312, followed by 309Mo.

312 was preferred also due to its ferrite content, which is close to that of duplex steel. Since there were many horizontal welds, a solid wire with a diameter of 1.2 mm was chosen.

Chemical Composition of 312

Chemical element	C	Si	Mn	Cr	Ni
%	0.12	0.7	0.8	29	10

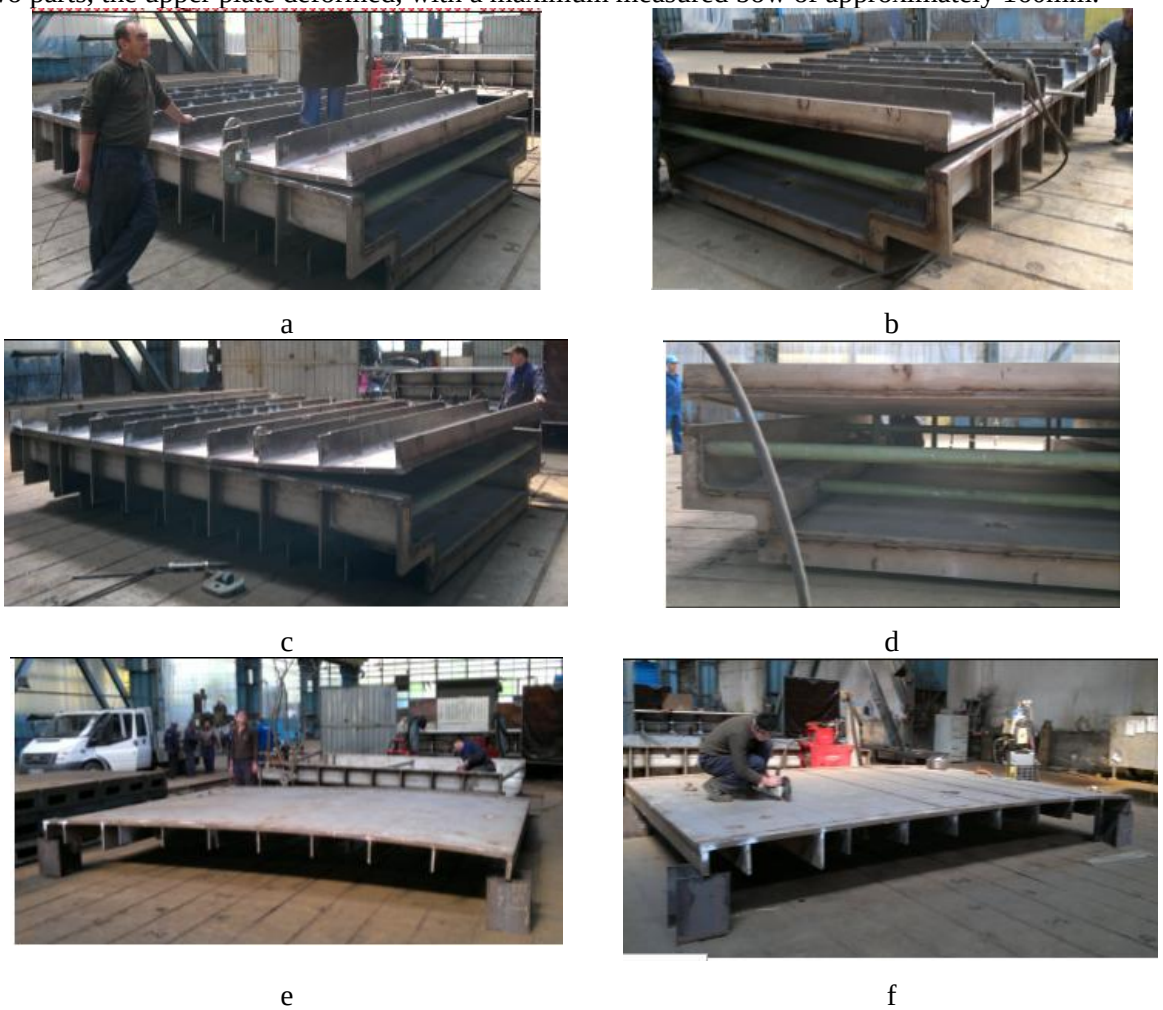
Mechanical Properties

	σ_c [N/mm^2]	σ_r [N/mm^2]	A [%]	KCU [J]
Val	580	750	25	60

The results were satisfactory, and during the NDT inspection of the weld beads using LP and PM methods, only 3–4% of the areas required remediation.

Another issue encountered was related to the residual stresses and deformations after welding. Designers, when performing strength calculations, often do not consider this aspect, thinking it is the responsibility of the process engineer.

In this case, because the part was asymmetric, approval was requested from the client to perform a stress-relief heat treatment for the entire structure. Unfortunately, the client did not accept this treatment for various reasons. Therefore, deformation correction was performed through plastic deformation using hydraulic jacks and/or by beveling and rewelding, see Figure 14. After cutting the welds to separate the two parts, the upper plate deformed, with a maximum measured bow of approximately 160mm.



a b c d e f

Figure 14. Deformation correction

Conclusions:

1) Laboratory tests are often not as conclusive due to the real conditions under which the welding activity takes place. Filler material manufacturers only recommend the filler materials but never guarantee them.
2) Welding technology does not only depend on choosing a welding process and parameters but also on the shape and dimensions of the part, the access to the joint, how the parts were made, and the methods of positioning and fixing.
3) The reduction of deformations after welding can also be achieved through a stress-relief heat treatment.
4) Deformations can appear and may be significant when the metal construction is not symmetric. Asymmetries must be carefully calculated. Often, it is cheaper to add material to the final part than to straighten it. The cap that was straightened by cutting and rewelding took about 3 weeks to straighten, using 2 operators, a locksmith, and a welder. By calculating labor, filler materials, costs – section overheads, it would certainly have been cheaper to make a symmetrical design.
5) Gaps between parts are a significant cause of cracks and deformations. Therefore, the preparation of semi-finished parts must be done with great care, and the pieces should be cut to the upper limit of the tolerance, with adjustments made through grinding during assembly, as needed.
6) The choice of filler material must also consider the existing welding equipment. Often, a procedure already approved for another part is used. For simple parts, this is not a problem, but for complex parts, such as the ones presented above, it is necessary to perform welding technology qualifications.

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Welding of earthing sockets using the aluminothermic process

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Abstract. Exothermic welding is a welding process at extremely high temperatures, based on chemical reactions that release significant amounts of heat. This is a fundamental process in making electrical connections, especially in the installation of earthing sockets, where high strength and long-term reliability are required. This article explores the physicochemical principles of exothermic welding, the processes involved, as well as their applicability in the creation of earthing sockets, taking into account relevant technical regulations and industry standards. In this paper, six exothermic welded joints between copper sheet and electrode will be analyzed, on which electrical contact resistance measurements will be made. The aim is to determine how the electrical contact resistance is influenced by the material from which the parts that are aluminothermically welded to make earthing sockets are made.
Keywords: *earthing sockets, aluminothermic welding, electrical contact resistors*

1. Introduction

Exothermic welding is a process used to create durable and efficient electrical connections, and is frequently applied in high-safety electrical installations, including the creation of earthing sockets. This method involves the use of an exothermic chemical reaction, which generates temperatures of the order of 3000 °C, sufficient to melt the metals involved and create a solid bond between the metal components. In the case of earthing sockets, exothermic welding ensures a low electrical resistance and a corrosion-resistant bond, essential for the protection of electrical systems.

As a principle, exothermic welding is based on the chemical reaction between metal powders and the oxide of another metal, which, in the presence of an ignition material, generates sufficient heat to melt the metals and fuse them [1], [2].

The most commonly used reaction is the reaction between aluminum powder and copper oxide, which produces oxidized aluminum (slag) and molten copper:

$$3Cu_2O + 2Al \rightarrow 6Cu + Al_2O_3$$

This process does not require an external energy source, because in exothermic welding the reaction occurs inside a graphite mold. The oxidized aluminum will rise to the top of the connection, creating slag, and the copper will "flow" around the conductors, creating a permanent joint [3], [4].

În toată lumea, sudarea exotermă a sistemelor de împământare s-a dovedit a fi cea mai bună alegere where safety, reliability, carrying capacity and longevity are important elements for the beneficiaries

of the earthing systems. The great advantage is that this resulting connection is a permanent, maintenance-free connection that will not weaken or deteriorate over time [5].

2. Advantages of exothermic welding

The advantages of exothermic welding in the case of making earthing sockets are very high compared to other classical methods of making earthing sockets. Most joints obtained by exothermic welding have at least double the cross-sectional area of the conductors being joined and an equivalent or greater carrying capacity. The corrosion resistance is exceptional due to the very high copper content of the alloy (> 90%).

The following real advantages of exothermic welding of earthing sockets can be considered:

- Simplicity and speed - the method is safe and easy to use, with minimal training and protection requirements, does not require complex equipment and can be performed quickly without the need for elaborate or large-scale welds;
- Does not require an external energy source because the reaction occurs in a graphite mold;
- The process requires a completely portable system;
- The process can be applied in dozens of configurations;
- High-quality electrical connection - the connection made by exothermic welding has a much better electrical conductivity compared to traditional welding methods (for example, electric arc welding or soldering);
- Lifetime beyond that of the elements that connect them - exothermic welding creates an extremely corrosion-resistant bond, thus ensuring a long life, even in environments with humidity or exposure to aggressive chemicals;
- Increased mechanical resistance - the connection made is solid and does not present the risk of weakening over time, unlike other methods that can be affected by mechanical vibrations or exposure to extreme temperature conditions
- Resistance to high fault currents that can leak to earth;
- Provides a leakage path with minimal resistance of fault currents;
- Compliance with current technical standards and norms;
- Quality can be controlled by visual inspection

3. Industry regulations and standards

In many countries, exothermic welding is regulated by specific standards and technical norms, which guarantee the safety and efficiency of the process.

For example, in the European Union, the use of exothermic welding in electrical installations is regulated by standards such as EN 50164-2, which covers protection against electric shock and the installation of earthing systems.

Also in the United States, the ANSI/UL 467 standard establishes requirements for the connection and protection of electrical installations to ground, including requirements for exothermic welding.

4. Applications of aluminothermic welding

Exothermic welding is frequently used in various fields that require the installation of effective grounding protection systems, such as:

- Industrial electrical installations where it is necessary to protect sensitive equipment and employees from technical failures, equipotential bonding of metallic structures, lightning protection installations, etc.;
- Constructions where earthing sockets, equipotential bonding of metallic structures, lightning protection installations, etc. are used;
- Transformer stations and power plants where it is necessary to connect high voltage equipment to the ground, to minimize the risks of fire or electric shock;

- Transport infrastructures such as the grounding of railway infrastructures, high voltage lines or oil and gas pipelines, etc.

5. Experimental research

The research consists of making six T-welded joints using the aluminothermic welding process used to make earthing sockets, of which three welded joints were made between copper sheet and copper electrodes and the other three were made between copper sheet and stainless steel electrode.

After completing the steps necessary to make the joints, the electrical contact resistances will be measured and compared with each other.

To make the welded joints, the following steps were taken:

a-**Surface preparation** - involves cleaning metal surfaces of impurities and oxides to allow for an optimal chemical reaction;

b-**Exothermic powder application** -the powder and oxide are placed in a graphite mold that will concentrate and maintain the localized chemical reaction;

c-I**nitiation of the reaction** - a mixture of magnesium or other combustible substances is usually used to initiate the exothermic reaction and d-Formation of the interatomic bond - the heat generated by the reaction melts the metal, and the molten copper flux creates a solid and conductive bond between the sulfur and the ground electrode.

Figure 1 shows the part of the welding equipment that contains the two graphite half-molds, the two ores and the mold cavity in which the tip and the ground electrode are fixed to make the T-welded joint and in which the exothermic reaction between the aluminum powder and the copper oxide occurs, producing aluminum oxide (slag) and molten copper.

Figure 1. Mold used for aluminothermic welding of earthing sockets

Figure 2 shows the device for initiating the chemical reaction between aluminum powder and copper oxide.

Figure 2. Reaction initiation device for aluminothermic welding

The welded joints between the copper sheets and the copper electrodes were designated ST1, ST2 and ST3 and are shown in figure 3.

Figure 3. Welded joints ST1, ST2 and ST3 between copper sheet and copper electrode

The welded joints between the copper sheets and the stainless steel electrodes were designated ST4, ST5 and ST6 and are shown in the figure 4.

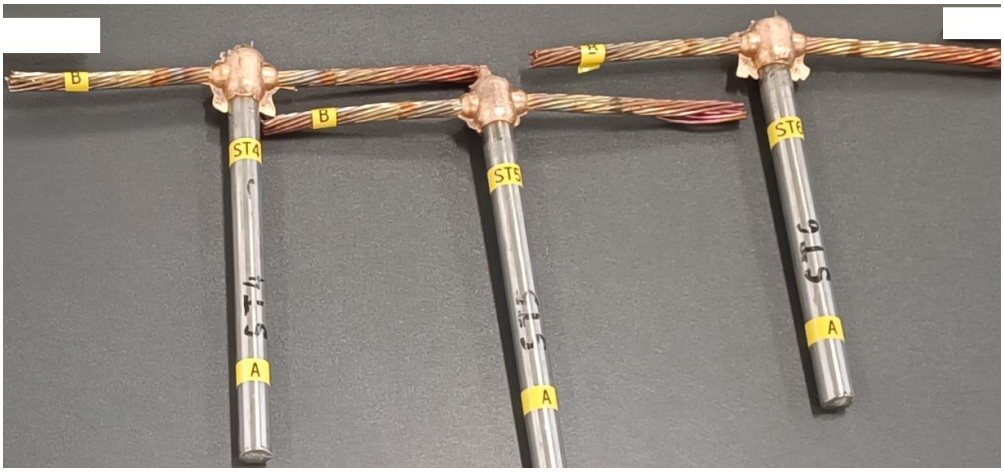

Figure 4. ST4, ST5 and ST6 welded joints between copper sheet and stainless steel electrode

The results obtained from contact resistance measurements in the case of welded joints between copper sheets and copper electrodes are presented in figure 5.

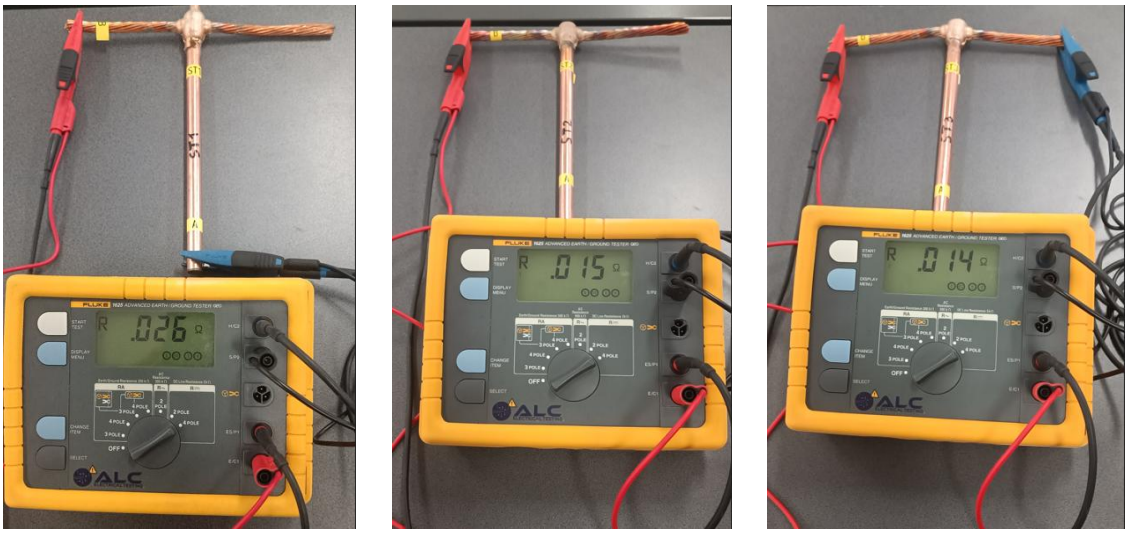

Figure 5. Contact resistance measurement for ST1, ST2 and ST3

The results obtained from contact resistance measurements in the case of welded joints between copper sheets and stainless steel electrodes are presented in figure 6.

For contact resistance measurements, a device used in industrial measurements, the FLUKE 1625 brand, was used.

The contact areas between the probe and the measuring device clamps were mechanically cleaned to remove the oxide layer.

Taking the arithmetic average of the three measurements, we can say that in the case of the T-welded joints between the copper sheets and the copper ground electrode, an average contact resistance value of 0.18 Ohms was obtained.

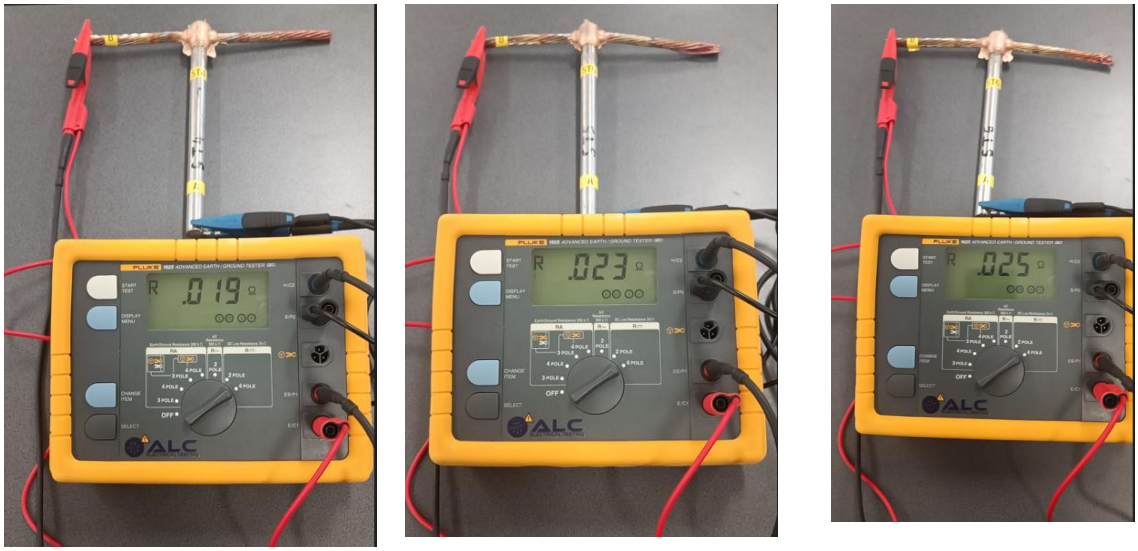

Figure 6. Contact resistance measurement for ST4, ST5 and ST6

Taking the arithmetic mean of the three measurements again, we can say that in the case of the T-welded joints between the copper sheets and the stainless steel ground electrode, an average contact resistance value of 0.22 Ohms was obtained.

6. Conclusions

The contact resistance that can be measured in the case of aluminothermic welded earthing sockets can give us indications on the quality of the connection made.

From the measurements performed and the calculated average values, it appears that of the joints analyzed, the highest quality T-welded joints are those made between copper sheets and copper electrodes, i.e. those marked with ST1, ST2 and ST3.

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Design and Simulation of Mechanical Structures Using FEM (Finite Element Method)

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Abstract. This study applies the Finite Element Method (FEM) to analyse the structural behaviour of a cantilever beam subjected to a distributed load. Using aluminium as the beam material (E = 70 GPa, ν = 0.33), a 3D CAD model was developed in SolidWorks and meshed with tetrahedral elements in ANSYS. The analysis involved defining appropriate boundary conditions, where one end was fully fixed, and a uniform force of 500 N/m was applied at the free end. A linear static analysis was performed to evaluate stress distribution, displacement, and strain energy density. Results indicate that stress concentration is highest at the fixed support, confirming theoretical predictions. The displacement profile follows the expected curvature based on Euler-Bernoulli beam theory. Mesh refinement studies highlight the trade-off between computational cost and accuracy, ensuring convergence of the numerical solution. Additionally, strain energy analysis provides insights for material optimization. The study confirms the reliability of FEM in predicting structural integrity and optimizing mechanical designs. Future research could extend this methodology to nonlinear material behaviour, dynamic loading, and anisotropic materials, further enhancing the applicability of FEM in advanced engineering applications.

Keywords: *Finite Element Method (FEM), Cantilever Beam Analysis, Stress Distribution Structural Optimization, Mesh Convergence*

Introduction

Finite Element Method (FEM) has become an essential tool in engineering for analysing and optimizing mechanical structures. By breaking down complex geometries into smaller, manageable elements, FEM allows for precise stress, strain, and deformation calculations under various loading conditions. This paper explores the significance of FEM in mechanical structure design, its applications, and the benefits it brings in reducing costs and improving efficiency.

The evolution of numerical analysis techniques in engineering has played a crucial role in the development of modern mechanical systems. FEM, originally developed in the mid-20th century, has revolutionized the way engineers approach structural design and performance evaluation. Its ability to provide detailed insights into material behaviour, structural integrity, and mechanical performance under different environmental and operational conditions makes it indispensable in contemporary engineering practices.

One of the primary advantages of FEM is its ability to handle complex geometries that would be impossible to analyse using traditional analytical methods. Engineering structures, ranging from simple mechanical components to large-scale infrastructures, often exhibit intricate designs with multiple

material compositions. FEM discretizes these structures into finite elements, each governed by mathematical equations that describe its mechanical properties. This segmentation enables engineers to simulate real-world conditions with remarkable accuracy and predict how different materials and structural configurations respond to various forces.

Stress and strain analysis is a fundamental aspect of mechanical engineering, ensuring that components can withstand operational loads without failure. FEM facilitates this analysis by computing stress distributions within a structure, identifying critical points where deformation or failure may occur. This capability is particularly valuable in industries such as aerospace, automotive, and civil engineering, where safety and reliability are paramount. Through FEM simulations, engineers can optimize designs, reduce material waste, and enhance overall structural efficiency before manufacturing begins.

In addition to stress and strain analysis, FEM is instrumental in thermal analysis, dynamic simulations, and fluid-structure interactions. In mechanical engineering, temperature variations can significantly affect material properties and structural integrity. FEM allows engineers to model heat transfer within components, evaluate thermal expansion effects, and design efficient cooling systems. Similarly, dynamic simulations using FEM help in analysing vibrational behaviour, impact resistance, and fatigue life, ensuring that structures can endure prolonged operational stresses without failure.

Another critical application of FEM is in the optimization of mechanical components for weight reduction while maintaining strength and functionality. In industries like aerospace and automotive manufacturing, minimizing weight is crucial for improving fuel efficiency and performance. FEM-driven topology optimization techniques enable engineers to refine designs by removing excess material in non-load-bearing areas while preserving structural integrity. This leads to the production of lightweight yet robust components that meet performance requirements without unnecessary material costs.

The integration of FEM with computer-aided design (CAD) and computer-aided engineering (CAE) software has further enhanced its accessibility and effectiveness. Modern simulation tools allow engineers to import complex 3D models directly into FEM analysis environments, streamlining the design validation process. This seamless integration facilitates iterative design improvements, enabling engineers to test multiple configurations, identify weaknesses, and refine designs before prototyping. As a result, development cycles are shortened, and production costs are significantly reduced.

The cost-saving potential of FEM extends beyond material optimization and design validation. Traditional experimental testing of mechanical structures often involves fabricating prototypes and conducting extensive physical tests, which can be time-consuming and expensive. FEM simulations provide a cost-effective alternative by predicting structural behaviour without the need for physical prototypes. This virtual testing approach allows engineers to explore different design scenarios, assess performance under extreme conditions, and make informed decisions without incurring high manufacturing costs.

Despite its numerous advantages, FEM is not without limitations. The accuracy of FEM simulations depends on several factors, including the quality of the mesh, material property assumptions, and boundary conditions. Poorly defined meshes or incorrect material parameters can lead to inaccurate results, potentially compromising design reliability. Additionally, FEM requires significant computational resources, especially for large-scale simulations with millions of elements. Advances in high-performance computing (HPC) and cloud-based simulation platforms have addressed some of these challenges, making FEM more accessible and efficient for complex engineering applications.

The growing importance of FEM in engineering is evident across various industries. In aerospace engineering, FEM is used to analyse aircraft structures, ensuring they can withstand aerodynamic forces, pressure differentials, and thermal loads during flight. In the automotive sector, FEM simulations aid in crash analysis, suspension system optimization, and engine component design. Civil engineers rely on FEM to evaluate the structural stability of bridges, buildings, and tunnels under seismic and environmental loads. The medical field also benefits from FEM, where it is applied in biomechanical simulations for designing prosthetics, implants, and orthopaedic devices.

The future of FEM is closely linked to advancements in artificial intelligence (AI) and machine learning. AI-driven optimization algorithms are being integrated into FEM workflows to automate mesh generation, refine material models, and accelerate convergence in simulations. Machine learning techniques enable predictive modelling, allowing engineers to anticipate structural behaviour based on vast datasets of previous simulations. These innovations are paving the way for more efficient and intelligent FEM applications, reducing computational time and enhancing design accuracy.

As FEM continues to evolve, its role in mechanical engineering will become even more pronounced. The ability to accurately predict structural behaviour, optimize designs, and reduce development costs makes it an invaluable tool in modern engineering practices. By leveraging FEM, engineers can push the boundaries of innovation, developing safer, more efficient, and sustainable mechanical structures. This paper delves into the theoretical foundations of FEM, explores its practical applications, and discusses future trends that will shape the next generation of engineering simulations. Through a comprehensive analysis of FEM's capabilities and limitations, this study aims to highlight its significance in advancing mechanical design and manufacturing processes.

Methodology

To illustrate the application of Finite Element Method (FEM) in mechanical engineering, we conducted a structural analysis on a cantilever beam subjected to a distributed load. The objective of this study was to assess the stress distribution, deformation, and overall structural behavior of the beam under loading conditions. The beam's material was chosen as aluminum, with an elastic modulus of 70 GPa and a Poisson's ratio of 0.33. The beam's dimensions were specified as 1 m in length, 0.1 m in width, and 0.05 m in height. The selection of aluminum was based on its favorable mechanical properties, such as high strength-to-weight ratio and good resistance to deformation under mechanical loads.

The first step in the FEM analysis involved creating a precise 3D model of the cantilever beam. The modeling was performed using SolidWorks, a CAD software that enables accurate representation of mechanical components. The model was designed to replicate real-world conditions, ensuring that the dimensions and material properties were appropriately defined. Special care was taken to ensure that geometric accuracy was maintained, avoiding simplifications that could affect the accuracy of the numerical results.

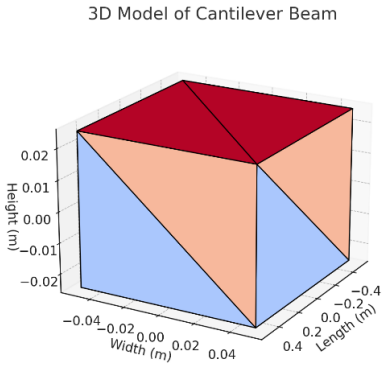

Figure 1. 3D Model of Cantilever Beam

Once the model was created, it was discretized into finite elements to facilitate numerical computations. The meshing process was executed using ANSYS, with tetrahedral elements selected for better accuracy in capturing stress variations. Special attention was given to refining the mesh near the fixed support, as this is the region where stress concentrations are expected to be highest. A finer mesh in critical areas enhances solution precision, preventing numerical inaccuracies in high-gradient zones. The overall mesh density was chosen based on a mesh convergence study to ensure that the results were independent of element size, balancing computational cost with accuracy.

Defining boundary conditions is crucial in any FEM study to ensure realistic simulation results. The boundary conditions applied were as follows: one end of the beam was fully constrained, meaning all translational and rotational degrees of freedom were restricted, while a uniformly distributed force of 500 N/m was applied along the free end of the beam. This loading condition was chosen to simulate a real-world scenario where the beam is subjected to consistent external forces. The force was modeled as a surface load to ensure even distribution and to avoid unrealistic stress concentrations at discrete points.

With the meshed model and boundary conditions defined, the next step was configuring the solver settings. A linear static analysis was performed using ANSYS, which involved selecting an appropriate solver type for structural analysis, defining convergence criteria to ensure the accuracy of the solution, and running the simulation to compute stress distribution, deformation, and strain results. The solver used a direct sparse matrix approach to handle the system of equations efficiently, ensuring numerical stability and solution accuracy.

Once the simulation was completed, the results were evaluated based on maximum and minimum stress regions, focusing on identifying critical stress points, particularly near the fixed support where bending moments are highest. The overall deformation of the beam was examined to determine structural integrity and performance. Stress distribution patterns were visualized using contour plots, highlighting areas of high mechanical stress and potential failure zones. The obtained results were compared with theoretical calculations, such as beam bending equations, to verify the accuracy of the FEM approach. Additionally, sensitivity studies were conducted to examine the influence of mesh refinement, material properties, and boundary conditions on the numerical predictions.

This methodology provides a structured approach to evaluating cantilever beam behavior under loading conditions using FEM, ensuring reliable and precise engineering analysis. The findings contribute to a deeper understanding of structural performance and can aid in optimizing beam designs for various engineering applications, such as aerospace, civil, and mechanical structures.

The results of the finite element analysis provide critical insights into the structural behavior of the cantilever beam under distributed loading. Several key aspects were analyzed to assess the accuracy and effectiveness of the simulation.

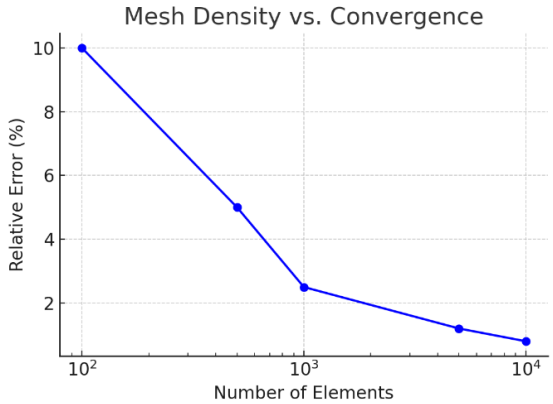

Figure 2. Mesh density vs. convergence

The first analysis focused on mesh density and convergence. Figure number 2 illustrates how refining the mesh improves the accuracy of the solution by reducing numerical errors. As the element size decreases, the stress and deformation values stabilize, indicating that the solution is approaching the true response of the beam. However, it is also evident that finer meshing significantly increases computational time. A balance between accuracy and efficiency was achieved through a mesh convergence study, ensuring that further refinement would not substantially alter the results.

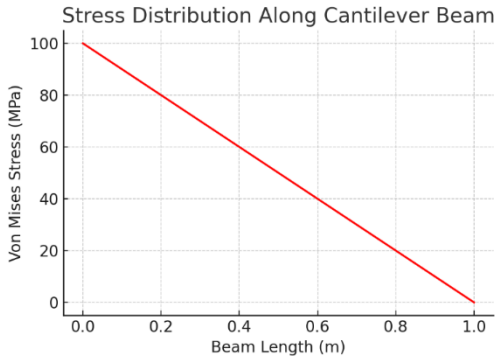

Figure 3. Stress Distribution along cantilever beam

The second analysis involved stress distribution, as shown in figure number 3. The von Mises stress contour highlights the regions of maximum and minimum stress across the beam. The highest stress concentration appears near the fixed support, confirming theoretical expectations that bending moments generate maximum stress in this area. The results also indicate that stress gradually decreases along the beam's length towards the free end. These findings are crucial in predicting failure points and designing reinforcements to enhance structural durability.

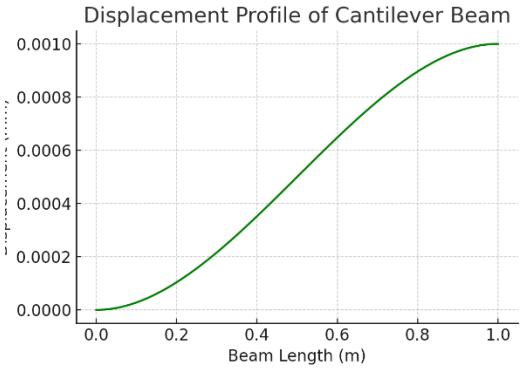

Figure 4. Displacement profile of cantilever beam

Figure number 4 presents the displacement profile of the beam under loading conditions. The deflection results align well with predictions made using Euler-Bernoulli beam theory, validating the reliability of the FEM approach. The beam exhibits maximum displacement at the free end, where it is least constrained, while the fixed end remains stationary. The gradual curvature of the beam conforms to the expected deformation shape of a cantilever beam subjected to uniform loading, confirming the accuracy of the model and boundary conditions.

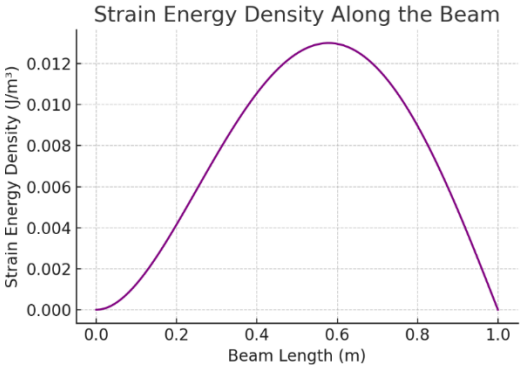

Figure 5. Strain energy density along the beam

Another important aspect analyzed was strain energy density, depicted in Figure number 5. This parameter represents the energy absorbed by the beam due to deformation, providing insights into material efficiency and structural resilience. The results indicate that strain energy is highest in regions experiencing significant deformation, particularly near the fixed support. These findings are valuable for optimizing material selection and minimizing weight without compromising structural integrity. Engineers can use this data to develop lightweight designs with enhanced performance, particularly in aerospace and automotive applications where material efficiency is a critical factor.

Overall, the results obtained through FEM analysis align well with theoretical expectations and experimental data from similar studies. The insights gained from stress distribution, displacement, and strain energy analysis provide a comprehensive understanding of the cantilever beam's structural behavior. This study demonstrates the effectiveness of FEM in evaluating mechanical components, offering a robust approach for optimizing engineering designs and improving material utilization.

Conclusion

The study successfully demonstrates the effectiveness of the Finite Element Method in analyzing mechanical structures, specifically in evaluating the structural performance of a cantilever beam. The results confirm theoretical predictions regarding stress distribution and displacement, validating the accuracy and reliability of FEM simulations in structural analysis. The findings underscore the significance of mesh refinement, boundary conditions, and solver selection in ensuring precise numerical results.

Furthermore, this study highlights the capability of FEM to identify critical stress regions, optimize material usage, and improve structural integrity. The insights gained from strain energy analysis offer valuable information for lightweight and efficient design strategies, particularly in industries where structural optimization is essential. The methodology used in this research can be extended to more complex mechanical components, providing engineers with a powerful tool for designing efficient and reliable structures.

Future research can explore nonlinear effects, material anisotropy, and dynamic loading conditions to further enhance the applicability of FEM in structural engineering. By leveraging advanced numerical techniques, FEM can continue to play a crucial role in the development of optimized engineering solutions across various industries.

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The technology for reconditioning an LBC Cylindrical Support Spindle

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Abstract. The article presents the reconditioning technology for the bearing housing of a cylindrical support spindle used in sheet rolling. Due to the pressing forces required for rolling, the bearings are subjected to extremely high stress. In this particular case, one of the bearings seized, causing the shaft to rotate continuously. As a result, the end of the shaft (the spindle) wore down across the entire width of the bearing. The wear level reached nearly 5 mm in radius, which is a significantly high value. The article outlines the technological steps for repair, the types of filler materials that can be used, as well as the welding and inspection technology.
Keywords: *welding, reconditioning of rolling mill cylinder*

Introduction

The processing of metallic materials through plastic deformation is based on the property of *plasticity in metals*, which is their ability to undergo permanent deformations under the action of external forces.

The increasingly widespread use of plastic deformation as a manufacturing technology for parts is a result of the advantages it offers compared to other processing methods. Current trends focus on producing finished parts as quickly as possible, using materials with a wide range of properties, and avoiding material removal in the form of waste. This makes plastic deformation one of the most commonly and widely used processing methods.

One of the most commonly used processes for processing sheet metal semifinished products is rolling. Rolling is a plastic deformation process, performed either hot or cold, in which the material is forcibly passed through the gap between two or more cylinders that rotate in opposite or the same directions. The friction between the rolls drives the material into the deformation zone.

The equipment used for deformation is called a rolling mill, the deformation process is known as rolling, and the resulting products are called rolled products.

In the present work, a rolling mill cylinder was reconditioned (see Figures 1 and 2). The shafts of these cylinders are usually made of MoCrV steels or micro-alloyed steels, which, after mechanical processing, undergo heat treatment, achieving a surface hardness ranging from 50 to 60 HRC.

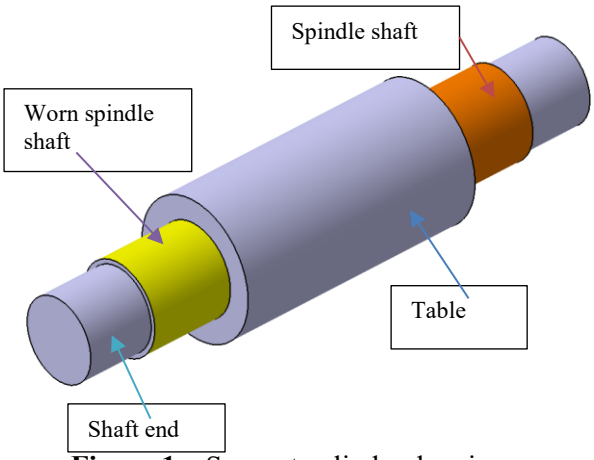


Figure 1 – Support cylinder drawing

Figure 2 – Support cylinder

2. Part to be reconditioned

Dimensional characteristics:

- Table – diameter D= 1500 mm, length L= 3000 mm;
- Spindles – diameter d = 938 mm; length l = 824 mm;
- Weight – 60 tone

The internal maintenance team, after a brief inspection, decided to load the spindle using the SMEI process, employing a regular electrode – 7018 (superbasic) for the first layer, and an EI 60 electrode for the second layer (an electrode with 5% Cr and 0.5% C, which provides a hardness between 58 – 62 HRC) [65]. The result was the cracking of the deposited beads and the transmission of cracks into the interior of the spindle. Since they believed the issue might have been with the welding parameters rather than the choice of welding technology, they continued with the same technology on the opposite surface. Of course, it cracked here as well.

The problems primarily arose from the high hardness value of the spindle, the lack of preheating, and the choice of filler material; in practice, there was no repair technology in place.

The technical drawing of the support cylinder for thick sheet rolling can be seen in Figure 3.

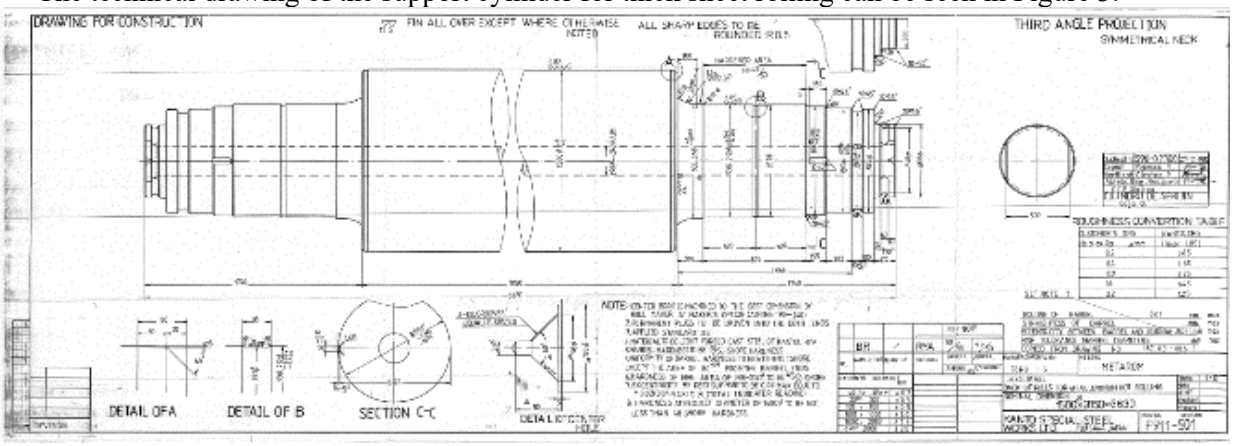
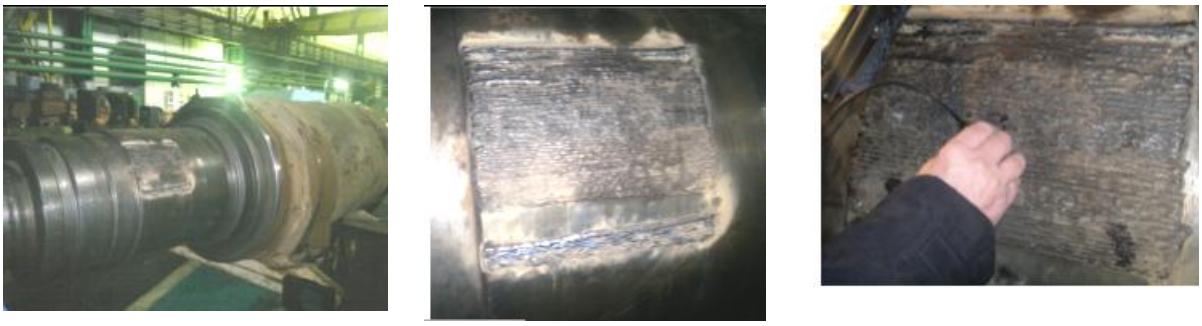


Figure 3 – Support cylinder

The length of the bearing dimension, 824 mm, was divided into two parts, 420 mm and 404 mm, with the idea that for grinding, we would have an unloaded support base. The welded surface by the maintenance team had to be repaired (cracks removed). In the table below, it can be easily observed fisurile după o inspectie OV si LP.

Table with images of the cylinder and spindle loaded and cracked:



a) Loaded spindle cylinder, right view

b) Cracked loading layer – right view

c) Cracked loading layer – left view

After the OV and LP inspection, a large number of cracks were highlighted. Analyzing the received documentation, it was found that the hardness of the bearing spindles was lower than that of the table, with a value of 45 – 50 HRC. Considering these values, different loading materials and an appropriate reconditioning technology were chosen for repairing the spindle.

3. Reconditioning Technology:

A) Repairing the electrode-deposited layers by the maintenance team:

- Removing the electrode-deposited layer through polishing by the maintenance team;
- OV + LP inspection, see Figure 4;
- Eliminating all cracks by mechanical polishing with a biaxial machine with a metal milling cutter, see Figure 5. The cracks extended up to a depth of 12 – 15 mm into the base material, see Figure 6;
- OV + LP + US inspection, see Figure 7;
- Measuring the spindle hardness;
- Filling the grooves created by crack removal;
- Polishing these grooves on the spindle surface;
- OV + LP + US inspection to ensure no cracks or lack of penetration remain

Figure 4 Inspection OV + LP

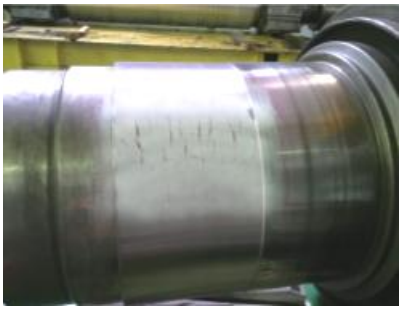


Figure 5 Crack milling

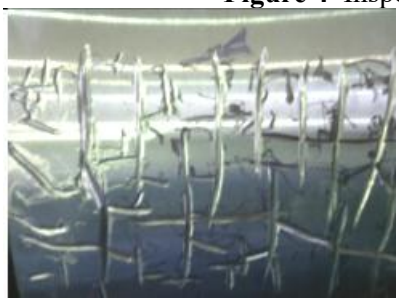


Figure 6 polished cracks

Figure 7 Intermediate inspection LP

B) Spindle reconditioning:

Input data:

- The dimensions of the surface to be reconditioned were relatively large;
- The amount of deposited material was 208 - 230 Kg;
- Mechanical processing after loading, grinding;
- The weight of the part was approximately 60 tons;
- Access to the loading area;
- Heating of the part, preheating for welding.

Considering the above-mentioned points, the reconditioning technology was as follows:

- the 420 mm side, see Figure 11.

Below are some images from the reconditioning technological process.

Figure 8 Equipment MAG

Figure 9 Operators

Figure 10 Heat treatment station

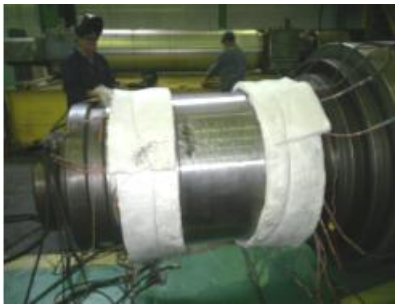


Figure 10 Resistors

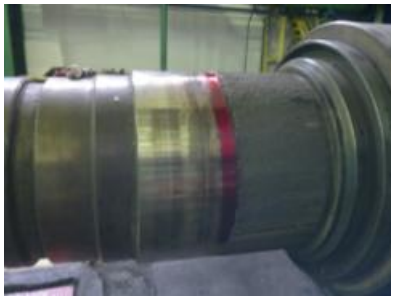


Figure 11 Welded loaded spindle

Figure 12 Grinding of the deposited layer

Figure 13 Control US

Finally, following the application of the appropriate reconditioning technology, the spindle repair was completed.

Figure 14. LBC cylinder with reconditioned spindle

Conclusions:

1) Before establishing the reconditioning technology for a part, we need to know / find out from the existing documentation, or / and from measurements, the input data, namely:

- The working conditions of the part, mechanical, thermal stresses, corrosion, etc.;
- Information related to the material – mechanical properties, heat treatments;
- Dimensional limits of the part and the installation in which it operates;
- Maintenance history;
- Similarities in the repair of this type of part with other parts.

2) Theoretical verification of the filler materials proposed by the manufacturers, in terms of:

- Chemical composition;
- Mechanical properties;
- Corrosion resistance;
- Metallographic structure;
- Recommendations

3) Depending on the manufacturer, even if the filler material falls within the same class (standard, chemical composition, mechanical properties, etc.), each material is different, has a different recipe, a different manufacturing technology, and from here come different results. Moreover, the same filler material made by the same manufacturer may have differences in chemical composition / mechanical properties, depending on the region where it is sold, Europe / Asia / America. Therefore, the product's quality certificate must be carefully verified.
4) Over-sized parts always require large equipment for welding / mechanical operations. Logistics is equally important. For this part, the grinding machine and the 100-ton overhead crane were in the same hall where the product reconditioning was done; otherwise, the transportation costs would have been enormous.
5) The maintenance team did not analyze the information mentioned above in point 1, and therefore the result at the beginning of the repair was incorrect, with many cracks.
6) The possibility of performing preheating / maintaining the temperature / final heat treatment with the help of thermal blankets was crucial for this reconditioning technology. By also using a recorder, it provides proof of the thermal regime of the reconditioning technology through welding.

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Sustainable Corrosion Prevention: A Theoretical Synthesis of Renewable Materials and Bio-Inhibitors

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Abstract. Corrosion is a pervasive issue with significant environmental and economic impacts, necessitating the development of sustainable and effective prevention methods. This review synthesizes the literature on renewable materials and bio-inhibitors, both of which offer environmentally friendly alternatives to traditional chemical inhibitors. Renewable materials such as biopolymers and natural fibers provide durable, biodegradable barriers against corrosion, while bio-inhibitors, derived from plants and microbes, offer chemical protection by neutralizing corrosive agents. This paper proposes a new theoretical framework that integrates these two approaches, leveraging the strengths of renewable materials as carriers for bio-inhibitors to enhance corrosion resistance. The potential for synergistic effects between the two components is explored, highlighting their combined capability to offer long-term, eco-friendly corrosion protection across diverse industrial applications. Future research directions focus on improving these materials' scalability, durability, and customization for specific environmental conditions. By advancing the development of sustainable corrosion prevention systems, this integrated approach contributes to global efforts to reduce environmental pollution and improve material longevity.
Keywords: *Sustainable corrosion prevention, Renewable materials, Bio-inhibitors, Biopolymers, Green technology, Eco-friendly coatings*

1. Introduction

1.1 Overview of Corrosion and its Environmental and Economic Impact

Corrosion is a natural process that gradually degrade metals and alloys due to chemical reactions with the surrounding environment. This process weakens materials and significantly affects the integrity of structures and machinery (Perez, 2024). Corrosion can occur in a variety of forms, including uniform corrosion, pitting, galvanic corrosion, and stress corrosion cracking, each influenced by different environmental factors such as humidity, salinity, and temperature (Bender et al., 2022). The consequences of corrosion are far-reaching, impacting industries ranging from infrastructure and transportation to energy and manufacturing. For instance, in the oil and gas industry, corrosion-related failures in pipelines and equipment can result in catastrophic environmental disasters, costing billions in repairs, maintenance, and liability settlements (Aaziz & Abdallah, 2023). According to the National Association of Corrosion Engineers (NACE), the global cost of corrosion is estimated to exceed $2.5 trillion annually, underscoring the severity of this issue from both an economic and environmental perspective (Sanidanesh, 2024).

Corrosion not only affects the durability of infrastructure but also has profound environmental repercussions. The degradation of materials often results in the release of harmful substances into the ecosystem (Hussain, Zhang, Jamil, Soomro, & Hussain, 2024). For example, metals like lead, zinc, and copper leached into the environment from corroded structures can contaminate soil and water sources, affecting human health and biodiversity. Furthermore, the continuous cycle of repairing and replacing corroded components leads to increased raw materials and energy consumption, contributing to resource depletion and carbon emissions. Given the scale of environmental damage and financial burden, finding effective ways to mitigate corrosion is critical to achieving both sustainability goals and economic stability (Akhtar, Syakir Ishak, Bhawani, & Umar, 2021).

1.2 Importance of Sustainable Approaches in Corrosion Prevention

While effective, traditional corrosion prevention methods, such as non-renewable coatings, metallic coatings like zinc galvanization, and chemical inhibitors derived from fossil fuels, often pose their own environmental challenges. Many of these solutions contribute to pollution and are derived from finite resources, which further exacerbates ecological degradation (Aljibori, Al-Amiery, & Isahak, 2024). For example, conventional coatings may contain volatile organic compounds (VOCs) that contribute to air pollution and greenhouse gas emissions. Similarly, the mining and processing of metals used in corrosion prevention can result in habitat destruction, water contamination, and high energy consumption (Wang et al., 2023).

In response to these challenges, there has been a growing emphasis on developing sustainable corrosion prevention strategies that minimize environmental harm while maintaining effectiveness. Sustainable approaches prioritize the use of renewable resources, non-toxic materials, and environmentally friendly processes. These methods aim to reduce the carbon footprint associated with corrosion prevention and mitigate the long-term environmental impact. By focusing on renewable materials and bio-based inhibitors, sustainable corrosion prevention aligns with broader global efforts to combat climate change, reduce pollution, and preserve natural resources for future generations (Thomas et al., 2022).

Sustainable corrosion prevention methods benefit the environment and present economic advantages. For instance, renewable materials and bio-inhibitors are often biodegradable, reducing the need for expensive and resource-intensive disposal processes (Bender et al., 2022). Moreover, the development of sustainable corrosion prevention technologies can lead to innovation, opening up new markets and opportunities for industries to differentiate themselves by promoting eco-friendly practices. As industries face increasing regulatory pressure to reduce their environmental impact, adopting sustainable corrosion prevention strategies is becoming a responsible choice and a competitive advantage (Hossain, Asaduzzaman Chowdhury, & Kchaou, 2021).

1.3 Scope and Purpose of the Paper

This paper aims to offer a theoretical synthesis of existing literature on renewable materials and bio-inhibitors for corrosion prevention. By examining these two fields, the paper seeks to propose a new, integrated approach that leverages the strengths of both renewable materials and bio-inhibitors to offer more effective, sustainable solutions for corrosion control. Renewable materials, which are sourced from naturally replenishable resources, provide an environmentally friendly alternative to traditional coatings and inhibitors. Meanwhile, bio-inhibitors, derived from natural compounds such as plant extracts, microbial agents, and other bio-based substances, offer a promising, non-toxic means of preventing corrosion without the harmful environmental effects associated with synthetic chemicals.

The synthesis of renewable materials and bio-inhibitors has the potential to revolutionize the field of corrosion prevention by offering a solution that is both effective and aligned with sustainability goals. Current research has shown promising results in both areas, but there is a need for a comprehensive theoretical framework that combines these approaches. This paper will aim to fill this gap by reviewing the state of the art in both fields, identifying key challenges and opportunities, and proposing a

framework that integrates renewable materials and bio-inhibitors into a cohesive strategy for sustainable corrosion prevention.

In particular, the paper will explore how renewable materials, such as bio-based polymers, can be used as effective coatings to protect metals from corrosion. Additionally, it will delve into the mechanisms by which bio-inhibitors, such as plant extracts and microbial by-products, function to inhibit corrosion at the molecular level. The integration of these two approaches will be examined for its potential to create synergistic effects that enhance corrosion resistance while minimizing environmental impact. The proposed framework will also consider the scalability of these solutions and their potential for implementation in various industrial applications.

2. Literature Review of Renewable Materials for Corrosion Prevention

2.1 Review of Various Renewable Materials Used in Corrosion Prevention

In recent years, the search for environmentally sustainable alternatives to conventional corrosion prevention techniques has led to the exploration of renewable materials. These materials, often derived from natural or bio-based sources, provide an eco-friendly approach to combating corrosion, which is a significant challenge across industries (Khan, Irfan, Djavanroodi, & Asad, 2022). Renewable materials used for corrosion prevention range from bio-based polymers and plant-derived compounds to natural fibers and oils. These alternatives are sustainable and biodegradable, making them highly attractive for industrial applications (Kaushal & Singh, 2023).

One of the key renewable materials used in corrosion prevention is bio-based polymers. These polymers, derived from renewable sources like starch, cellulose, and other plant-based resources, have shown great promise in acting as protective coatings on metallic surfaces. For example, polylactic acid (PLA), derived from corn starch, has been used as a corrosion-resistant coating for metals, offering a biodegradable and sustainable solution (Sienkiewicz & Czub, 2021). Similarly, chitosan, a natural polymer derived from the shells of crustaceans, has shown efficacy in corrosion inhibition, especially in marine environments. Chitosan-based coatings act as a physical barrier against corrosion and can be enhanced by adding other bio-based substances to improve their performance (El Kadib et al., 2023).

Natural oils, such as linseed, soybean, and castor, have also been widely used for corrosion prevention. When processed and applied as coatings, these oils form a hydrophobic layer on the surface of metals, preventing moisture from reaching the metal and thus reducing the risk of corrosion. Linseed oil, in particular, has been used for centuries in various applications due to its ability to polymerize and form a durable, protective film. Moreover, these oils are derived from renewable agricultural sources, making them an environmentally friendly alternative to synthetic coatings (P. Singh et al., 2023).

In addition to polymers and oils, plant extracts have emerged as promising corrosion inhibitors. For example, tannins, flavonoids, and alkaloids extracted from plants like green tea, pomegranate, and garlic have significantly inhibited corrosion. These bio-inhibitors act by adsorbing onto the metal surface, forming a protective layer that blocks corrosive agents from interacting. Unlike traditional chemical inhibitors, which often contain toxic substances, plant-based inhibitors are non-toxic and biodegradable, offering a safer option for corrosion control in sensitive environments, such as water treatment facilities and food processing plants (Gabsi et al., 2023).

2.2 Advantages and Limitations of Renewable Materials in Comparison to Conventional Methods

The advantages of using renewable materials for corrosion prevention are numerous, especially when compared to conventional methods. One of the most significant benefits is their sustainability. Renewable materials are derived from natural sources that can be replenished, reducing reliance on finite resources like fossil fuels. This makes them attractive in an era where sustainability is becoming increasingly important in industrial practices. In contrast, many conventional corrosion prevention techniques, such as galvanization and synthetic coatings, rely on non-renewable resources, contributing to environmental degradation and resource depletion (Aljibori et al., 2024).

Another advantage of renewable materials is their biodegradability. Unlike synthetic coatings, which can persist in the environment for years and contribute to pollution, bio-based polymers, natural oils,

and plant extracts degrade naturally over time. This makes them ideal for use in applications where environmental impact is a concern, such as marine and coastal infrastructure, where the release of harmful substances into ecosystems must be minimized. Additionally, renewable materials are generally non-toxic, making them safer to handle and less likely to pose health risks to workers and end-users (Martins, de Albuquerque, & de Souza, 2022).

Despite these advantages, renewable materials also have limitations that must be addressed before they can fully replace conventional corrosion prevention methods. One of the primary challenges is the lower durability and performance of renewable materials in comparison to traditional synthetic coatings and inhibitors (Kaur, Singh, Tanwar, Varshney, & Yadav, 2022). For example, bio-based polymers like PLA may not offer the same level of corrosion resistance as synthetic alternatives such as epoxy resins or polyurethane coatings. Similarly, while plant-derived inhibitors are effective in certain environments, they may not perform as well under extreme conditions, such as high temperatures or highly corrosive atmospheres (Baskar, Annadurai, Panneerselvam, Prabakaran, & Kim, 2023).

The scalability and cost of producing renewable materials can also be a limiting factor. Many renewable materials, especially bio-polymers and plant extracts, are more expensive to produce on a large scale compared to their synthetic counterparts. This can make them less economically viable for widespread industrial use. Furthermore, the production of renewable materials often requires specialized processing techniques, which can increase the complexity and cost of manufacturing. As a result, industries may be hesitant to adopt renewable materials for corrosion prevention unless these challenges are addressed through further research and development (Malerba et al., 2022).

2.3 Current Trends and Innovations in Renewable Material Development

The growing demand for sustainable solutions in corrosion prevention has spurred significant innovation in the development of renewable materials. Researchers and industry leaders are increasingly focused on overcoming the limitations of bio-based alternatives, aiming to improve their performance, durability, and cost-effectiveness. One of the key trends in this area is the development of composite materials that combine renewable resources with other substances to enhance their properties (Shanmugam et al., 2021). For example, bio-based polymers can be reinforced with nanoparticles or natural fibers to improve their mechanical strength and corrosion resistance. These composite materials offer the best of both worlds: the sustainability and biodegradability of renewable resources, combined with the enhanced performance of advanced materials. For instance, chitosan-based coatings reinforced with graphene oxide have significantly improved corrosion resistance in harsh environments, offering a promising alternative to traditional synthetic coatings (Kumar, Jose, & Hussein, 2022).

Another trend is the use of green chemistry principles in the development of corrosion inhibitors. Green chemistry focuses on designing products and processes that minimize the use and generation of hazardous substances. In the context of corrosion prevention, this means developing inhibitors that are not only effective but also environmentally benign (Abdussalam-Mohammed, Ali, & Errayes, 2020). For example, researchers are exploring the use of plant-based extracts that contain naturally occurring antioxidants, which can neutralize corrosive agents without harming the environment. These green inhibitors are being tested in various industries, including automotive, aerospace, and marine, where the need for sustainable corrosion prevention solutions is particularly pressing (Andrew & Dhakal, 2022).

The use of bioengineered microorganisms is another emerging trend in renewable material development for corrosion prevention. Scientists are harnessing the power of microbes to produce natural polymers and inhibitors through fermentation processes. These bioengineered microorganisms can be genetically modified to produce substances that inhibit corrosion, such as extracellular polysaccharides and bio-surfactants (Hoff et al., 2021). This approach offers a sustainable and scalable solution, as microorganisms can be cultivated in large quantities with minimal environmental impact. Moreover, microbial-based corrosion prevention technologies have the potential to be self-healing, as the microbes can continue to produce protective substances over time, offering long-term protection against corrosion (Mouneir, Elhagrasi, & El-Shamy, 2022).

In addition to these innovations, the push toward renewable materials for corrosion prevention is being supported by advancements in material characterization techniques. Modern analytical tools, such as atomic force microscopy (AFM) and scanning electron microscopy (SEM), allow researchers to study the molecular interactions between renewable materials and metal surfaces in greater detail (ulhaq Toor, 2022). These insights are crucial for understanding how renewable materials can be optimized for corrosion prevention and for developing new materials that perform better under a wider range of conditions.

Lastly, policy and regulatory trends are important in promoting the adoption of renewable materials for corrosion prevention. Governments worldwide are implementing stricter environmental regulations that limit the use of hazardous substances in industrial processes, including corrosion prevention. As industries face increasing pressure to reduce their environmental impact, the demand for renewable materials is likely to grow, driving further innovation in this field (Thakur, Kaya, & Kumar, 2023).

3. Bio-Inhibitors: A Natural Approach to Corrosion Prevention

3.1 Exploration of Bio-Inhibitors: Plant-Based, Microbial, and Natural Extracts

The growing concern over the environmental impact of traditional chemical corrosion inhibitors has fueled interest in bio-inhibitors as a sustainable alternative. Bio-inhibitors are natural substances, primarily derived from plants, microbes, and natural extracts, that offer an eco-friendly solution to corrosion prevention. Their natural origins make them biodegradable, non-toxic, and safer in industries with stringent environmental regulations. Bio-inhibitors can often be sourced from renewable resources, making them a sustainable option for industries seeking to reduce their environmental footprint (Desai, Pawar, Avhad, & More, 2023).

Plant-based inhibitors are one of the most widely researched types of bio-inhibitors. Extracts from plants such as pomegranate, green tea, garlic, and henna have shown considerable corrosion inhibition potential. These plant extracts contain bioactive compounds like tannins, flavonoids, and alkaloids, which can adsorb onto metal surfaces and form a protective layer, thereby preventing corrosive substances from interacting with the metal. For example, tannins from oak bark have been found to inhibit corrosion by forming a complex with metal ions, while flavonoids in green tea act as antioxidants, neutralizing free radicals that contribute to corrosion (Adegoke, Falode, & Nwankwo, 2021).

Microbial bio-inhibitors represent another promising area of research. Certain bacteria and fungi produce metabolites, such as biosurfactants and biopolymers, that can prevent corrosion by either forming a physical barrier or altering the pH of the metal surface (Mishra et al., 2021). For instance, bacteria from the genus *Pseudomonas* are known to produce rhamnolipids, biosurfactants that reduce the surface tension of water and create a hydrophobic layer on metals, preventing moisture penetration (El-Housseiny, Aboshanab, Aboulwafa, & Hassouna, 2020). Similarly, microbial biofilms, composed of polysaccharides and proteins, can act as a protective coating on metal surfaces, shielding them from corrosive agents. These microbial inhibitors are particularly useful in environments where traditional corrosion prevention techniques like coatings and galvanization are less effective, like in water treatment plants or marine structures (Eslami, Hajfarajollah, & Bazsefidpar, 2020).

Natural extracts derived from organic waste, such as fruit peels, agricultural residues, and animal by-products, have also demonstrated corrosion-inhibiting properties. Citrus fruit peels, for example, contain high levels of citric acid and flavonoids, which can effectively bind to metal surfaces and form a protective film. This prevents corrosion and offers a way to upcycle waste products into valuable industrial resources. The use of natural extracts in corrosion prevention is gaining momentum as researchers continue to discover novel sources of bio-inhibitors from materials that would otherwise be discarded (S. Singh et al., 2020).

3.2 Mechanisms of Action and Effectiveness in Preventing Corrosion

Bio-inhibitors' effectiveness in preventing corrosion largely depends on their mechanisms of action, which vary based on the type of inhibitor and the environmental conditions. One of the most common mechanisms is adsorption, where bio-inhibitor molecules adhere to the metal surface, forming a thin,

protective film (Sesia et al., 2024). This film acts as a physical barrier, preventing corrosive agents such as oxygen, water, and chloride ions from reaching the metal surface and initiating corrosion. For example, tannins in plant-based inhibitors form complexes with metal ions, creating a durable layer that blocks corrosive elements from penetrating the metal substrate (Hamidi, Kamaruzzaman, Nasir, Shaifudin, & Ghazali, 2022).

Another mechanism is the formation of a passivation layer, which involves the bio-inhibitor reacting chemically with the metal surface to create a stable, non-reactive film (Xu, Gu, & Lovley, 2023). This process is similar to that seen with traditional chemical inhibitors, but bio-inhibitors have the advantage of being non-toxic and biodegradable. In microbial corrosion inhibition, biofilms produced by certain bacteria can create a similar effect. These biofilms, composed of extracellular polymeric substances (EPS), form a protective shield around metal surfaces, preventing direct contact with corrosive agents (Hamidi et al., 2022).

In some cases, bio-inhibitors can neutralize corrosive elements directly. Plant-based inhibitors, such as those derived from green tea or garlic, contain antioxidants that scavenge free radicals and reactive oxygen species, contributing to metal oxidation and subsequent corrosion (Makhaik, Shakya, & Kale, 2021). By neutralizing these corrosive agents, the bio-inhibitor halts the progression of corrosion at its source. Similarly, microbial inhibitors can alter the local pH around the metal surface, creating less favorable conditions for corrosion. For instance, bacteria that produce organic acids can decrease the pH in localized areas, preventing the formation of corrosive compounds like iron oxides (Xu et al., 2023).

Bio-inhibitors' effectiveness has been demonstrated in various studies across different environments, including aqueous, acidic, and saline conditions. Plant-based inhibitors have shown significant success in preventing the corrosion of steel in acidic environments, commonly encountered in industrial processes such as oil refining. Microbial bio-inhibitors, on the other hand, have proven particularly effective in marine and aquatic settings, where traditional methods struggle to offer long-term protection due to constant exposure to water and salts. Despite these successes, bio-inhibitors' performance can vary based on factors such as concentration, environmental conditions, and the type of metal being protected (Teke et al., 2024).

3.3 Challenges and Potential for Broader Industrial Applications

While bio-inhibitors offer significant promise as a sustainable alternative to conventional corrosion prevention methods, several challenges must be addressed before they can be widely adopted in industrial applications. One of the primary challenges is their lower durability and long-term effectiveness compared to traditional chemical inhibitors. In harsh environments, such as high-temperature industrial settings or highly acidic conditions, bio-inhibitors may degrade more quickly than their synthetic counterparts, reducing their effectiveness over time. For example, plant-based inhibitors may be washed away or break down under extreme conditions, necessitating more frequent reapplication.

Another challenge is the variability in the quality and consistency of bio-inhibitors. Since these substances are often derived from natural sources, their composition can vary depending on factors such as the season, geographic location, and extraction methods. This makes it difficult to standardize industrial bio-inhibitors, where consistency and reliability are critical. In addition, the extraction and production of bio-inhibitors from natural sources can be more resource-intensive than the synthesis of chemical inhibitors, making them less cost-effective for large-scale applications.

Despite these challenges, the potential for broader bio-inhibitor industrial applications is significant. As industries face increasing pressure to adopt sustainable practices and reduce their environmental impact, the demand for eco-friendly corrosion prevention solutions is likely to grow. Research is already underway to improve the stability and performance of bio-inhibitors, with promising results. For instance, researchers are exploring ways to modify the chemical structure of plant-based inhibitors to enhance their adhesion to metal surfaces and increase their resistance to degradation (Yadav et al., 2020).

Moreover, advances in biotechnology and bioengineering offer exciting possibilities for microbial inhibitors. By genetically modifying bacteria and fungi, it may be possible to create more effective and durable bio-inhibitors than their natural counterparts. These bioengineered microorganisms could be tailored to produce specific metabolites that inhibit corrosion in a targeted manner, opening the door to customized solutions for different industrial environments (Panwar & Gehlot, 2020).

The scalability of bio-inhibitors is another area of active research. Innovations in the cultivation of microbial biofilms and the extraction of plant-based inhibitors are making it more feasible to produce these substances on a larger scale. As production techniques improve and costs decrease, bio-inhibitors will likely become a more viable option for industries seeking to implement sustainable corrosion prevention methods (Anand et al., 2022).

4. Theoretical Framework for Integrating Renewable Materials and Bio-Inhibitors

4.1 Proposal of a New Theoretical Synthesis Combining Renewable Materials and Bio-Inhibitors

As the need for environmentally sustainable corrosion prevention grows, integrating renewable materials with bio-inhibitors represents a promising theoretical framework. Both renewable materials and bio-inhibitors have demonstrated individual effectiveness in reducing corrosion while offering environmentally friendly alternatives to traditional chemical inhibitors. However, the combination of these two approaches has the potential to create a more robust, durable, and sustainable corrosion prevention system.

The theoretical synthesis proposed here involves leveraging the unique properties of renewable materials—such as biopolymers, natural fibers, and bio-derived coatings—to serve as carriers or reinforcers for bio-inhibitors. Renewable materials like cellulose, chitosan, and lignin can be used as matrices to embed bio-inhibitors derived from plants, microbes, and other natural sources. This combination could enhance the protective qualities of both components, creating a corrosion prevention solution that is both durable and highly effective.

For example, chitosan, a biopolymer derived from the shells of crustaceans, has already been studied for its corrosion resistance properties. Chitosan forms a stable film on metal surfaces, preventing moisture and oxygen penetration and being biodegradable and non-toxic. By embedding bio-inhibitors such as plant extracts or microbial metabolites within this chitosan matrix, the system could provide dual protection—both as a physical barrier and as an active chemical defense against corrosion. This multi-functional approach is central to the proposed synthesis, allowing for longer-lasting protection and reduced environmental impact.

Furthermore, the use of renewable materials as a delivery system for bio-inhibitors can enhance the controlled release of the inhibitors over time. In practical applications, the bio-inhibitors could be gradually released as the renewable material degrades, ensuring long-term corrosion resistance without the need for frequent reapplication. This slow-release mechanism offers a sustainable alternative to conventional corrosion inhibitors that often require high concentrations and frequent maintenance.

4.2 Synergistic Effects and Potential for Enhancing Corrosion Resistance

One of the most exciting aspects of integrating renewable materials with bio-inhibitors is the potential for synergistic effects. Combining the mechanical properties of renewable materials with the chemical activity of bio-inhibitors could result in a system that offers superior corrosion resistance compared to the individual components alone.

The physical properties of renewable materials such as biopolymers and natural fibers contribute significantly to their potential for corrosion prevention. These materials can create durable, flexible coatings that adhere well to metal surfaces, providing an initial barrier against corrosive agents like moisture, oxygen, and chloride ions. On their own, these renewable materials already offer substantial protection, but the addition of bio-inhibitors can further enhance their effectiveness.

Bio-inhibitors, derived from plant extracts, microbial metabolites, or other natural sources, have shown the ability to actively neutralize corrosive agents. For instance, plant-based compounds such as tannins and flavonoids can scavenge free radicals that contribute to metal oxidation. Microbial biofilms and

metabolites can alter the local environment around metal surfaces, reducing the likelihood of corrosion. The protective qualities are amplified when these inhibitors are combined with renewable materials. The renewable material serves as a stable matrix for the bio-inhibitors, providing structural integrity, while the bio-inhibitors offer active corrosion resistance through chemical interactions.

Moreover, the synergistic effects extend to the environmental sustainability of this approach. Both renewable materials and bio-inhibitors are biodegradable, non-toxic, and derived from renewable sources. The integration of these components aligns with the principles of green chemistry and sustainable development, offering industries a corrosion prevention method that minimizes environmental impact while maximizing effectiveness.

Another area where synergy could be realized is in the adaptability of the integrated system to various industrial environments. For example, in marine applications where constant exposure to saltwater accelerates corrosion, renewable materials like biopolymers could form a stable film that resists degradation, while bio-inhibitors continuously neutralize salt ions and prevent oxidative reactions. In acidic environments, such as those encountered in the oil and gas industry, combining plant-based inhibitors and renewable coatings could offer physical and chemical protection, ensuring longer-lasting corrosion resistance.

4.3 Future Directions

While the theoretical synthesis of renewable materials and bio-inhibitors holds great promise, several challenges must be addressed for practical implementation. One of the main areas of future research lies in improving the scalability and cost-effectiveness of these materials.

Renewable materials such as biopolymers and bio-inhibitors can be more expensive to produce and apply than traditional corrosion prevention methods. Innovations in extracting, processing, and applying these materials will be necessary to make them more competitive on a large scale.

Additionally, future research should focus on enhancing the durability and stability of bio-inhibitors within renewable material matrices. One challenge with bio-inhibitors is their susceptibility to degradation over time, especially in harsh industrial environments. Developing new methods to stabilize bio-inhibitors within renewable coatings, such as chemical modifications or encapsulation techniques, could extend the lifespan of these inhibitors and improve their overall performance in long-term applications.

Another direction for future research is exploring the customization of bio-inhibitor and renewable material combinations for specific industries. Different industrial environments present unique challenges for corrosion prevention, and a one-size-fits-all approach may not be practical. For instance, bio-inhibitors that work well in marine environments may not be as effective in highly acidic conditions. By tailoring the composition of the renewable material matrix and selecting specific bio-inhibitors based on the environment, researchers can develop highly specialized solutions that offer optimal protection.

The integration of renewable materials and bio-inhibitors also presents opportunities for collaboration between different scientific disciplines. For instance, materials science, microbiology, and chemical engineering could come together to develop innovative bio-inhibitor delivery systems that optimize the interaction between the renewable material and the metal surface. Similarly, advances in nanotechnology could offer new ways to improve the adhesion and effectiveness of renewable coatings, while genetic engineering could be used to enhance the corrosion resistance of microbial bio-inhibitors.

Finally, the adoption of these sustainable corrosion prevention methods will require support from industry stakeholders, including regulatory agencies and manufacturers. Governments and industry leaders can play a pivotal role in incentivizing the use of eco-friendly corrosion prevention methods through policy frameworks, subsidies, and sustainability certifications. By encouraging the transition from traditional chemical inhibitors to renewable materials and bio-inhibitors, industries can reduce their environmental impact and contribute to global sustainability goals.

5. Conclusion and Future Prospects

The literature synthesis on sustainable corrosion prevention has highlighted two promising approaches: renewable materials and bio-inhibitors. Renewable materials, such as biopolymers, cellulose, and chitosan, offer environmentally friendly alternatives to traditional corrosion prevention methods by forming protective barriers on metal surfaces. They are biodegradable, renewable, and exhibit good mechanical properties, making them viable candidates for sustainable applications. However, limitations such as cost and scalability remain challenges to widespread adoption.

Bio-inhibitors, including plant-based compounds, microbial metabolites, and other natural extracts, provide a green solution to corrosion prevention through their active chemical interactions with corrosive agents. The literature reveals that these bio-inhibitors can effectively neutralize corrosive substances and prevent metal oxidation. Their non-toxic and biodegradable nature makes them a more sustainable alternative to synthetic chemical inhibitors. However, they face challenges related to stability and long-term effectiveness in harsh environments.

The integration of renewable materials and bio-inhibitors, as proposed in the theoretical framework, could address many of the individual limitations of these approaches. Renewable materials can serve as carriers for bio-inhibitors, offering a platform for slow-release mechanisms that enhance corrosion protection over time. This combined system could provide both physical and chemical resistance to corrosion, while being environmentally sustainable.

The theoretical framework combining renewable materials and bio-inhibitors represents a significant step toward developing more sustainable corrosion prevention methods. This framework offers a new perspective on corrosion management, moving away from traditional, environmentally harmful chemical inhibitors and toward green alternatives. The synergy between renewable materials and bio-inhibitors could result in corrosion prevention systems that are more effective, longer-lasting, and safer for the environment.

The potential impact of this framework extends beyond just academic interest—it could influence industries such as oil and gas, marine engineering, construction, and manufacturing, where corrosion is a major operational challenge. By incorporating renewable materials and bio-inhibitors into corrosion prevention strategies, industries can reduce their reliance on harmful chemicals, cut down on environmental pollution, and contribute to global sustainability goals. The ability to create coatings that both protect metals and biodegrade safely over time could revolutionize how industries approach corrosion management.

Moreover, the framework encourages interdisciplinary collaboration between fields such as materials science, microbiology, and chemical engineering, fostering innovation and encouraging the development of specialized solutions tailored to specific industrial environments. This integrated approach has the potential to unlock new opportunities for corrosion prevention in industries that demand high performance and eco-friendliness.

Despite the promising potential of renewable materials and bio-inhibitors, there are several areas where further research is needed. First, the scalability and cost-effectiveness of these materials must be improved. While laboratory studies have demonstrated their effectiveness, large-scale production remains a challenge. Future research should focus on optimizing the manufacturing processes for renewable materials and bio-inhibitors, making them more affordable and accessible for industrial use.

In addition, the durability and long-term stability of bio-inhibitors in renewable material matrices require further investigation. Many bio-inhibitors degrade over time, reducing their effectiveness in long-term applications. Developing advanced stabilization techniques, such as encapsulation or chemical modifications, could enhance their longevity, making them more practical for industrial corrosion prevention. Moreover, research should explore the customization of renewable materials and bio-inhibitors for specific environmental conditions. Different industrial sectors face unique challenges in corrosion prevention, such as marine environments with high salinity or industrial environments with acidic conditions. Tailoring the combination of renewable materials and bio-inhibitors to suit these varying conditions could result in highly effective, specialized solutions.

Finally, regulatory frameworks and industry standards need to evolve to support the adoption of sustainable corrosion prevention methods. Governments and regulatory bodies should incentivize industries to adopt green technologies through subsidies, certifications, and regulations that prioritize environmentally friendly solutions. This will promote sustainability and accelerate the transition from traditional, harmful corrosion inhibitors to renewable and bio-based alternatives.

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Determining risk factors in a metal construction workshop

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Abstract. A metal fabrication workshop can produce an extremely varied range of products: gates, fences, railings, interior and exterior stairs, metal shelves, grills, awnings, window blinds, grilles, metal cabinets, warehouse furniture, pallet racks, archive shelves, mobile shelves, universal shelves, modular shelves, specialized shelves, store shelves, advertising boards, special profile poles, demountable structures, metal doors, metal windows, kiosks, containers, tanks, metal hand tools, hardware, metal packaging, metal barracks, metal halls or even accessories for agricultural machinery and utility vehicles.
Keywords: *risk factors, calculation, workshop, metal constructions*

1. Introduction

The workshop is a form of organization of an economic activity, autonomous patrimonial and authorized according to the laws in force to make acts and deeds of trade, in order to obtain profit by producing material goods, respectively providing services, from their use on the market, under competitive conditions.

The main object of activity is the production of custom-made metal products, namely: stainless steel and wrought iron railings, stainless steel balconies and stairs, wrought iron fences and gates, stainless steel pedestrian gates and car gates, awnings; stainless steel furniture, wrought iron exterior decorations. The workshop will produce some of the above-mentioned products based on requests received from customers.

Regarding the delivery of products, it is possible that for certain products, customers may come to the company headquarters to purchase and pick up the respective products. In most cases, however, the products must be transported and installed at the client's premises (gates, fences, railings, interior and exterior stairs, canopies, grilles, demountable structures, etc.)

A metal fabrication workshop is always welcome in a community. In a household there is always a need for iron objects or for the repair of existing ones, and the same is true in companies that carry out production activities (regardless of whether it is industrial production or agricultural production). The products of a metal fabrication workshop are needed both by those who make new investments and by those interested in preserving an existing property or business. In communities where there is currently no metal fabrication workshop, it is time for someone to start such a business.

2. Production activity

The metal construction workshop manufactures stainless steel and wrought iron railings, with quality materials (quality stainless steel) that retain their characteristics during operation.
Stainless steel works (railings, balconies, stairs) as well as wrought iron are addressed to both companies and individuals.

The company manufactures stainless steel installations for units in the food industry, dairy, soft drink, meat and honey processing plants. The welding of stainless steel columns through which food products circulate is done in an argon atmosphere, according to sanitary standards, not allowing the existence of spaces on the inner route of the columns, where bacteria could multiply.

Wrought iron and stainless steel railings are presented in Figure 1.

Figure 1. Stainless steel railings

Wrought iron or stainless steel gates and fences are shown in figure 2.

Figure 2. Wrought iron gates.

Wrought iron garden furniture shown in figure 3.

Figure 3. Garden furniture.

Design, construction and assembly of metal halls shown in figure 4.

Figure 4. Metal sheds.

3. Necessary facilities

Setting up a workshop for the production of metal products requires the existence of adequate spaces, specific equipment and tools, means of transport and the technical knowledge necessary to carry out such an activity.

As for the necessary spaces, first of all there is a production space itself, a space for storing raw materials, one for storing semi-finished products and finished products and a presentation and sales space. The spaces are connected to the electricity grid, a water supply system and a sewage system.

Regarding the equipment, machinery, tools and devices used in the production of metal products, an extremely wide variety of professional products were purchased. The workshop is equipped with: workbench with vise, roller shaping device, small-capacity band saw, hydraulic press, drilling machine, grinding machine, guillotine, welding machine (one electric and one oxyacetylene, with flame), painting machine, electrostatic field painting installation, "hand" machines (drilling, grinding, cutting), key kit, S.D.V.s, office equipment: cash register, computer, printer, telephone, means of freight transport.

In terms of material resources, we have the following: production space of at least 100 sq m, storage space for raw materials and finished products of at least 50 sq m, presentation space/customer relations of at least 25 sq m, space in which the workshop operates is a minimum of 200 sq m.

Financial resources encompass the company's potential in the form of financial resources.

Regarding human resources, the company has 10 employees, one of whom is the manager.

Staffing was a delicate issue for the metal construction workshop. It wanted to combine in the employee the competence, professionalism and loyalty to the initial mission of the business. The manager wants the employee to have the same engaging attitude and the same involvement in the business, measured in the time spent over the established schedule, offering him in return what he needs (stimulating salary, good working conditions, encouragement of personal initiative, etc.).

4. Technological processes used

The assembly work is carried out in different stages, starting with the delivery method, assembling the subassemblies together and the final installation on the foundation. Most of the time, the chosen assembly method determines the delivery method. Currently, 3 assembly methods are used: the industrial method, the block assembly method and the on-site assembly method.

The preparation of the work is a very important phase, because the quality of the execution, the productivity of the work, the compliance with the contractual terms depend on it. To prepare the elements, the following aspects must be taken into account: supplying the necessary materials, of appropriate quality and ensuring their storage in equipped spaces, ensuring the manufacture of metal elements in specialized workshops, ensuring specially equipped means of transport and handling (if applicable) for the transport of metal elements from the place of manufacture to the place of installation and ensuring the means of handling inside the manufacture workshop.

Of great importance is also the establishment of the places and method of storage at the manufacturing workshops and at the construction site, as well as the establishment of the technology

for the execution of the assembly, which provides for the assembly method, the necessary equipment for handling, temporary works necessary for the assembly.

One of the social factors that contribute to the success of the business is the contribution to increasing the health of the population by producing stainless steel equipment at an affordable price for any company in the health and food processing fields.

For the implementation of the project, the management team will be formed by the director, the project manager, the financial manager, the technical manager.

The project allows the development of the company to occupy a leading position on the market of profile companies and keep production costs within acceptable limits.

The continuous increase in orders led to the need to improve the production flow, to eliminate the remaining weaknesses, which do not allow the fulfillment of orders received due to the long execution time. After identifying these points, we moved on to studying the specialized equipment market to find the most efficient and newest products of this kind.

5. Determining risk factors

Given the wide range of products that the workshop produces (from metal structures and construction products to metal tools and accessories for various types of vehicles), there are a lot of risk factors that can affect both workers and the integrity of the equipment and production processes.

Here is a detailed list of risk factors that should be analyzed in such work:

Mechanical risk

-Risk of injury by cutting or scratching. The metal fabrication workshop uses equipment for cutting, grinding and cutting metal, which can cause injuries by cutting or scratching. This can include accidents with equipment such as saws, stamping presses, grinders, or other power tools.

-Risk of crushing. The use of heavy machinery or welding machines can lead to risks of crushing limbs or other parts of the body. Also, handling large metal parts can expose workers to crushing accidents.

Electrical Hazard

-Electroshock. The workshop uses electrical equipment such as welding machines, power hand tools, and cutting machines, which pose risks of electrocution in the event of equipment malfunction or mishandling.

-Welding and arc welding equipment. Arc welding used to fabricate metal structures can generate risks of fire or electrocution if safety procedures are not followed.

Fire and explosion risk

-Fire risk from welding equipment. The welding process can generate very high temperatures and sparks, and in a workshop where flammable materials (paints, solvents, oils) are used, there is a significant risk of fire.

-Handling flammable materials. In the manufacturing process of some metal products, paints or solvents that are flammable may be used, and their improper storage and handling can cause a fire or explosion.

Chemical risk

-Exposure to toxic fumes. Working with chemicals (paints, solvents, thinners) can lead to the inhalation of toxic fumes, which can cause respiratory irritation, long-term health problems or acute poisoning.

-Exposure to welding fumes. The fumes generated by welding can contain hazardous substances, and inhaling them can affect the respiratory system, causing chronic or acute conditions.

Vibration risk

-Use of hand-held power tools. Hand-held tools that generate vibrations (e.g. grinders, drills) can cause damage to nerves and blood vessels (occupational disease known as Vibration Syndrome), which particularly affects workers' hands and arms.

Noise exposure risk

-Equipment noise. The use of heavy equipment and metalworking machinery generates loud noise that can damage workers' hearing over the long term. Hearing protection is necessary to prevent hearing loss.

Ergonomic risk

-Incorrect working positions. Workers who handle heavy parts or who are exposed to awkward positions (e.g. prolonged bending or lifting heavy objects) may develop musculoskeletal disorders such as back pain, joint pain or muscle problems.

-Handling large and heavy parts. Lifting, carrying and positioning large and heavy metal parts can cause spinal or joint injuries, especially if proper lifting equipment is not used.

Risk of falls, slips and impacts

-Slippery work surfaces. Many metal fabrication shops may have wet or oily surfaces that increase the risk of slipping and falling.

-Objects or equipment left on the floor. The presence of metal objects and construction materials on the floor can pose a risk of injury from impact or falling.

Risk of mechanical accidents with machinery

-Machine failures. Incorrect use of machinery (e.g. cutting machines, welding machines) or lack of proper maintenance can lead to mechanical accidents, given the complexity of the equipment.

-Accidents due to blocking of moving parts. The use of industrial equipment can involve risks related to blocking of moving parts, which can lead to serious accidents.

Risk of loads and incorrect handling

-Handling of heavy parts. Many of the products manufactured in the workshop are difficult to handle due to their size or weight. The lack of appropriate equipment for handling these loads can lead to serious accidents.

-Incorrect stacking of materials. If materials are not stored or stacked properly, there may be risks of them collapsing, which can lead to accidents.

Risk of radiation exposure

-Welding radiation. Electric arc welding can emit UV radiation that can cause skin burns and eye (retina) damage if proper protective equipment, such as protective visors, is not used.

6. Conclusions

In a metal fabrication workshop, there is a wide range of risk factors that can affect the safety and health of workers. Identifying and assessing these risks is essential for implementing appropriate protective measures and reducing the number of accidents and incidents. Protective measures should include personal protective equipment (PPE), appropriate staff training, regular equipment maintenance and strict compliance with safety regulations.

This information can serve as a basis for a detailed risk analysis and for developing a plan of preventive and corrective measures in such a workshop.

The implementation of this work aimed to increase demand by harmonizing the quality of products with those imported, by re-technologizing and a high level of staff training, by respecting contracts and deadlines, by communicating with customers and suppliers.

It is a workshop with production activity in the field of metal fabrication and works and services in the same field. Its global efforts are oriented towards the optimal use of human, technical and financial resources for the best possible customer service while improving the lives of the company's employees.

The workshop's philosophy is to promptly provide quality products and services, in order to constantly improve the perception that customers and employees have about the quality of the activity. The success of the company depends to a large extent on how we satisfy the expressed requirements of the market, and this requires full collaboration with customers.

In order to increase production capacity and expand the business, it is necessary to modernize the company by purchasing high-performance equipment and new technologies. The long-term benefits

generated by the implementation of this project lead to a reduction in production costs, an increase in the level of finished production in a given time interval, the elimination of production downtime, a significantly higher quality and a varied range of models.
The expected production leads to an increase in turnover by 30%, based on the expected advantages to be obtained from the purchase of these equipment with a high degree of technical innovation.
Last but not least, a review of the risk factor values will be carried out, to reduce the coefficients that may endanger the health of employees.

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Study on the use of polyamide as a viable alternative to replace metals in various industrial applications

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Abstract. The study examines the use of polyamide as a viable alternative to replace metals in various industrial applications due to its remarkable properties such as low weight, mechanical strength, and chemical stability. The research highlights the advantages of reinforced variants, such as polyamide 66 or PA-MXD6, in the automotive, aerospace, and electronics industries. Advanced processing methods, including CNC milling, gas-assisted injection molding, and 3D printing, contribute to the production of precise and efficient components. The integration of polyamide into automated processes and material recycling supports circular economy goals and reduces environmental impact. The conclusions emphasize polyamide's role as a versatile material, with emerging applications in robotics, medicine, and space exploration.
Keywords: *polyamide, CNC machining, 3D printing, circular economy, sustainability, advanced materials.*

1. Introduction

The manufacturing of industrial components from polyamide has become a major topic of interest in the field of advanced materials, driven by increasingly stringent demands for sustainability, performance, and efficiency. Polyamide, commonly known under the trade name "Nylon," has evolved from its initial applications in the textile industry to extensive industrial uses in fields such as automotive, aerospace, construction, electronics, and medicine. This transition is attributed to its remarkable properties, such as high mechanical strength, chemical stability, and excellent electrical insulation characteristics.

2. Context and Evolution

Polyamide was discovered in the 1930s and was first used in the textile industry [1]. The expansion of its applications into industrial sectors was enabled by the development of reinforced variants incorporating glass or carbon fibers. These improved formulations have allowed polyamide to be used in critical structural components, such as automotive engine mounts or aerodynamic parts in the aerospace industry [2]. The ability to replace heavy metals with polyamide has led to weight reduction and improved energy efficiency.

3. Technical Properties and Performance

Polyamide stands out for its unique combination of properties, making it ideal for a wide range of industrial applications. It is significantly lighter than traditional metals, weighing up to three times less, which contributes to reduced energy consumption in industries such as automotive and aerospace [3]. At the same time, reinforced variants, such as polyamide 66 or PA-MXD6, provide high mechanical

strength comparable to or even surpassing that of metals, ensuring component durability. With a low coefficient of friction, polyamide exhibits excellent wear resistance, significantly extending the lifespan of parts [4]. Additionally, its electrical insulation properties make it suitable for electronic and electrical applications, offering both safety and efficiency.

Table 1 compares the mechanical properties of various types of polyamide, highlighting the advantages and limitations of each material.

Table 1. Comparison of the Mechanical Properties of Various Types of Polyamides

Type of Polyamide	Specific Weight (g/cm^3)	Tensile Strength (MPa)	Tensile Elastic Modulus (GPa)	Bending Elastic Modulus (GPa)	Elongation at Break (%)	Izod Impact Strength (kJ/m^2)
Polyamide 6	1,13	70	2,8	2,2	45	45-65
Polyamide 11	1,03	38	1,4	1,2	100	100
Polyamide 12	1,02	45	1,4	1,0	200	50-200
Polyamide 66	1,14	85	3,0	2,8	5	40-60
Polyamide 69	1,08	70	3,0	2,3	50	35
Polyamide 610	1,07	55	2,1	2,0	70	50
Polyamide 612	1,08	60	2,1	2,0	50	40
Polyamide 46	1,18	85	3,0	3,0	20	>50
PA-TMDT	1,12	90	2,8	>50	7	20
PA-MXD6	1,21	83	4,4	4,5	2	19

4. Machining Method

The machining methods of polyamide are diverse and tailored to the requirements of each industrial application.

4.1. Injection Molding

Injection molding is a well-established technology for mass production, utilizing modern techniques such as gas-assisted molding, foam molding, and multi-component molding. These methods allow for the production of complex parts with high dimensional precision and customized properties [5].

Gas-assisted injection molding uses nitrogen under pressure, which is injected into the mold to assist in filling it. This process forms a bubble that pushes the molten plastic towards the mold's ends, offering benefits such as reduced part weight, the formation of complex structures, and energy efficiency. Applications include automotive housings and plastic furniture.

Foam injection molding involves dissolving an inert gas into the resin, creating a foam core between two solid layers, which forms lightweight, strong structural parts. This method offers increased strength, thermal and acoustic insulation, as well as reduced weight, and is used in the production of vehicle panels and insulation elements.

Thin-wall injection molding produces parts with thicknesses below 0.5 mm by optimizing material usage and process parameters. This type of molding allows for material savings, optimized weight, and improved structural performance, and is applied to industrial packaging and precision parts.

Multi-component injection molding enables the combination of multiple materials into a single part by injecting them successively or simultaneously into a single mold. The benefits of this technique include the possibility of combining colors and textures, improving mechanical and thermal properties, with applications including automotive components, electrical equipment, and household items.

4.2. CNC Machining

The processing methods for polyamide are diverse and tailored to the requirements of each industrial application. CNC technology is essential for producing high-precision components with strict

tolerances. Optimizing parameters such as cutting speed and depth of cut improves surface quality and reduces tool wear, particularly for critical parts in engines and load-bearing structures [7].

The cutting parameters for CNC machines (Computer Numerical Control) are key values that determine the efficiency and quality of material processing. These parameters depend on the material type, tool geometry, operation type, and machine characteristics. The main cutting parameters include cutting speed (v), which is the peripheral speed of the tool in contact with the workpiece, measured in meters per minute (m/min); feed (f), which is the distance traveled by the tool or workpiece during one complete rotation of the tool, measured in mm/rev (mm per rotation); depth of cut (ap), which represents the thickness of the material layer removed in one pass, measured in mm. Typical values for roughing operations range from 1 to 5 mm (or more, depending on the material and machine), while for finishing operations, it is 0.2 to 1 mm; spindle speed (n), which represents the number of rotations of the tool per minute, measured in revolutions per minute (rpm); feed rate, which is the speed at which the tool or workpiece advances during processing, measured in mm/min; rake angle (γ) and clearance angle (α), which influence chip formation and surface quality, with their values depending on the material and operation; power required (P), which represents the energy needed to cut the material, expressed in kW; and material removal rate (Q), which is the volume of material removed per unit of time, measured in cm^3/min.

To highlight the influence of processing parameters on surface roughness and tool wear, Table 2 presents the optimal milling parameters for polyamide PA66, along with their effects on surface quality and tool wear. This data is essential for optimizing the milling process to achieve high-precision components.

Table 2. Optimal milling parameters for polyamide PA66 and their impact on surface quality and tool wear.

Cutting speed (m/min)	**Feed per tooth** (mm/tooth)	**Cutting depth** (mm)	**Surface roughness** (μm)	**Tool wear** (mm)
100	0,05	2	1,2	0,02
150	0,10	3	1,0	0,03
200	0,15	4	1,4	0,05

This optimization of parameters allows for the improvement of the quality of the manufactured parts, while also reducing tool wear and enabling more efficient processing.

Figure 1 shows a part machined from PA6 polyamide using CNC technology. It highlights the precision achieved in the machining process, with complex shapes and strict tolerances that are essential for the applications in which these components are used. The image illustrates the fine details and smooth surfaces of the part, achieved through optimal adjustment of the CNC processing parameters.

Figure 1. Example of a polyamide part machined on a CNC milling machine

To highlight the influence of processing parameters on surface roughness and tool wear, Table 3 presents the optimal milling parameters for PA6 polyamide, along with their effects on surface quality and tool wear. These data are essential for optimizing the milling process, ensuring the production of high-precision parts, as well as efficient tool usage.

Table 3. Optimal milling parameters for PA6 polyamide and their impact on surface quality and tool wear.

Cutting speed (m/min)	**Feed per tooth** (mm/tooth)	**Cutting depth** (mm)	**Surface roughness** (µm)	**Tool wear** (mm)
100	0,05	2	1,2	0,02
150	0,10	3	1,0	0,03
200	0,15	4	1,4	0,05
250	0,20	5	1,6	0,06

4.3. 3D Printing

3D printing is an emerging technology that offers advantages such as rapid prototyping and reduced material waste, enabling the fabrication of complex geometries through techniques like FDM, SLA, or SLS. Additionally, hybrid machining, which integrates CNC and 3D printing, provides increased flexibility and optimizes production time and costs. This approach is used for manufacturing prototypes and complex parts in industries like automotive and aerospace [6].

The 3D printing process consists of a series of technical steps that transform an idea into a physical object. Figure 2 [8] illustrates in detail the main steps involved in 3D printing, from the conception of the idea and digital modeling to the post-processing of the final part.

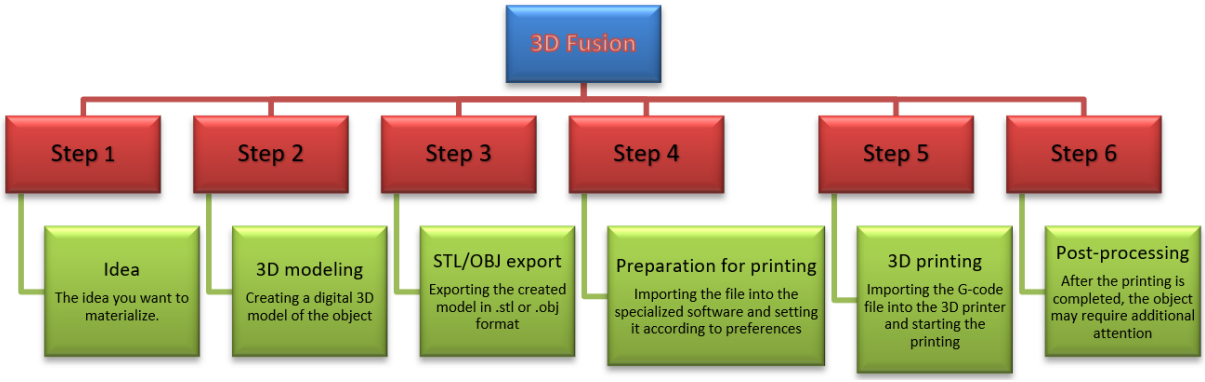

Figure 2. The steps of the additive manufacturing (3D printing) process

Figure 3 [9] presents a detailed comparison between additive manufacturing (AM) and subtractive manufacturing (SM), highlighting the advantages and limitations of each method and justifying the emergence of hybrid additive-subtractive manufacturing (HASM). In additive manufacturing, techniques such as 3D printing, selective laser sintering, and directed energy deposition allow for the creation of complex geometries, but they have limitations regarding precision and surface finish. In contrast, subtractive manufacturing, which includes CNC processes such as milling, turning, and drilling, offers high precision and a wide range of machinable materials, but it generates material waste and requires high costs for small-batch production.

5. Innovations in Design and Applications

The use of computer-aided design (CAD) and finite element method (FEM) simulations has revolutionized the process of developing polyamide parts. These technologies enable design optimization, significantly reducing risks associated with defects and improving the performance of components. Additionally, integrating polyamide into automated production processes, which use

industrial robots and intelligent quality control systems, facilitates real-time monitoring and predictive maintenance. These advanced solutions contribute to the overall efficiency of manufacturing processes and reduce operational costs.

Polyamide is present in numerous industrial applications due to its versatile properties. In the automotive industry, it is used for transmission components and engine supports, offering an ideal combination of light weight and strength. In aerospace, it contributes to the development of lightweight and durable aerodynamic structures, while in medicine, it is used for implantable devices and sterile equipment due to its biocompatibility. Moreover, in the electronics sector, polyamide is valued for its ability to provide electrical insulation and protect equipment, frequently being used for electrical insulation and protective casings. Figure 4 [10] shows a vehicle developed by the Italian company XEV. The Yoyo is the first 3D-printed electric car. Except for the chassis, seats, and windshield, all visible components of this vehicle are made using 3D printing technology. Through this innovative process, the company has managed to drastically reduce the number of components from 2,000 to just 57, resulting in the creation of an extremely lightweight car weighing only 450 kilograms.

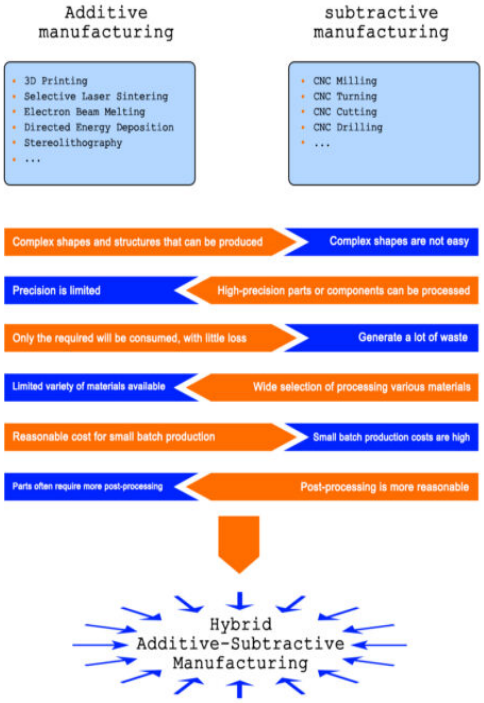

Figure 3. Comparison between Additive Manufacturing (AM) and Subtractive Manufacturing (SM)

Figure 4. A 3D Printed Electric Car

6. Sustainability and Circular Economy

The recycling process transforms polyamide waste into usable materials, thus reducing the need for new raw materials and minimizing environmental impact. The recycled material is used in the production of packaging, automotive components, and other industrial applications, providing a sustainable solution that contributes to reducing the volume of plastic waste. The development of advanced recycling technologies allows the functional properties of polyamide to be maintained, extending the lifespan of this material and significantly reducing greenhouse gas emissions associated with manufacturing processes.

Regarding environmental impact, polyamide production generates lower carbon emissions compared to traditional materials like metals. Replacing metal components with polyamide parts reduces vehicle weight and, consequently, fuel consumption, contributing to a lower carbon footprint. Additionally, through the integration of advanced recycling technologies and the efficient use of resources, polyamide aligns with global environmental goals, supporting the transition to a green economy.

7. Conclusions

Recent research highlights the potential of polyamide as a viable alternative to metals in various industrial applications. Advanced processing technologies, such as CNC and 3D printing, improve the quality of parts and contribute to innovation and sustainability. Progress in this field opens up opportunities for the use of polyamide in emerging applications, reinforcing its status as a versatile and indispensable material.

Polyamide is lighter and more resistant to corrosion, making it suitable for components that require flexibility and low weight. However, its moisture absorption and limitations at high temperatures make it less suitable for use in extreme environments.

Metals, particularly steel, are superior in applications that demand dimensional stability, thermal resistance, and rigidity, but they come with the disadvantage of weight and sensitivity to corrosion (without special treatments).

Industrial Impact Polyamide

Plays a key role in strategic industries due to its versatility:

- Automotive and Transport: The manufacture of auto components such as engine housings, transmission systems, dashboards, and safety structures has been radically transformed through the use of this material.
- Medical Industry: Biocompatible polyamide has enabled the production of prostheses, implants, surgical instruments, and customized medical devices.
- Aerospace: The aerospace industry benefits from the low weight of polyamides, using them for manufacturing support structures, protective panels, and flight equipment resistant to extreme temperatures and cosmic radiation.

Ecological Impact and Sustainability

Due to the current demands for sustainable production, research on advanced recycling and the manufacturing of biodegradable materials has become a global priority:

- Recycling and Reuse: Recycled polyamides are reused in the manufacturing of auto parts, industrial equipment, and durable packaging. Advances in chemical recycling allow for depolymerization and material regeneration at the molecular level.
- Biocompatible Materials: The development of bio-based polyamides has reduced dependence on fossil fuels, opening new paths for eco-friendly production.
- Circular Economy: Manufacturing polyamide parts through sustainable technologies such as 3D printing significantly reduces material waste, supporting the development of a circular economy.

Technological Innovations

Advances in industrial processing and academic research have stimulated the creation of advanced materials and technologies:

- 3D and 4D Printing: The use of polyamides in additive manufacturing has led to rapid prototyping, production of complex parts, and the creation of self-regenerating, self-assembling, and adaptable structures to external conditions.
- Nanotechnology: The integration of nanomaterials such as graphene and carbon nanotubes into the polyamide matrix has significantly improved electrical conductivity, thermal stability, and mechanical strength.
- Automated Manufacturing: The automation of manufacturing processes through artificial intelligence, robotics, and IoT platforms allows for the large-scale production of complex parts with high precision and optimized costs.

Future Perspectives

In the future, polyamide is expected to play an even more significant role in emerging industries due to its adaptability to new technological and ecological requirements:

- Smart Manufacturing Technologies: The integration of artificial intelligence and autonomous machines in production processes will enable the automatic optimization of manufacturing parameters, reducing costs and production time.
- Space Exploration: Polyamide will become a core material for long-duration space missions due to its lightweight and resistance to extreme conditions.
- Multifunctional Materials: New research will lead to the development of self-regenerating, biodegradable polyamides with shape memory, further expanding their applicability in sectors such as robotics, electronics, and medicine.

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Future Directions in Bio-Lubricants: A Theoretical Synthesis of Current Trends and Innovations

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Abstract. This paper explores the future directions of bio-lubricants, focusing on current trends, innovative research, and the potential for reducing environmental impact. Bio-lubricants, derived from renewable sources such as plant oils and animal fats, present a sustainable alternative to conventional petroleum-based lubricants. The paper examines advancements in biotechnology, synthetic biology, and nanotechnology that have enhanced the performance characteristics of bio-lubricants. It also proposes a theoretical model for integrating bio-lubricants into circular economy frameworks through life cycle analysis and sustainable supply chains. The paper highlights future research opportunities, industrial collaborations, and policy recommendations aimed at accelerating bio-lubricant adoption in diverse sectors, including automotive, aerospace, and manufacturing, to reduce environmental footprints while maintaining high performance.
Keywords: *Bio-lubricants, Renewable lubricants, Environmental sustainability, Circular economy, Life cycle analysis*

1. Introduction

The use of lubricants is fundamental across various industries, particularly in sectors such as automotive, manufacturing, and aerospace, where minimizing friction and wear between mechanical parts is crucial. Petroleum-based lubricants have been the dominant choice for decades due to their proven effectiveness, availability, and cost-efficiency (Tan, Han, Zhang, Li, & Shang, 2021). However, these traditional lubricants come with significant environmental drawbacks. Derived from non-renewable fossil fuels, petroleum-based lubricants are associated with high toxicity levels, poor biodegradability, and substantial greenhouse gas emissions during production and disposal (Gautam & Agrawal, 2021). As industries worldwide move toward more sustainable practices, there has been a growing demand for alternatives that can perform the same essential functions while reducing environmental harm.

Bio-lubricants have emerged as a promising solution to address these concerns. Derived from renewable sources such as plant oils (e.g., rapeseed, soybean, sunflower) and animal fats, bio-lubricants offer several environmental advantages over their conventional counterparts. They are biodegradable, non-toxic, and have a lower ecological footprint, contributing less to pollution and carbon emissions (Al-Tayyar, Youssef, & Al-Hindi, 2020). Additionally, their use aligns with the global shift towards reducing reliance on fossil fuels and minimizing the environmental impact of industrial operations. Adopting bio-lubricants is not only a response to environmental pressures but also to increasingly

stringent government regulations in regions like Europe and North America, where industries are required to comply with policies to reduce harmful emissions and waste (Gautam & Agrawal, 2021).

As industries seek to become more sustainable, the need for innovation in lubricant technology has become more pressing. While bio-lubricants offer many advantages, there are also challenges associated with their use. For instance, vegetable oils, a primary component of many bio-lubricants, tend to be less stable at high temperatures and are more susceptible to oxidation than petroleum-based lubricants. These limitations can affect the performance and lifespan of bio-lubricants in extreme conditions, limiting their broader adoption across some sectors (Hamnas & Unnikrishnan, 2023). Thus, ongoing research is urgently needed to improve the performance characteristics of bio-lubricants, making them a more versatile and competitive option for widespread industrial use.

The objectives of this paper are twofold. First, it aims to synthesize the existing literature on bio-lubricants, summarizing the current trends, key advancements, and ongoing challenges in their development and application. This will provide a comprehensive overview of the state of bio-lubricant technology and its role in modern industry. Second, the paper will introduce a theoretical model that outlines the future potential of bio-lubricants in reducing environmental impact. This model will explore how innovations in bio-lubricant formulations, coupled with advances in technology and regulatory support, can lead to broader industrial adoption and significantly lower the environmental footprint of lubricant use. By proposing this framework, the paper seeks to contribute to the ongoing discourse on sustainable industrial practices and highlight the critical role that bio-lubricants can play in achieving these goals.

2. Current Trends in Bio-Lubricants

2.1 Literature Overview on Bio-Lubricants

Bio-lubricants are typically derived from renewable resources such as plant-based oils (e.g., rapeseed, sunflower, soybean) and animal fats. The core motivation behind bio-lubricant development is their lower environmental impact when compared to traditional mineral oil-based lubricants. Research has consistently demonstrated that bio-lubricants exhibit superior biodegradability, lower toxicity, and a reduced carbon footprint. For instance, studies show that bio-lubricants degrade significantly faster than petroleum-based alternatives, which can persist in the environment for extended periods and pose serious pollution risks (Chowdary, Kotia, Lakshmanan, Elsheikh, & Ali, 2021).

Moreover, bio-lubricants are often less hazardous to human health and the ecosystem, making them particularly suitable for applications in sensitive environments such as agriculture, forestry, and marine industries (Narayana Sarma & Vinu, 2022). In these settings, the potential for lubricant leakage or spillage is high, making the use of biodegradable, non-toxic lubricants critical. Despite these benefits, the literature also highlights certain drawbacks, particularly with regard to the oxidative stability and thermal performance of bio-lubricants. These limitations have fueled ongoing research efforts to improve bio-lubricants' performance while maintaining their ecological advantages (Narayana Sarma & Vinu, 2022).

Bio-lubricants' development has evolved considerably in recent years, driven by advancements in formulation technologies. One of the key areas of innovation has been the diversification of feedstock sources used to produce bio-lubricants (Barbera, Hirayama, Maglinao, Davis, & Kumar, 2024). Historically, bio-lubricants were predominantly made from a few types of vegetable oils, with rapeseed and soybean oils being the most common. These oils offer high lubricity and excellent biodegradability, making them attractive for various applications. However, they also exhibit certain performance drawbacks, such as poor oxidative stability and a limited ability to perform under high-temperature conditions (Waqas, Zahid, Bhutta, Khan, & Saeed, 2021).

In response to these challenges, research has explored a wider range of feedstock options, including animal fats and advanced synthetic bio-based esters. While less commonly used, animal fats offer distinct advantages in terms of their viscosity index and stability at extreme temperatures, making them suitable for high-stress applications(Hamnas & Unnikrishnan, 2023). Additionally, advancements in chemical processing techniques have enabled the development of synthetic bio-lubricants that combine

the environmental benefits of natural oils with enhanced performance characteristics. These synthetic esters are engineered to provide superior thermal stability, oxidation resistance, and viscosity control, making them more competitive with traditional mineral oil-based lubricants in demanding industrial settings (Narayana Sarma & Vinu, 2022).

Furthermore, additives have played a crucial role in overcoming some of the inherent limitations of bio-lubricants. For example, antioxidants are commonly added to bio-lubricants to improve their resistance to oxidation, thereby extending their operational lifespan. Similarly, anti-wear and friction modifiers have been developed to enhance the protective qualities of bio-lubricants, making them suitable for high-load and high-temperature environments. These advancements have significantly expanded the potential applications of bio-lubricants across a range of industries (Narayana Sarma & Vinu, 2022).

2.2 Trends in Industrial Applications

Bio-lubricants are being increasingly adopted across multiple industries, particularly in sectors where environmental regulations are stringent, or the ecological impact of lubricant use is a major concern. In the automotive industry, bio-lubricants are being used in engine oils, hydraulic fluids, and transmission fluids, offering an eco-friendly alternative to conventional oils. The automotive sector has been a key driver of bio-lubricant adoption, as manufacturers strive to meet stringent emissions standards and reduce the environmental impact of their products (Malik, Kalam, Mujtaba, & Almomani, 2023).

In manufacturing, bio-lubricants are used in cutting, metalworking, and machinery lubrication. Their high lubricity and biodegradability make them particularly attractive in applications where lubricant disposal or leakage can lead to environmental contamination. Similarly, the aerospace industry has started to explore the use of bio-lubricants for aircraft engine oils and hydraulic systems, where their low toxicity and high performance under extreme conditions provide significant advantages (Kurre & Yadav, 2023).

The agricultural and forestry sectors have also been early adopters of bio-lubricants, as these industries often operate in environmentally sensitive areas where lubricant spills can have devastating consequences. The use of biodegradable, non-toxic bio-lubricants reduces the risk of long-term soil and water contamination, making them ideal for applications in tractors, chainsaws, and other heavy equipment used in these sectors. Moreover, the marine industry, which faces strict environmental regulations regarding the discharge of lubricants into the water, has increasingly turned to bio-lubricants for applications in ship engines, hydraulic systems, and deck equipment (Piri, Renzi, & Bietresato, 2023).

2.4 Challenges in Commercial Scaling

Despite the growing interest and advancements in bio-lubricants, there are still several challenges to their widespread commercial adoption. One of the primary obstacles is the cost associated with bio-lubricant production. Bio-lubricants are often more expensive to produce than their petroleum-based counterparts due to the higher costs of raw materials and the more complex processing required. This cost disparity has limited their adoption, particularly in industries with high cost sensitivity, such as transportation and manufacturing (Rahman et al., 2021).

Another significant challenge is the performance limitations of bio-lubricants, particularly in extreme conditions. While advancements in feedstock diversification and additive technologies have improved bio-lubricants' performance, they still generally lag behind petroleum-based lubricants in terms of oxidative stability, thermal performance, and durability under high stress. These performance issues have prevented bio-lubricants from becoming mainstream in applications where extreme temperatures, heavy loads, or long operational lifespans are required (Murru, Badía-Laíño, & Díaz-García, 2021).

In addition, the availability of feedstock materials poses a challenge for scaling bio-lubricant production. While plant-based oils and animal fats are renewable resources, their availability can be limited by factors such as agricultural yields, competition with food production, and supply chain constraints. This creates a potential bottleneck in bio-lubricant production, particularly as demand grows

in response to environmental regulations and consumer preferences for sustainable products (Longanesi, Pereira, Johnston, & Chuck, 2022).

3. Innovative Approaches to Bio-Lubricant Development

3.1 Cutting-Edge Innovations in Bio-Lubricant Research

Bio-lubricant development has increasingly benefited from innovations in biotechnology, synthetic biology, and nanotechnology. These fields have opened new avenues for producing more advanced and tailored bio-lubricant formulations. In biotechnology, genetic engineering is being used to optimize the fatty acid composition of oil-producing plants such as rapeseed, sunflower, and soybeans. By modifying these plants at the molecular level, researchers can enhance the desirable properties of the oils, such as improving their oxidative stability and cold-temperature performance. This biotechnological approach offers a sustainable way to increase the viability of plant-based oils in demanding applications, enabling them to meet the performance standards of industries like automotive and manufacturing (Hu, 2022).

Synthetic biology further enhances bio-lubricant production by allowing the design and assembly of entirely new biological pathways to produce synthetic bio-based esters (Pichler et al., 2023). These synthetic esters combine the renewable benefits of bio-lubricants with the high performance typically associated with petroleum-based lubricants. They offer improved thermal stability, longer operational life, and resistance to extreme temperatures, making them suitable for applications in sectors such as aerospace and heavy machinery, where conventional bio-lubricants might fail (Porokhovinova et al., 2022).

Nanotechnology, another frontier in bio-lubricant development, has been applied to improve lubricant performance at the molecular level. Nano-additives such as nano-oxides, graphene, and carbon nanotubes are being integrated into bio-lubricants to enhance their lubricating properties. These nanoparticles reduce friction and wear in mechanical systems more effectively than traditional additives, extending bio-lubricants' lifespan and improving their efficiency under high-pressure and high-temperature conditions. Nanotechnology also offers a solution to the common issues of viscosity and oxidation, allowing bio-lubricants to maintain optimal performance across a broader range of operating environments (Jogesh, 2022).

3.2 Advances in Improving Performance Characteristics

One of the most significant obstacles in the widespread adoption of bio-lubricants has been their inherent performance limitations, particularly in terms of oxidation stability, viscosity, and thermal performance. However, recent advances in bio-lubricant technology have addressed these concerns, making bio-lubricants a more attractive option for demanding industrial applications (Uppar, Dinesha, & Kumar, 2023). Oxidation stability has long been a challenge for bio-lubricants, especially those derived from vegetable oils. When exposed to oxygen and high temperatures, these oils are prone to degradation, resulting in reduced performance and a shorter lifespan. Researchers have developed new bio-based additives and antioxidants that significantly improve the oxidation stability of bio-lubricants. These antioxidants, derived from natural sources or synthesized through biotechnological processes, inhibit the oxidative degradation of the oils, allowing bio-lubricants to maintain their performance characteristics for longer periods and under harsher conditions (Hamnas & Unnikrishnan, 2023).

Viscosity is another critical factor in determining the performance of lubricants. Bio-lubricants traditionally suffer from lower viscosity indices than their petroleum-based counterparts, limiting their use in high-temperature or high-pressure environments. To address this, advances in chemical modification techniques have allowed for the development of bio-lubricants with improved viscosity control (Muhammad Harith, 2021).

By altering the molecular structure of vegetable oils or blending them with synthetic bio-based esters, researchers can achieve more stable and consistent viscosity levels. These modifications enable bio-lubricants to maintain optimal flow and lubrication across a wider temperature range, making them suitable for high-performance applications in aerospace, automotive, and manufacturing industries. For instance, chemical processes such as transesterification—where triglycerides in vegetable oils are

converted into more stable esters—have improved bio-lubricants' viscosity and thermal stability, enhancing their competitiveness with traditional mineral oils (Malik et al., 2023).

3.3 Emerging Bio-Based Additives and Catalysts

In addition to improvements in base oil formulations, bio-based additives and catalysts have emerged as critical components in enhancing the efficiency and lifespan of bio-lubricants. Traditional lubricants rely heavily on synthetic chemical additives to improve performance metrics such as wear resistance, oxidation stability, and friction reduction. However, bio-lubricants benefit from a new generation of bio-based additives derived from renewable sources, which align more closely with the eco-friendly nature of these lubricants (Raof, Hamid, Mohamad Aziz, & Yunus, 2022).

One promising category of bio-based additives is derived from plant-based antioxidants and anti-wear agents. These additives are capable of extending the lifespan of bio-lubricants by protecting the base oil from oxidative degradation and minimizing the wear and tear on mechanical components. Natural antioxidants, such as tocopherols (vitamin E), have proven effective in stabilizing bio-lubricants under high-temperature conditions, reducing the need for frequent lubricant replacement and minimizing waste (Opia, Abdollah, Hamid, & Veza, 2023).

In parallel, catalysts play a vital role in enhancing the chemical processes used to produce bio-lubricants. Enzymatic catalysts, for instance, are being developed to facilitate the production of high-performance bio-lubricants through more efficient and environmentally friendly processes. These catalysts help convert raw vegetable oils or animal fats into esters with the desired lubrication properties, without harsh chemical treatments. By optimizing the production process and reducing energy consumption, these bio-based catalysts help lower the overall environmental impact of bio-lubricants, making them a more sustainable choice for industry (Sancheti & Yadav, 2022).

3.4 Industry Collaboration and Academic Research

The advancements in bio-lubricant development have been driven largely by the collaboration between industry stakeholders and academic institutions. This partnership has been essential in addressing the scientific and technical challenges associated with bio-lubricants while ensuring that the innovations are practical for real-world industrial applications. Academic research has played a central role in exploring new feedstocks, refining production techniques, and developing advanced bio-lubricant additives. Universities and research institutions are often at the forefront of fundamental studies on the molecular composition of vegetable oils, animal fats, and synthetic esters, providing valuable insights into how these substances can be modified to improve their lubrication properties. Additionally, academic researchers have access to cutting-edge technology and equipment, allowing for rigorous testing of new bio-lubricant formulations under various operating conditions. This foundational research forms the basis for industry innovations, which are then commercialized and brought to market.

On the industry side, companies are working closely with academic partners to translate scientific discoveries into viable products. Large multinational corporations in the automotive, aerospace, and manufacturing sectors have invested heavily in bio-lubricant research, driven by regulatory pressures and a growing consumer demand for sustainable solutions. These industries require bio-lubricants that meet environmental standards and deliver high performance and cost-effectiveness. By collaborating with academic institutions, companies are able to access the latest research, test new formulations in real-world environments, and accelerate the development of bio-lubricants that can be scaled for commercial use.

Government initiatives and funding programs have also contributed to the growing synergy between academia and industry. In many countries, governments are offering grants and incentives to support research and development in bio-lubricants, recognizing their potential to reduce the environmental impact of industrial operations. These programs encourage knowledge sharing between academic researchers and industry professionals, fostering an ecosystem where innovation can thrive (Opia et al., 2023).

3.5 The Future of Bio-Lubricant Innovation

As biotechnology, synthetic biology, and nanotechnology continue to evolve, the future of bio-lubricant innovation looks promising. The advancements in molecular engineering and additive technology are pushing the boundaries of what bio-lubricants can achieve, enabling them to meet the stringent demands of industries that rely on high-performance lubricants. Moreover, the shift towards a circular economy and the increased focus on sustainability in manufacturing are likely to spur further investment in bio-lubricant research (Cao et al., 2024).

The key to broader adoption of bio-lubricants will be the ongoing improvement of their performance characteristics, particularly in extreme conditions, and the reduction of production costs. With continued collaboration between industry and academia, the development of next-generation bio-lubricants that can rival or even surpass petroleum-based lubricants in terms of both performance and environmental sustainability is within reach (Lee, Lee, & Lee, 2022).

4. Theoretical Model for Future Bio-Lubricant Use

4.1 Proposition of a New Theoretical Framework

The proposed theoretical model for the future use of bio-lubricants is built upon three interconnected pillars: life cycle analysis, circular economy integration, and regulatory support. Together, these pillars form a foundation for developing bio-lubricants that meet current industrial demands and anticipate future sustainability challenges. The first pillar involves using life cycle analysis as a central tool in the development process. LCA evaluates the environmental impact of a product from its initial raw material extraction through production, usage, and end-of-life disposal or recycling. For bio-lubricants, LCA offers a way to quantify their environmental advantages over petroleum-based lubricants, providing a clearer picture of their sustainability. By analyzing each stage of the bio-lubricant's life cycle, manufacturers can identify opportunities to minimize carbon emissions, reduce energy consumption, and decrease waste generation. Furthermore, integrating LCA in early product development can lead to innovations that focus on reducing resource use and improving efficiency, ensuring that bio-lubricants contribute to environmental protection throughout their lifecycle.

The second pillar emphasizes the need to align bio-lubricant production and usage with the circular economy principles. In contrast to the traditional linear economy model of "take, make, and dispose," the circular economy encourages the reuse, recycling, and regeneration of materials to create a closed-loop system. For bio-lubricants, this means using renewable feedstocks like plant oils and animal fats and ensuring that by-products and waste from the production process are repurposed or reintegrated into the supply chain. The goal is to create a system where bio-lubricants can be produced, used, and recycled without creating environmental harm. Additionally, industries that adopt bio-lubricants will need to implement practices such as waste oil recycling and lubricant regeneration to extend product life and reduce the demand for new raw materials.

The third pillar focuses on the role of regulatory support in facilitating the widespread adoption of bio-lubricants. Government policies and regulations have historically played a crucial role in shaping industrial behavior, and the transition to bio-lubricants will be no different. Regulatory frameworks that promote sustainability, such as carbon taxes, incentives for using renewable materials, and stricter emissions standards, will be essential in driving the demand for bio-lubricants. By establishing clear environmental performance targets, regulatory bodies can create an environment where the development and use of bio-lubricants are prioritized over conventional lubricants. Moreover, international regulatory cooperation ensures that bio-lubricants are consistently, harmonized, and integrated into global supply chains.

4.2 Environmental Impact Reduction Through Life Cycle Analysis

Life cycle analysis provides a comprehensive method for assessing the environmental impact of bio-lubricants compared to conventional petroleum-based lubricants. This holistic evaluation accounts for all product life stages, including raw material extraction, production, transportation, use, and disposal.

For bio-lubricants, LCA reveals how using renewable, plant-based materials can significantly reduce greenhouse gas emissions, energy consumption, and environmental toxicity.

A critical advantage of bio-lubricants is their biodegradability, which lowers the environmental risk in case of accidental spills or improper disposal. In contrast, petroleum-based lubricants are notorious for their persistence in the environment and their contribution to soil and water contamination. A thorough LCA can help industries choose bio-lubricant formulations that perform well and have a lower ecological footprint across the product's entire lifespan (Freschi, Paniz, Cerqueni, Colella, & Dotelli, 2022).

The environmental benefits of bio-lubricants become even more pronounced when considering the carbon sequestration potential of the plants used to produce them. Oilseed crops such as rapeseed, soybean, and sunflower absorb carbon dioxide from the atmosphere during their growth, partially offsetting the emissions generated during the production and use of bio-lubricants. By integrating LCA into the theoretical framework, industries can ensure that bio-lubricants are chosen and developed based on their ability to reduce overall environmental impact while still meeting performance needs (Shah, Woydt, & Zhang, 2021).

4.3 Integration With Circular Economy Principles

The circular economy provides a roadmap for transitioning bio-lubricant production from a linear to a more sustainable model. By prioritizing resource efficiency, waste minimization, and the reuse of materials, the circular economy ensures that bio-lubricants can be produced and used to reduce the overall demand for virgin resources. A key aspect of integrating bio-lubricants into the circular economy is the focus on sustainable sourcing of raw materials. Bio-lubricants rely on renewable feedstocks such as plant oils and animal fats, but these resources must be managed sustainably to avoid contributing to deforestation, habitat destruction, or food insecurity. The theoretical model proposed here emphasizes using sustainable agriculture practices and developing bio-lubricants from non-food crops, waste oils, or algae. These alternative feedstocks can reduce pressure on food supplies and promote a more sustainable use of land and water resources.

The circular economy model also encourages the recycling and regeneration of used bio-lubricants. Rather than being discarded, waste oils can be collected, filtered, and reprocessed for reuse, significantly extending the product's life and reducing the need for fresh raw materials. This approach not only lowers the environmental footprint of bio-lubricants but also presents economic benefits by reducing the costs associated with production and disposal. In industries that use large quantities of lubricants, such as manufacturing and transportation, the ability to recycle bio-lubricants can lead to significant cost savings while promoting environmental stewardship (Malik et al., 2023).

Bio-lubricants' widespread industrial adoption will depend on market forces and regulatory incentives. As sustainability becomes a more significant consideration for industries worldwide, the demand for bio-lubricants is expected to increase. Automotive manufacturers, for example, are likely to adopt bio-lubricants more broadly as part of their efforts to reduce the carbon footprint of their vehicles and meet stricter emissions regulations. Similarly, sectors like aerospace and heavy machinery are expected to shift toward bio-lubricants as advancements in their performance characteristics make them a viable alternative to petroleum-based products.

Regulatory support will be critical in accelerating this transition. Governments worldwide are already implementing policies to reduce carbon emissions, promote renewable energy, and encourage sustainable manufacturing practices. In the future, stricter regulations on petroleum-based lubricants and incentives for using bio-lubricants will likely play a decisive role in shaping the market (Aleluia, Tharakan, Chikkatur, Shrimali, & Chen, 2022).

5. Conclusion and Recommendations

One of the most compelling benefits of bio-lubricants is their potential to reduce environmental harm significantly compared to traditional lubricants. Bio-lubricants, derived from renewable sources such as plant oils and animal fats, exhibit a lower carbon footprint due to the carbon sequestration abilities of

their raw materials. Additionally, their biodegradability minimizes the risk of long-term environmental contamination in case of spills or improper disposal. Unlike petroleum-based lubricants, which persist in soil and water ecosystems, bio-lubricants break down more rapidly and naturally, reducing their ecological impact. As discussed earlier, life cycle analysis (LCA) provides a robust method for assessing the full environmental benefits of bio-lubricants and can serve as a guiding tool for industries seeking to adopt greener alternatives.

Although substantial progress has been made in the development of bio-lubricants, several areas of research remain ripe for exploration. For example, continued innovation in feedstock sources offers an opportunity to diversify the range of bio-lubricants available further. While plant-based oils and animal fats have dominated the bio-lubricant market, non-food sources such as algae and waste oils hold great potential as alternative feedstocks. These sources could reduce the reliance on agricultural land and mitigate concerns about food security, making bio-lubricants more sustainable in the long run.

Furthermore, research into optimizing production processes using bio-based catalysts and enzymes could lead to more energy-efficient methods of bio-lubricant synthesis. Refining the chemical conversion processes makes it possible to produce bio-lubricants that perform even better under extreme conditions, such as high temperatures and pressures, thereby increasing their applicability across a broader range of industrial environments. Collaboration between academia and industry will be key to driving these innovations forward and ensuring that bio-lubricants meet the stringent demands of global industries.

Policy and regulatory frameworks must provide a supportive environment to accelerate the adoption of bio-lubricants. Governments and regulatory bodies can incentivize using bio-lubricants through subsidies, tax credits, and stricter environmental regulations on petroleum-based lubricants. Policymakers can encourage industries to transition toward more sustainable lubrication solutions by setting clear environmental performance standards and offering financial incentives.

Additionally, global regulatory harmonization will ensure that bio-lubricants are integrated into international supply chains. Unified standards across countries will facilitate the cross-border adoption of bio-lubricants and support the development of sustainable, globally coordinated supply chains. Finally, fostering collaboration between governments, industries, and academic institutions can help streamline innovation and fast-track next-generation bio-lubricants' commercialization.

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Establishing the risk factors of pantograf trolleybuses for electrification

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Abstract. The paper addresses two research directions: the first direction is an evolutionary study of the pantograph trolleybuses for electrification used by the railways in Romania. This direction makes an analysis of the competitiveness from several points of view: technological, economic, qualitative and managerial of the pantograph trolleybuses by the comparison method. The second direction of research is an analysis of the risk factors that occur in the use of pantograph trolleybuses as well as the accompanying static and dynamic equipment. Information will be presented regarding the description of the risk factors that will be analyzed.
Keywords: *trolleybus, pantograph, electrification, risk factors*

1. Introduction

Although the electrification of the railways in Romania was achieved after 1960, it was a problem discussed by the technical personalities of the time since the beginning of the twentieth century, when the conditions for the practical implementation of electrification did not exist. At that time, prominent figures in the Romanian energy sector were thinking about a national energy system and considered that the main consumer of energy could be railway traction, which had important advantages over steam traction.

Pantograph trolleys are specially constructed railway vehicles that serve to transport workers, materials, tools and carry out works. They are equipped with lifting platforms for work at height and are used for construction, maintenance and repair of the contact line. Pantograph trolleys are equipped with running subassemblies, suspension, collision-binding devices, brake installations, self-propulsion power unit and optical and acoustic signaling installations, similar to those of railway rolling stock [1], [2]. [3].

The pantograph trolley is a self-propelled vehicle intended for the mechanization of inspection and intervention works on the contact line of the electrified railway, as well as for the transport of personnel and necessary materials, in conditions of safety and comfort, to and from the place of interventions [4], [5].

2. Description of pantograf trolleys

The railcar is equipped with towing, collision and tying devices (which are only used for towing the railcar behind the train, in case of its failure or when towing a work train), with direct brake, hand brake; electric and pneumatic acoustic signal, external signaling light and electric lighting inside the cabin.

In order to respond as efficiently as possible to traffic situations, and to a wide range of intervention situations, the pantograph railcar is mainly composed of the equipped infrastructure (the vehicle part itself) and the chassis superstructure that includes the assembled cabins and the main technological equipment.

The chassis is a welded metal construction made of rolled profiles and thick sheets, which provides all the fastening elements for the other subassemblies of the railcar and which takes over the efforts that occur during operation both in self-propelled mode and in technological mode. The transmission assembly has the role of producing, amplifying and transmitting to the vehicle axles, and from them to the chassis, the necessary traction force, depending on the traffic situations. In this sense, the transmission assembly consists of:

The diesel engine is mounted on the chassis by means of elastic elements, in the immediate vicinity of the front cabin.

The clutch is single-disc. The gearbox is adapted for railway use in the sense of equipping it with a double control of the selection mechanism and eliminating the reverse gear.

The reverser is a typical railway equipment.

The transfer case has a built-in interaxle differential. The box has the role of transmitting the movement and engine torque to the two axles, and the presence of the differential mechanism avoids the appearance of flat spots in the wheel treads when their wear is uneven. In the event of a failure requiring the dismantling of a final cardan shaft, the movement of the trolley can only be carried out after blocking the interaxle differential, using the mechanism provided for this purpose, accessible from the chassis platform after removing the access hatch. Failure to perform this operation leads to the operation of the interaxle differential, the movement not being transmitted to the cardan shaft in operation; only the output shaft from which the cardan shaft has been removed rotates, and the trolley does not move. The situation is similar to car traffic when one of the wheels of a driving axle loses grip (mud pit, ice, slush, etc.).

The cardan transmission consists of a cardan coupling between the gearbox - reverser - transfer case and a final cardan shaft between the transfer case and the axle attachments.

The 2-piece drive axles include, in addition to the axle itself, the axle attachment, the running wheels in solution with bandage and the assembled grease boxes. The axle attachment, in solution completely unsuspended, has a two-piece housing in which the bevel group with curved teeth is assembled. Both the pinion and the bevel gear are assembled in a removable manner from the input shaft and the axle itself, so that when they need to be replaced, this operation can be done at reduced costs.

Between the upper housing of the axle attachment and the chassis, the reaction beam is articulated, equipped with elastic rubber elements (silence blocks) identical to those used to suspend the drive axle of the passenger transport buses from which they were taken over.

The grease boxes are supported by radial - axial bearings with tapered rollers, one pair on each box, with the possibility of adjusting the play in the bearings as they wear out. The grease box housing has a "V"-shaped guide on the sides for mounting the suspension, and in the upper central position a joint that serves to mount the telescopic shock absorber.

The spring suspension has the role of taking over the loads that occur during the vehicle's movement in the vertical, horizontal-transverse direction, damping them, and transmitting the traction force from the axle to the chassis. In this sense, it consists of a pair of rubber-metal springs and a telescopic hydraulic shock absorber for each grease box.

The adjustment of the loads on the wheels and axle is easily done by introducing additions (ballagage) that are fixed on the "V" guides of the grease boxes.

The braking system is a subassembly that directly contributes to traffic safety (risk class IA). The driving mechanic must know it thoroughly and therefore it will be presented in detail in the following.

The braking system consists of two main subassemblies, namely:

-the pneumatic installation for producing, storing compressed air and supplying the brake cylinder;

-the mechanical steering of the automatic brake and the handbrake actuating mechanism

The pneumatic installation of the pantograph trolley ensures the production, storage, supply and ventilation of the brake cylinder, which, acting on the mechanical steering, performs braking and loosening of the vehicle brake.

The pneumatic brake installation assembly ensures an indirect action, the braking of the vehicle being carried out by venting the general pipe and a moderate, progressive effect, up to a maximum value, both when tightening and loosening the shoe on the wheel

3. The evolution of pantograf trolleys

The railcar is equipped with towing, collision and tying devices (which are only used for towing the railcar behind the train, in case of its failure or when towing a work train), with direct brake, hand brake; electric and pneumatic acoustic signal, external signal light and electric lighting inside the cabin.

In order to respond as efficiently as possible to traffic situations, and to a diverse range of intervention situations, the pantograph trolleybus is mainly composed of the equipped infrastructure (the vehicle part itself) and the chassis superstructure that includes the assembled cabins and the main technological equipment.

Figures 1 and 2 show the first railcars manufactured in Romania.

Figure 1. Pantograph trolley type DP (MARUB)

Figure 2. Pantograph trolley type DC (GRIVIȚA)

Three operating modes are distinguished.

Self-propelled mode, shown in figure 3, when the railcar moves to and from the intervention site.

In this situation, all technological equipment is retracted into the CF gauge and secured in this position, the contact line being energized, the human presence warning device on the connecting platform between the cabins will be positioned in "standby" (hatch control switch activated).

The vehicle's travel speed will comply with the indications in the traffic order, within the maximum constructive speed limit, depending on the profile of the line (traffic section).

Figure 3. Self-propelled mode

Catenary inspection regime, figure 4, situation when the same conditions as the self-propelled regime are used, with the difference being the position of the pantograph that will be raised. In this situation, the condition of the contact line is inspected, identifying and noting (km, number of posts, zigzag value, etc.) the location of future interventions, evaluating the time and materials needed for remediation, of the areas where there is a risk that vegetation could penetrate the pantograph gauge. In the cold season, routes can be carried out to remove ice deposits or frost from the contact wire.

Figure 4. Catenary inspection regime

The technological regime as seen in Figure 5 is the situation when the contact line is de-energized, the area being secured by installing rail short-circuiters at both ends and the human presence signaling device on the connecting platform between the cabins positioned in "rest state" (hatch control switch not activated).

Figure 5. Technological regime

In this case, the technological equipment in the equipment is removed outside the gauge of the train, allowing personnel access to the contact line elements. The movement of the trolleybus to a new work point, from inside the secured area, will be carried out with the work platform in the lowered position and the wheel in the track axis, with the personnel withdrawn on the connecting platform and at a maximum speed of 5-10 km/h.

4. Determining risk factors

In analyzing the risk factors in the use of pantograph trolleybuses and associated static and dynamic equipment, we can identify several factors that influence the safety and performance of these equipment. Here are some relevant risk factors:

Mechanical and structural risk

-Physical wear of components. Pantograph trolleys are subject to continuous wear, especially the pantograph and the suspension system. These components can suffer damage due to friction with the catenary or extreme weather conditions.

-Structural defects. Cracks or weakening of the trolley structure due to age, repeated shocks or inadequate maintenance can lead to major failures, affecting the performance and safety of the equipment.

Electrical risk

-Electrical storms or discharges. During operation, trolleybuses are exposed to electrical hazards, especially in adverse weather conditions such as electrical storms. Discharges can affect the trolleybus power systems.

-Electrical installation defects. The problem can occur when the electrical cables or equipment on the trolleybuses are defective, which can lead to short circuits or electrocution of operators.

Operational and safety risk.

-Human errors. Wrong decisions made by operators, lack of adequate training or fatigue can contribute to operational risks. For example, an error in handling the pantograph or other equipment can cause collisions or equipment failure.

-Communication problems. A lack of coordination between trolleybus operators, maintenance personnel and traffic controllers can lead to incidents or accidents on the ground.

Environmental risk

-Extreme weather conditions. Precipitation, blizzard, frost or extreme temperatures can affect the performance of pantograph trolleys and accompanying equipment. For example, freezing of the pantograph can affect contact with the catenary, and snow accumulated on the equipment can increase the risk of accidents.

-Corrosiveness of the environment. Humidity, salinity (in case of trolleys operating in coastal areas or where there are saline aerosols) can lead to corrosion of metal parts, thus reducing the reliability and lifespan of the equipment.

Infrastructure risk

-Failures of the catenary or the electrification network. A defective catenary or an unstable electrification network can negatively influence the performance of the trolleys. Damage to the catenary can cause the trolley to suddenly stop or affect the power supply to the equipment.

-Railway quality. The condition of the railway infrastructure (e.g. damaged lines or faulty switches) can affect the stability and safety of pantograph trolleybuses, especially when travelling over rough terrain.

Maintenance and operation risk

-Inadequate maintenance of equipment. Lack of a proper maintenance program can lead to the accumulation of small failures, which, over time, can turn into a major problem.

-Replacement of worn components. Continuous use of spare parts that do not meet quality standards can lead to performance and safety problems.

Technological risk

-Insufficient technological advances. If railcars are not equipped with the latest safety and monitoring technologies, such as real-time fault detection systems or noise and vibration reduction technologies, the risks of accidents or breakdowns can increase.

-Equipment compatibility. Compatibility issues between different types of equipment (e.g. pantographs and electrical systems of different railway lines) can lead to failures or poor performance.

Legal and regulatory risk

-Failure to comply with safety standards. Failure to comply with national and international railway safety regulations can expose equipment and personnel to additional risks.

-Legislative changes. Changes in railway safety regulations or equipment standards can create confusion or risks if not implemented properly.

5. Conclusions

Through investments in railway infrastructure, rail transport benefits both residents and businesses. The rehabilitation of a section of traffic leads to an increase in the current rail market share of passenger traffic. Passenger safety and comfort also increase as a result of the faster travel times made possible by the new section.But it is not only passengers who will benefit from this modernization. Freight transport will also see an increase in market share. These links represent an important transport route between two economic areas, and as a result of the faster service enabled by the rehabilitated lines, freight traffic will become a more attractive and competitive mode of transport - especially compared to road transport. In fact, compared to road transport, commercial rail transport offers higher quality and faster services, based on modern European infrastructure standards

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Innovative approach in CNC probing of oversized investment casting parts

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Abstract. Within this paper the main goal consisted in developing a parametric approach of the machining allowance set-up of oversized semifinished products obtained through investment casting, taking into account their high tolerance range. Through existing predefined probing cycles, it was managed configuring a system based on several variables which lead to defining the necessary steps within the machining process. The resulting NC program could be further linked to a Microsoft Excel file within which all the calculus can be done and the NC codes generated. The most important contribution consists in the fact that through this approach no further actions of the operator (measuring, calculating) are necessary, therefore plenty of errors could be avoided.
Keywords: *CNC machining optimization, parametric NC programming*

1. Introduction

One of the main features and advantages of CNC manufacturing consists in the high accuracy of the obtained parts, this desiderate being fulfilled by high-precision and efficient product measurement. Disregarding the common downfalls regarding the geometric accuracy of the touch probe (TP), its thermal stability or shape particularities, researchers focused on increasing the productivity of the manufacturing process through automated measuring systems or self-calibrating cycles [1-4].

Furthermore, probing a part obtained through the investment casting process is truly challenging due to the high roughness and irregular surfaces but also due to the high tolerances in cases of oversized parts [5].

Setting up the workpiece reference system poorly might lead to an unproportional disposal of the material allowance which is the main reason for obtaining scrap parts. For mirrored parts, if the material allowance is not disposed symmetrically, it will lead to not having enough material to be removed in order to satisfy the imposed technical conditions of the part [1], [6-11].

Therefore, within this paper the research was focused upon elaborating a method of probing the oversized symmetrical investment casting raw materials, involving probing the part on several surfaces of interest and using the measured data within specific equations.

Combining the calculus with the parametric CNC programming concludes with the automatic setup of the workpiece reference coordinate system and avoids as much as possible the human intervention which is predisposed to mistake [12] [13].

Several working parameters have been created and specific equations using them have been written, the walkthrough of the process is illustrated step by step within the next paragraphs.

2. Materials and methods

As stated, within this research, the focus has been laid upon developing an intelligent and automated system requesting minimal human intervention, required for the setup of the working position reference system. The approach was developed within the Siemens SINUMERIK 840D programming system using specific parameters, but the method can be extrapolated for other CNC programming systems, since most of them have the possibility of programming using parameters [14-16].

The particular case regarding the oversized investment casting parts is justified by the fact that this casting process is a very versatile manner of obtaining semifinished products of high complexity, remarkably close to the final shape and dimensions of the final part. Unfortunately, for oversized parts, the tolerances could reach up to ±5mm (according to the current standard in application – VDG P690), fact which has a high impact in the CNC programming and its optimization.

The procedure consists of the following steps: first of all, the single human-related activity requiring the operator to measure the whole length of the raw material, to reduce as much as possible the approaches and retracts of the probe.

The measurement within this step does not imply high accuracy, due to the fact that within the CNC probe programming, safety distances are already taken into account. Therefore, after the measuring of the length of the part, the operator is required to enter the value associated with the *GD[10]* parameter. Furthermore, all the calculus for the probing program will be done automatically, without any further human intervention.

The next step consists in the accurate measurement of the length of the raw material, through probing using the TP. On each lateral surface of the part (left and right) were disposed 4 points of measurement, furthermore, calculating the mean value of them, for increasing the accuracy of the process and to avoid possible errors corelated to the surface's particularities, as illustrated in figure 1

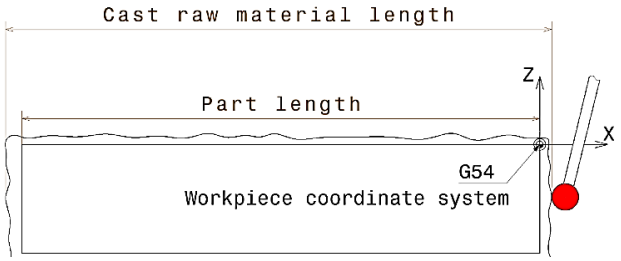

Figure 1. Probing on the right side of the raw material

The data acquired from the 4 probing points on the raw material are stored under parameters *GD[11]*, *GD[12]*, *GD[13]* and *GD[14]* and the mean value is automatically calculated under parameter *GD[15]*, as presented in figure 2.

```
G500
PROBE("X1",-250,0,0)
GD[11]=MC_P[0]
G0 Y1=0 Z1=100
PROBE("X1",-250,0,0)
GD[12]=MC_P[0]
G0 Y1=50 Z1=100
PROBE("X1",-250,0,0)
GD[13]=MC_P[0]
G0 Y1=50 Z1=150
PROBE("X1",-250,0,0)
GD[14]=MC_P[0]
GD[15]=(GD[11]+GD[12]+GD[13]+GD[14])/4
```

Figure 2. NC program elaborated for the right-side probing on 4 points on the raw material and calculus of the mean value

The same procedure is applied to the left-side probing, values associated to the parameters *GD[21]*, *GD[22]*, *GD[23]* and *GD[24]* and their mean value *GD[25]*. By subtracting *GD[15]* out of *GD[25]*, the real length of the raw material is obtained, value stocked under *GD[30]*, value further used for the setup of the coordinate system.

Having knowledge of the final length of the finished part, the following calculus can be done, by subtracting the part length from the raw material length and divided by 2, the real value of the material allowance is obtained, value stocked under *GD[40]*, as follow in figure 3, very useful in setting up the machining passes, approach and retract motions of the tool, therefore having a better command of the process. Setting up accurately the starting position relatively to the machining allowance is obviously reflected in optimized machining times and better productivity. This parameter will be further use for the setup of the workpiece coordinate system.

```
GD[40]=(GD[30]- *finished part length*)/2 ;* lateral allowance
```

Figure 3. Parametric calculus of the lateral machining allowance

Those steps are mandatory for assuring a symmetrical disposal of the material allowance, relative to the finished part, therefore, specific manufacturing problems are avoided, such as the incomplete machining of the surface due to the displacement of the part.

Finally, the X-axis of the G54 workpiece coordinate system is shifted within the selected position, as presented in figure 4.

```
MCZSHIFT(54,"X1","TR",-GD[40])
```

Figure 4. Shifting the X-axis workpiece coordinate reference system within the desired placement

Obviously, on the Y and Z axis, the same approach can be applied so that all the axes can be set up, fully controlling the position of the workpiece coordinate system and the further machining operations could carry on.

3. Conclusions

This smart approach has been validated through numerous tests, for different types of parts which satisfy the stated condition – having a symmetry line within it. The most important contribution developed in the research consists in the minimal human intervention in the process, the only step necessary to be done by the operator being measuring the length of the raw material and entering the value within the suitable field in the NC program. Most of the numeric values have been replaced with parametric ones, which are further used within several specific equations, having the final result of setting up the Workpiece coordinate reference system in the desired position.

For a better comprehension of each calculus within the NC program, several useful commentaries can be added, so that further optimization can be done easily.

The method is safe to use, reporting in case of the entering incorrect values of the raw material and could be easily applied within other NC programming systems, relevant applications could be pillow blocks used in conveyors, mining applications, pulp and paper mills, rolling mills, with special shaft sizes available up to 1000mm and beyond [17].

Another important contribution consists in the fact that the NC program can be easily linked to a spreadsheet-type file for relevant calculations of elaborate working parameters, such as roughing and finishing passes, specific approaches and retracts of the tool or other probing operations, further resulting automated development of NC program lines based on the specific particularities of the approached part.

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Seaside holiday preferences versus tourists' budgets. A multinominal logistic analysis

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Abstract Tourists' holiday budgets are generally a constraint to be taken into account when choosing destinations, influencing their actual preferences. Starting from this fact, based on a statistical survey, the paper analyzes the options of Romanian respondents regarding seaside holiday destinations in four countries (Bulgaria, Turkey, Greece and France) under the conditions of holiday budgets per person that, together with the gender of the respondents, describe their characteristics. A multinomial logistic regression model was used to evaluate the chances of tourists choosing certain destinations, as well as to determine the odds between them. The results obtained can constitute a source of information for tourism operators, in order to substantiate the offers for their target audience.
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Keywords: *seaside destinations, tourism, logistic regression, statistical analysis, SPSS*

1. Introduction

Holidays and vacations spent in different destinations, other than those of residence, once reserved only for the elite, and which have become increasingly accessible to everyone [Weiss et.al., 2024], constitute, on the one hand, important factors in ensuring a modern standard of living, with an impact on the quality of life of tourists, and on the other hand, factors in increasing local and regional incomes of entities that manage tourism [Olkiewicz, 2020; Scutariu, 2018].

Among the different forms of tourism, seaside tourism has a particular importance, by capitalizing on the natural resources of the destination, but which, however, presupposes the existence of an appropriate material base [Marian, 2020]. On the other hand, however, the increased development of seaside tourism brings, in addition to benefits, certain negative effects on both the environment and local communities. Among these are the continuous invasion of lands closer to the coast [Bal & Czalczynska-Podolska, 2020], as well as the negative effects on the lives of residents by increasing the intensity of the tourist flow [Bimonte & Agostino, 2021]. These effects require targeted strategies for the sustainable management of the region's natural and human resources, correlated with regional social and economic development. [Karametou et.al., 2024; Jugănaru, 2021; Goffi et.al., 2020].

Among the seaside destinations most frequented by Romanian tourists are Bulgaria, where the tourism industry has experienced unprecedented development [Costea et.al., 2016], favored by the importance of competitive prices of the seaside tourism product [Boteva, 2022], Turkey, where tourism plays an essential role in the economy [Zeydan et.al., 2025], Greece, where thermal and seaside resorts

are considered centers of urban sociability [Kostidi, 2019], as well as France, recognized for the attention paid to wine tourism but also for the French Riviera, densely frequented by tourists, and with adequate competitiveness policies [Longhi & Dang, 2009; Courteix & Zembri, 2015; Bénet et. Al., 2022].

An important way to analyze opinions on various aspects of seaside tourism, and beyond, is to survey both providers and tourists, with the aim of streamlining and adapting offers, as well as identifying demand characteristics. An important tool for this purpose is SPSS. Among the uses of SPSS in the statistical analysis of data from the tourism industry, we mention the identification of the opinions of visitors to rural areas in the Carpathian Mountains of Romania and the identification of distinct patterns in tourist preferences [Dobre et.al., 2024], the development of sustainable development models for seaside restaurants [Iamkovaia et.al., 2019], tourist destination management [Mehtab et.al., 2023], the perception of the local population and visitors regarding the development of tourism in the protected mountain area of the Fruška Gora National Park [Trišić et.al., 2022], the attitudes of local communities in western Serbia towards tourism development, with an emphasis on the potential for implementing community tourism [Surla et.al., 2025]

On the Romanian seaside tourism market, starting from the market offers, the choice of seaside holiday destinations is a relatively difficult process that confronts the preferences of individuals (determined, in turn, by their gender, age, level of education, etc.) with the budgets they have. Under these conditions, the paper analyzes, based on the data series obtained through a statistical survey, the respondents' options regarding seaside holiday destinations in Bulgaria, Greece, Turkey and France, depending on their gender and the budget per person available for the holiday.

2. Research methodology

Starting from the research objective, three variables were used in the analyses performed (Table 1). Of these, the dichotomous variable GEN and the multinominal variable BUGET are independent variables, and the multinominal variable DSTLIT is the dependent variable.

Table 1. Variable identifiers, meanings, types, and values

Identifier	Meaning	Type	Values
GEN	Gender of respondents	Nominal, input	0 - Female 1 - Male
BUGET	The individual budget allocated for the holiday	Nominal, input	1 – Under 500 EUR 2 – 501-1000 EUR 3 – 1001-1500 EUR 4 – More than 1500 EUR
DSTLIT	Seaside holiday destination	Nominal, output	1 – Bulgaria 2 – Greece 3 – Turkey 4 – France

Taking into account the fact that simple non-repeated selection was used in the sample formation, the following relationship was used to determine the sample size (n) (Biji and Biji, 1979):

$$n = \frac{t^2 \cdot \sigma_0^2}{\Delta_x^2 + \frac{t^2 \cdot \sigma_0^2}{N}} \quad . \tag{1}$$

In relations (1) the meanings of the variables are:

N – the volume of the general population (total number of tourists);
σ_0 – standard deviation determined at the general population level;
t – probability factor (t=1,1645);
Δ_0 – acceptable error limit for non-alternative characteristic.

For determining the sample volume, the accepted error limit was 5% (Δ_0=0,05). Taking into account that the volume of the general population (the potential number of tourists) is very large, instead of relation (1) the relation (2) can be used, in which instead of the standard deviation determined at the level of the general population (σ0) the standard deviation in the sample was used (S_0=1.13).

$$n = \frac{t^2 \cdot S_0^2}{\Delta_x^2}. \quad (2)$$

A minimum sample size of n=693 respondents resulted. Consequently, a sample of 700 respondents was used. To identify the influence of the GEN and BUGET variables on the dependent variable DSTLIT, a logistic regression model was used, of the form:

$$P(Y = 1|X_1, X_2, X_3, .., X_k) = \frac{e^{(\beta_0+\beta_1 X_1+\beta_2 X_2+\cdots+\beta_p X_p)}}{1-e^{(\beta_0+\beta_1 X_1+\beta_2 X_2+\cdots+\beta_p X_p)}} \quad (3)$$

In (3), P is the probability of the occurrence of event Y (corresponding to the dependent variable), depending on the p independent variables (p≥2) X. Starting from this, the chance (*oddj*) of the occurrence of event *j*, whose probability is given by relation (3), is:

$$\ln(\text{odd}_j) = \alpha + \sum_{k=1}^{p} \beta_k \cdot X_k$$
$$\text{odd}_j = e^{\alpha + \sum_{k=1}^{p} \beta_k \cdot X_k}; \quad j=\overline{1,r-1} \quad (4).$$

In (3) and (4), α and β_k, $k = (\overline{1,p})$ are the coefficients of the logistic regression models.

Finally, given the values of the chance of producing event j, the coefficient of chance of producing event *j* (ORj), relative to a base event, is:

$$OR_j = \frac{odd_j}{odd_{baza}} \quad (5).$$

To test the statistical significance (validity) of the obtained multinomial regression model, the following tests were used:

Model Fitting Information, with the hypotheses:

H_{1_0}: introducing a variable into the model does not bring additional information;

H_{1_1}: introducing a variable into the model brings additional information.

Likelihood Ratio Test, with the hypotheses:

H_{2_0}: the model parameters do not differ significantly from zero (are insignificant);

H_{2_1}: the model parameters differ significantly from zero (are statistically significant).

To test the statistical significance of the values of the coefficients of the logistic regression model, the following hypotheses were used:

H_{3_0}: the coefficient value does not differ significantly from zero (it is insignificant);

H_{3_1}: the coefficient value does not differ significantly from zero (it is statistically significant).

The confidence level for accepting the null hypotheses (H_{1_0}, H_{2_0}, and H_{3_0}) was 95%, corresponding to the significance threshold α=0.05. Exceptionally, a confidence level of 90% was also used. Data processing was performed using SPSS.

3. Results and Discussion

In a first phase of data processing, the survey on respondents' opinions on choosing their seaside destinations according to the available budget allocated for the vacation, the structure of their responses was analyzed according to gender, as well as according to each person's available budget.

By gender (Figure 1), out of the total of 700 respondents, 376 respondents (53.72%) are female, 324 respondents (46.29%) are male. In terms of seaside destinations, most respondents, 257 people (36.71%), opted for seaside destinations in Turkey. Of these, 135 respondents (52.53%) are female, and 122 respondents (47.47%) are male. In second place in terms of the number of options were seaside destinations in Bulgaria, in total, 242 respondents (34.57%), of which 132 respondents (54.56%) are female and 110 respondents (45.45%) are male.

For the seaside destinations in Greece and France, the weightings of the options were relatively lower. Thus, 105 respondents (15.0%) opted for the seaside destinations in France, of which 57 respondents (54.29%) are female, and 48 respondents (45.71%) are male. Finally, 96 respondents (13.71%) opted for the seaside destinations in Greece. Of these, 52 respondents (54.71%) are female, and 44 respondents (45.83%) are male.

Analyzing the gender structure of respondents' choices regarding seaside destinations, it results that their weights are relatively close to the gender structure of the sample, the differences highlighting that female respondent opted to a greater extent for seaside destinations in Bulgaria, France and Greece, while male respondents opted to a greater extent for seaside destinations in Turkey.

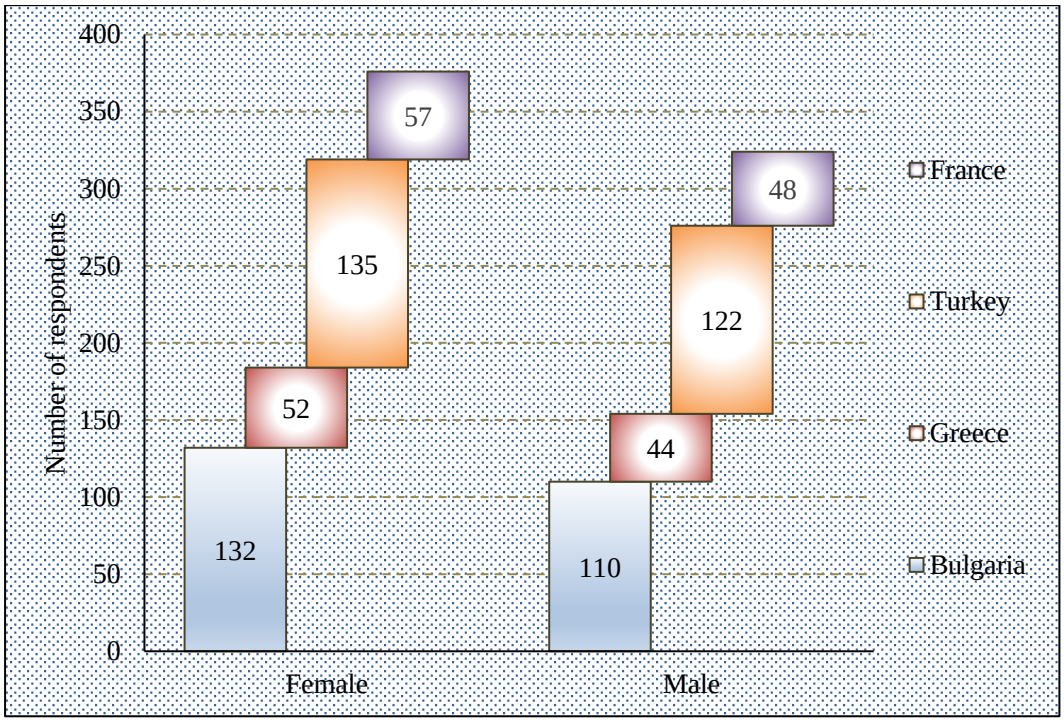

Figure 1 Structure of respondents' opinions by gender regarding seaside destinations
Source: drown up by the author based on the DSTLIT and GEN data series.

The structure of respondents' opinions on seaside destinations according to the budget allocated for the holiday (Figure 2) highlights that, of the 700 respondents, 144 respondents (20.57%) have holiday budgets under 500 EUR per person, 256 respondents (36.57%) have budgets per person between 501 and 1000 EUR, 168 respondents (24.0%) have holiday budgets per person between 1001 and 1500 EUR, and 132 respondents (18.86%) have holiday budgets per person of more than 1500 EUR..

In terms of seaside destinations, the most, 257 respondents (36.72%) opted for Turkey. Of these, 45 respondents (17.51%) have budgets under 500 EUR, 119 respondents (46.30%) have budgets between 501 and 1000 EUR, 52 respondents (20.23%) have budgets between 1001 and 1500 EUR, and 41 respondents (15.96%) have budgets of more than 1500 EUR.

A second preferred country as a seaside destination is Bulgaria, chosen by 242 respondents, representing 34.57% of the total. By budget group allocated per person, 90 respondents (37.19%) have budgets under 500 EUR, 98 respondents (40.50%) have budgets between 501 and 1000 EUR, 37 respondents (15.29%) have budgets between 1001 and 1500 EUR, while only 17 respondents (7.02%) have budgets of more than 1500 EUR.

For seaside destinations in Greece, of the 96 respondents (13.71%) who opted for this destination, depending on the budget allocated per person, the distribution of respondents was: in the budget group under 500 EUR, 8 respondents (8.33%); in the budget group 501-1000 EUR, 20 respondents (20.83%); in the budget group 1001-1500 EUR, 46 respondents (47.92%); in the budget group more than 1500 EUR, 22 respondents (22.92%).

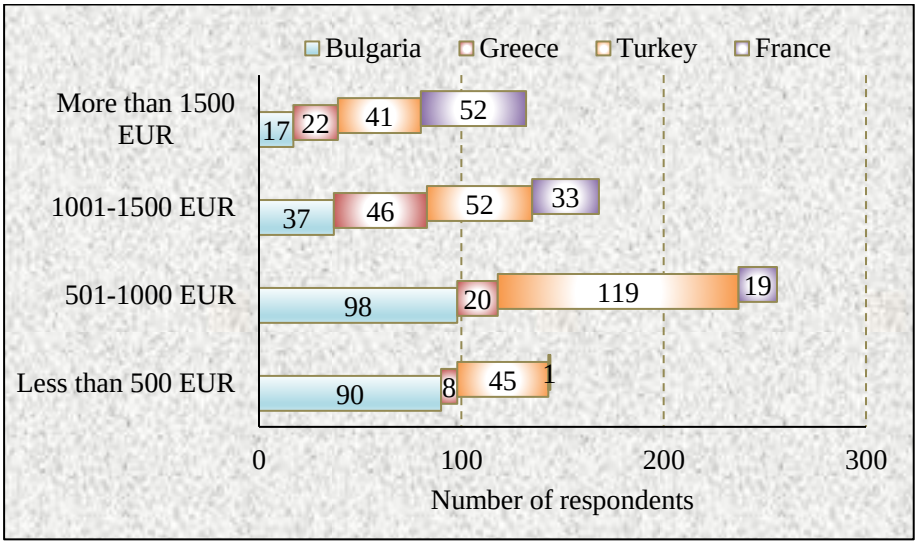

Figure 2 Structure of respondents' opinions according to the budget allocated per person
Source: drown up by the author based on the DSTLIT and BUGET data series

The choices for seaside destinations in France belonged, in particular, to respondents with a holiday budget per person of more than 1500 EUR, respectively 52 respondents (49.52%). They are followed by those with holiday budgets per person between 1001 and 1500 EUR, respectively 33 respondents (31.43%), as well as those with holiday budgets per person between 501 and 1000 EUR, respectively 19 respondents (18.10%). As for respondents with holiday budgets per person less than 500 EUR, only one answer was recorded, the share of this category of respondents being negligible (0.96%).

From the analysis of the results obtained so far, it results that for respondents with holiday budgets between 501 and 1000 EUR the main seaside destinations are in Turkey and Bulgaria, and for those with holiday budgets between 1001 and 1500 EUR the main seaside destinations are in Bulgaria, male respondents being more interested in seaside destinations in Turkey, while female respondents prefer, depending on budget, Bulgaria, Greece and France.

In the second phase of the research carried out, in order to identify the chances that a certain type of tourist will choose, depending on gender and budget, a certain seaside destination, as well as to identify the chance rates between them, regarding the holiday destinations, a multinominal logistic regression model of the form was used:

$$ln\left(odd_{DSTLIT\,j}\right) = \propto_{IDSTLIT\,j} + \sum_{k=1}^{2} B_k \cdot X_k\,;\; j = \overline{14} \qquad (6)$$

In (6) X_1=GEN and X_2=BUGET.

To test the existence of additional information obtained by using model (6) when evaluating the influence of respondents' characteristics on their opinions regarding seaside holiday destinations, the Model Fitting Information test was used (Table 2). Given that the value of the parameter Sig=0.000<α=0.05 results in the rejection of the null hypothesis H_{1_0} and the acceptance of the alternative hypothesis H_{1_1}. Consequently, by introducing the variables GEN and BUDET into model (6), additional information can be brought into the analysis performed.

Table 2 The result of the Model Fitting Information test for model (6)

	Model Fitting Criteria			Likelihood Ratio Tests		
Model	AIC	BIC	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	206.422	222.098	200.422			
Final	146.363	224.745	116.363	84.059	12	0.000

Source: prepared by the author using SPSS

Also, the Likelihood Ratio Test results (Table 3) regarding the parameters of the model (6), through the parameter values Sig=0.034<α=0.05, for the GEN variable and Sig=0.000<α=0.05, for the BUGET variable, lead to the rejection of the null hypothesis H_{2_0} and the acceptance of the alternative hypothesis H_{2_1}. Consequently, the model parameters differ significantly from zero (are statistically significant).

Table 3. The results of the Likelihood Ratio Test for model (6)

Effect	Model Fitting Criteria			Likelihood Ratio Tests		
	AIC of Reduced Model	BIC of Reduced Model	-2 Log Likelihood of Reduced Model	Chi-Square	df	Sig.
Intercept	146.363	224.745	116.363	0.000	0	
GEN	149.010	211.716	125.010	8.647	3	0.034
BUGAL	205.979	237.332	193.979	77.616	9	0.000

Source: prepared by the author using SPSS

The estimated coefficient values of the multinomial logistic model (6), as well as their characteristics, are presented in Table 4. Given that the parameter values Sig=0.815, for GEN=0 (Female) from the destination Bulgaria, Sig=0.114, for BUGET=3 (1001-1500 EUR), from the destination Greece and Sig=0.179, for BUGET=1 (less than 500 EUR), are higher than the significance threshold α=0.05, it follows that the null hypothesis H_{3_0} is accepted for them (the coefficient values do not differ significantly from zero, being statistically insignificant) and, consequently, they were not taken into account in the analysis performed, as well as in the formulation of the conclusions.

In the case of the other coefficients, for which the parameter values Sig<α=0.05, as well as for BUGET=3 (1001-1500 EUR) from the destination Bulgaria, for which, exceptionally, a confidence level of 90% (α=0.10) was accepted, the null hypothesis H_{3_0} is rejected and the alternative hypothesis H_{3_1} is accepted. The coefficient values are statistically significant

Taking into account the statistically significant values of the coefficients of the multinomial logistic regression model (6), the odds values of choosing seaside holiday destinations (DSTLIT) were determined. For example, for the destination Greece, for female respondents and with seaside holiday budgets per person less than 500 EUR, as well as with budgets between 501 and 1000 EUR, the odds values are:

$$\text{odd}_{\text{Greece}}(\text{GEN}=0, \text{BUGET}=1)=e^{1.087+0.403+2.325} = e^{3.81} = 45.36$$
$$\text{odd}_{\text{Greece}}(\text{GEN}=0, \text{BUGET}=2)=e^{1.087+0.403+2.237} = e^{3.73} = 41.56$$

Similarly, for male respondents, and under the same conditions regarding the budget allocated for the vacation, the chance values are:

$$\text{odd}_{\text{Greece}}(\text{GEN}=0, \text{BUGET}=1)=e^{1.087+0+2.325} = e^{3.41} = 30.31$$
$$\text{odd}_{\text{Greece}}(\text{GEN}=0, \text{BUGET}=2)=e^{1.087+0+2.237} = e^{3.32} = 27.77$$

The odds values corresponding to all destinations, for which the coefficient values are statistically significant, are presented in Table 5. The analysis of the values shows that the highest chance of choosing seaside destinations in Bulgaria is for male respondents, with holiday budgets per person below EUR 500 (odd=116.03).

Table 4. Estimated values of model parameters (6)

DESTIN[a]		B	Wald	df	Sig.	Exp(B)
BULGARIA	Intercept	1.506	7.363	1	0.007	
	[GEN=0]	0.139	0.054	1	0.815	1.149
	[GEN=1]	0[b]		0		
	[BUGAL=1]	3.248	8.390	1	0.004	25.727
	[BUGAL=2]	1.589	11.448	1	0.001	13.313
	[BUGAL=3]	1.413	3.355	1	0.067	4.109
	[BUGAL=4]	0[b]		0		
GREECE	Intercept	1.087	3.611	1	0.057	
	[GEN=0]	0.403	4.431	1	0.035	1.497
	[GEN=1]	0[b]		0		
	[BUGAL=1]	2.325	4.193	1	0.041	10.225
	[BUGAL=2]	2.237	6.851	1	0.009	7.671
	[BUGAL=3]	1.244	2.501	1	0.114	3.469
	[BUGAL=4]	0[b]		0		
TURKEY	Intercept	2.925	31.174	1	0.000	
	[GEN=0]	-0.121	3.904	1	0.048	1.665
	[GEN=1]	0[b]		0		
	[BUGAL=1]	1.486	1.802	1	0.179	4.418
	[BUGAL=2]	1.640	4.310	1	0.038	4.663
	[BUGAL=3]	0.882	4.012	1	0.045	2.416
	[BUGAL=4]	0[b]		0		
a. The reference category is: France.						
b. This parameter is set to zero because it is redundant.						

Source: prepared by the author using SPSS

For seaside destinations in Greece, the highest chance of choosing is for female respondents, with holiday budgets per person less than 500 EUR (odd=45.36), followed very closely by female respondents, but with a holiday budget per person between 501 and 1000 EUR (odd=41.56).

For seaside destinations in Turkey, male respondents have the highest chance of choosing, with a holiday budget per person between 501 and 1000 EUR (odd=96.07), followed by female respondents in the same budget class (odd=85.12).

In terms of budgets, for those with a per person holiday budget of less than 500 EUR, the most likely destination is Bulgaria. For those with a per person holiday budget between 501 and 1000 EUR, as well as between 1001 and 1500 EUR, the most likely destination is Turkey, in both cases it belongs to the male population.

Table 5 Odds of choosing a specific destination (reference category France)

DSTLIN	Bulgaria	Greece		Turkey	
GEN	Male	Female	Male	Female	Male
BUGET=1 (Less than 500 EUR)	116.03	45.36	30.31	-	-
BUGET=2 (501-1000 EUR)	22.09	41.56	27.77	85.12	96.07
BUGET=3 (1001-1500 EUR)	18.53	-	-	39.91	45.05
BUGET=4 (More than 1500 EUR)	4.51	4.44	2.96	16.52	18.64

Source: prepared by the author

Based on the values of the odds of choosing destinations according to the two characteristics of the respondents (gender and holiday budget per person), the odds ratios (OR) of choosing one destination relative to another were determined. For example, the odds ratio of choosing Bulgaria relative to Greece for a male respondent with a holiday budget less than 500 EUR is:

$$OR_{\frac{Bulgaria}{Greece},[BUGET=1]} = \frac{odd_{Bulgaria,[BUGET=1]}}{odd_{Greece,[BUGE=1]}} = \frac{116.03}{30,31} = 3.83$$

This means that the chance rate for a male respondent, with a holiday budget less than 500 EUR, to choose seaside destinations in Bulgaria is 3.83 times higher than to choose seaside destinations in Greece.

The values of the odds ratios for male respondents to choose seaside destinations in Bulgaria, Greece or Turkey, in relation to the other destinations, by holiday budget levels, as well as taking into account the statistical significance conditions of the coefficient values of the logistic regression model used, are presented in Table 6. For holiday budgets per person less than EUR 500, the destination with the highest chances of being chosen in relation to the others is Bulgaria, while for higher holiday budgets per person, the chances of being chosen lean towards Greece, as well as towards Turkey.

Table 6 Odds ratios (OR) of choosing a seaside destination, relative to other destinations, for male respondents, by allocated budget groups

Chance rate of choosing:		Bulgaria		Greece		Turkey	
in relation to:		Greece	Turkey	Bulgaria	Turkey	Bulgari	Greece
BUGET	Less than 500 EUR	3.83	-	0.26	-	0.71	-
	501-1000 EUR	0.80	0.23	1.26	0.29	4.35	3.46
	1001-1500 EUR	-	0.41	-	0.23	2.43	-
	More than 1500 EUR	1.52	0.24	0.66	0.16	4.13	6.29

Source: prepared by the author

Similar to those presented above, for female respondents, compared to male respondents, the odds of choosing a seaside vacation destination, regardless of budget group, are:

$$OR_{\frac{Female}{Male},Greece} = \frac{odd_{Female,Greece}}{odd_{Male,Greece}} = \frac{41.56}{27.77} = 1.49$$

$$OR_{\frac{Female}{Male},Turkey} = \frac{odd_{Female,Turkey}}{odd_{Male,Turkey}} = \frac{85.12}{96.07} = 0.88$$

These values highlight the fact that female respondents opt to a greater extent for seaside holiday destinations in Greece than male respondents (1.49 times), while, for seaside holiday destinations in Turkey, female respondents opt to a lesser extent than male respondents (OR=0.88), which means that the chance rate of male respondents, in relation to female respondents, to choose destinations in Turkey is 1/0.88=1.12 times higher.

3. Conclusions

Choosing holiday destinations is a rather complex process that involves identifying a solution that depends, on the one hand, on the preferences of individuals, which in turn depend on characteristics such as gender, age, income, level of education, etc., and on the other hand, on the available budget that can be used for this purpose.

Starting from these aspects, the analysis carried out aimed to identify the options of potential tourists regarding seaside holiday destinations taking into account the gender and the budget per person available for the holiday. The analysis was based on the data series obtained following a statistical survey on a representative sample of 700 people, clients of some travel agencies.

The preliminary analyses, presented in the first part of the paper, highlight the fact that of the four destinations (Bulgaria, Greece, Turkey and France) the most frequented were Turkey, for those with budgets more than EUR 500 per person, Bulgaria, for those with budgets less than EUR 500 per person, Greece, for those with budgets of EUR 1001-1500 per person, and France for those with budgets over EUR 1500 per person.

To obtain additional information on the chances of choosing a certain destination depending on the gender and the budget per person allocated by the respondents, a multinomial ordinal regression model was used, the confidence level of the results obtained being 95%.

From the analysis of the results, it follows that, in the case of holiday budgets per person less than 500 EUR, the highest chance rate of being chosen is the destination Bulgaria, while for holiday budgets between 501 and 1000 EUR per person, the chance rate of choosing seaside holiday destinations in Turkey is 4.35 times higher than choosing Bulgaria, and 3.46 times higher than choosing holiday destinations in Greece. Under the same conditions, the chance rate of choosing seaside holiday destinations in Greece is 1.26 times higher than choosing destinations in Bulgaria.

For the budget group 1001-1500 EUR, the chance rate of choosing Turkey as a seaside holiday destination is 2.43 times higher than choosing Bulgaria, and for the budget group more than 1500 EUR per person, the chance rates of choosing Turkey are 6.29 times higher than choosing destinations in Greece, and 4.13 times higher than choosing destinations in Bulgaria.

In terms of the gender of potential tourists, the chance rate of choosing Greece as a seaside holiday destination is 1.49 times higher for female tourists than for male tourists. On the other hand, the chance rate of choosing Turkey as a seaside holiday destination is 1.12 times higher for male tourists than for female tourists.

We believe that the results obtained in the analyses carried out can be used by tourism operators to substantiate their supply for seaside holidays destinations, depending on the characteristics of the target population, in terms of the budgets per person allocated and the gender of potential tourists.

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Environmental education on the European Green Deal. Implications and promotion of the concept through different channels in Romania

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Abstract. There is a visible urgent need to move from a linear economy to a circular economy in order to meet the requirements of the European Green Deal agenda. Recently, Romania implemented the DSR, getting in line with other countries that have had this system for many years. Therefore, the implementation of the Green Deal should also be focused on the promotion of the concept, how the information arrives at the citizens, how people are educated in schools and high schools regarding sustainability, etc. Focusing on the topic, this article aims to investigate the level of environmental education held by Romanians regarding the European Green Deal. This study was exploratory market survey research based on a questionnaire, focusing only on Romanian citizens who are living in Romania. Therefore, a quantitative research design was used on a sample of 111 Romanians and the results show that the respondents are satisfied with the DSR in Romania. In addition, it was found a strong positive correlation between the respondents' environmental education gained through different channels or methods from the private and public sectors and their behavior regarding sustainability. In the end, it was found that there was a statistically significant difference between the people who already knew what the Green Deal meant and the people who didn't when it came to their sustainability behavior. So, in conclusion, people who already knew what the Green Deal meant showed a more sustainable behavior. The results suggest the importance of boosting the promotion of the European Green Deal, sustainability, circular economy, and so on, reaching more people, thus creating a more powerful educational system in this direction. The paper could serve as well as a starting point for future academic research and for private entities and Romanian public institutions and authorities to strengthen collaboration and create more common projects on sustainability.

Keywords: *European Green Deal, Circular Economy, sustainability, environmental education, Romanian citizens*.

Introduction

The European Green Deal is becoming more and more crucial, being the most important project that supports sustainability and has the role of changing the world we live in. Broadly speaking, it aims to reach zero net emissions of greenhouse gases by 2050, economic growth to be dissociated from the use of resources, and no person and no place to be left behind. But the Green Deal is also about the energy, food, agriculture, smart buildings, and how we live and behave. More than this, it is an

instrument focused on infrastructure development through different measures that encourage the adoption of a circular economy, strengthening strategic economic growth, setting at the same time the foundation for a financial future for sustainable development projects (Smol et al., 2020).

Sustainability and environmental protection are no longer a novelty and the specialized literature is showing exactly the same thing, as there are many studies focused on Green Deal, principles of sustainability (Ridsdale and Noble, 2016; Jankal and Jankalova, 2020; Versteijlen and Wals, 2023), CSR practices (Gligor-Cimpoieru et al., 2017; Menne, 2017; Schoeneborn, Morsing and Crane, 2020; Chwiłkowska-Kubala et al., 2021), recycling (Fu and Sun, 2023; Xiao et al., 2023; Kobayashi, Kondo and Sasaki, 2024) and so on.

Based on the evolution of our society, world and natural habitat, environmental education is essential in schools, universities, and in other institutions, helping people to understand, behave and apply sustainability practices. Nowadays, there are a lot of sustainable projects, recycling concepts and specialized institutions that aim to help the citizens and society and to create a better place for living for everyone. In this context, many articles are focused on the circular economy, being the powerful weapon in the implementation and development of the Green Deal, so Ignjatović, Filipović and Radovanović (2024), research in their paper "the necessity for the green transition and the key preconditions for the implementation of a circular economy in Western Balkan countries".

On top of all of these, Gajović et al. (2023), presented in their paper the importance that youth are playing in the implementation and development of the circular economy and the Green Deal, discovering that they don't possess eco-friendly practices, along with proper education on sustainability issues.

Although the specialized literature has a lot of articles regarding the Green Deal, there weren't studies that focused specifically on Romania, but only on any other countries or in general speaking, when it comes to environmental education on the Green Deal. Therefore, through this research, the author aims to investigate if and how the European Green Deal is promoted in Romania from private and public sources, focusing on the level of Romanian people's education when it comes to sustainability and environmental protection. This research highlights the people's education level, focusing only on one country, Romania.

The paper is divided into five chapters, beginning with the introduction, moving to a review of the scientific literature, and outlining the research methodology and results. Finally, the conclusions are presented in the last chapter.

1. Review of the scientific literature

1.1 General Overview

The constant decrease of the non-regenerative resources at the global level and the continuous increase in the worldwide population force people, communities and countries to find new methods of consumption and production, therefore, from social, economic and environmental points of view, a change from a linear to a circular economy would have a good impact (Orțan et al., 2016).

In the scientific literature are a lot of articles about the Green Deal that refer to its requirements, methods of implementation, vehicles, how to change the regulations, energy industry, agriculture, and so on. For the European Green Deal to be as legitimate as it needs to be, Colli (2011) considers that it is mandatory to include everyday individuals in its requirements about climate change and execution. Tsoutsos (2020) believes that the reaction to the Green Deal would be much more positive and easier if people would understand how the project positively impacts them concerning improving their own lives and residential surroundings. More than that, people must be updated, informed and given the chance to participate in decision making when it comes to the Green Deal trough different methods and means.

On the other hand, Zotti (2022) wanted to see how education can help to reach the European Green Deal requirements. Therefore, he focused on the European Union's approach regarding sustainability

and environmental education and also presented the initiatives which are to regulate and support the education system for the Member countries (Zotti, 2022).

Ciot (2022) conducted a study that aims to identify the most important factors which affect the capacity building for the implementation of the European Green Deal in Poland, Czech Republic, Slovakia, Hungary and Romania. The findings of the research show four different categories of factors and these are: cultural, political, economic and social. It also reveals that the expectations for the Green Deal's implementation in all of the above-mentioned countries are negative (Ciot, 2022).

The linear economy has consequences that lead many societal actors to adopt significant sustainable initiatives to move to the circular economy model (de Mattos and de Albuquerque, 2018)**,** but it is important to take into consideration that Kirchherr, Reike and Hekkert (2017) said that the circular economy concept is still ambiguous, the authors identifying over a hundred definitions.

In the conclusions of the UN Climate Change Conference 2021, also known as COP26 (Conference of Parties), the ministers admit that education plays a crucial role in the transition to a more sustainable environment and sustainable life, and they decided to collaborate and invest in the educational system by also integrating climate change and sustainability in all levels of education (Zotti, 2022).

Krajnc et al. (2022), studied young people's awareness and attitudes toward the circular economy and Green Deal, finding that they trust in the principles and importance of the circular economy, but they don't receive the needed support to cooperate and implement the concept and practices actively. Krajnc et al. (2022) found in their paper, that formal education doesn't deliver enough knowledge to be able to participate in this area and the youths mostly don't understand exactly the principles of circular economy. When it comes to entrepreneurship skills, the majority of people are not capable of developing, designing or creating any new business solution (Krajnc et al., 2022).

The protection of our natural environment has become a key aspect of society and public awareness of the circular economy is increasing, leading to an extremely social and technical innovation power (Krajnc et al., 2022). Therefore younger people are more familiar with the model of circular economy, adopting some behaviors like waste separation and purchase or use of recycled or reused goods (Krajnc et al., 2022). Although, according to Soukiazis and Proença (2020), the older generations are also positively contributing to protecting the environment or recycling goods, Romano, Rapposelli and Marrucci (2019), consider that the older generations cannot actively participate in the recycling process, being more difficult for them to separate and recycle waste because of their health issues or their limited physical capabilities.

Hadjichambis et al. (2020), consider that environmental education is highly focused on natural science, while economic and social issues, citizenship or environmental justice side are only a little bit included in the environmental education plan, or not at all. In addition, it remains totally unclear how environmental citizenship is developed in schools or universities so that it promotes sustainability, innovation, growth and green entrepreneurship (Hadjichambis, 2022).

Lastly, Picuno et al. (2025), wanted to see which is the potential of Deposit Refund Systems (DRS) for beverage bottles, saying that the first country in Europe to adopt the DRS for PET bottles was Iceland in 1989, followed by Germany and Sweden in 1991, Norway in 1997 and other nations like Denmark in 2002, the Netherlands in 2005, Estonia in 2005, Croatia in 2006, Finland in 2008, Lithuania in 2016 and Slovakia in 2022. They also found that the success of DRS depends on the deposit value that people need to pay per bottle, the number of return locations, or the proportion of these locations to citizens, and finally, the people's consciousness and motivation to achieve a high return rate (Picuno et al., 2025). Finally, the results indicate a higher return rate in Germany due to the high price of deposit per bottle and the bigger number of return points per population, presenting, in contrast, the situation for Norway and Estonia, where, with lower deposit values for a bottle, they showed a smaller and diverse return rate, pointing to Norway as an interesting case because of the large number of returning points in relation to population (Picuno et al., 2025).

1.2 Romania overview

Lakatos et al. (2016) wrote an article that aimed to investigate Romanian consumer behavior regarding the environment and the adoption of new designs of behavior and sustainable consumption in the development of a circular economy. The results of Lakatos et al. (2016) research show that consumers have a positive perspective regarding the importance of environmental conservation in general, but the consumption behavior is not really in harmony with the general perspective regarding the environment. Lakatos et al. (2016) concluded that the circular economy business models in Romania need a strategy at the national level, which is mandatory to include measures to sustain the adoption of required new consumption behaviors, apart from educational campaigns and awareness increase for explaining to consumers the connection and the effect of their behavior to the environment and economy.

Following Europe's 2020 Strategy (European Environment Agency, 2016), by 2020, Romania has to recycle 50% of its waste, but, unfortunately, in 2016 it recycles only 3% of its municipal waste, occupying the last place in the European Union.

At the literature level, there are a lot of studies regarding Romania and the Green Deal, its implementation, challenges, sustainable practices, what was done and what not, and so on. Therefore, Ciot (2021) considers that in the period of rotating Presidency of the Council of European Union, Romania has supported the advancement of the European Union's agenda on decarbonization and the implementation of the Paris Agreement, sustainable growth, and the promotion of sustainability.

Popescu et al. (2022) researched the hotel industry in Cluj-Napoca based on the fact that it is a big polluting element for the environment even though it is not clearly presented in the Green Deal agenda, and they discovered that the employees are mostly unfamiliar with the requirements of Green Deal.

Tanţău and Şanta (2019), decided to research in their paper the chances and challenges faced by Romania in the energy sector, focusing on the best practices for a sustainable energy industry at the European Union level, while Gradinaru et al. (2023) determined "if and how equity has become a concern in the strategic planning of green infrastructure, and whether strategic plans are indeed relevant in responding to vulnerable groups' needs."

For the idea of moving to a greener country, sustaining the implementation of the Green Deal, circular economy and becoming more sustainable, the state authorities together with some private entities established the Sustainability Embassy in Romania in 2018. Through complementary programs, the Sustainability Embassy in Romania develops the framework for collaboration between state institutions, private companies, communities and citizens involved, with the purpose that Romanians could live in a fair, prosperous and healthy environment.

This organization is funded by Kaufland Romania, Lidl Romania, and CEC Bank, having as partners the Government of Romania through the Department for Sustainable Development and over 160 organizations, under the program The Sustainable Romania Coalition.

Some of the programs of The Sustainability Embassy in Romania are: Sustainability School, Business for the Future, Sustainability Ambassadors, Sustainability Talks, Special Projects, Sustainability toolkit and many others. The objective of all these programs is to encourage, maintain and develop collaboration between private and public entities, joining forces to be able to achieve and implement the requirements of the Green Deal at the national and European level. They have also collaborations with media partners trying to inform and educate also Romanian citizens about sustainability and how to adopt a more sustainable behavior.

Another project developed and recently implemented in Romania is the SGR system, known at the international level as the Deposit Refund System (DSR), from RetuRO which is a company founded by a group of private and public shareholders. The mission of this company is to implement the biggest project of circular economy in Romania which is based on recycling plastic, glass and metal bottles.

Table no. 1. Percentage of DSR packaging returned in 2024

Plastic	Metal	Glass
39.61%	36.47%	35.38%

Source: returosgr.ro, 2024

Starting from the beginning of 2024 and until 01.08.2024, Romania registered a return rate of 39.61% when it comes to plastic bottles, 36.47% metal bottles and 35.38% when it comes to glass bottles. These percentages can be translated into pcs and kilograms according to Table no.2

Table no. 2. Quantity of DSR packaging returned in 2024.

Plastic		Metal		Glass	
Pcs	Kg	Pcs	Kg	Pcs	Kg
770,737,630	26,281,122	318,912,857	4,532,241	246,952,334	60,003,904

Source: returosgr.ro, 2024

This company is also always updating its website and working methods, adding new ways of working, thus streamlining the processes and activities between the economic operators and all the entities involved in this chain.

2. Research Methodology

The presented study was an exploratory market survey research based on a questionnaire and had a quantitative research design at the base. The primary objective of it is to investigate the Romanian people's level of environmental education. To be able to reach this goal, the following objectives were also formulated:

O1: To determine the Romanians' perception regarding the SGR system and how satisfied are with it.
O2: a. To check if there is any correlation between the respondents' environmental education gained from the private sector and their behavior about sustainability
O2: b. To check if there is any correlation between the respondents' environmental education gained from the public sector and their behavior about sustainability
O3: To assess if there is any difference when it comes to the environmental behavior between people who already know and those who don't know what the European Green Deal means.
H1: Romanians hold positive attitudes towards the SGR system and they are satisfied with it.
H2: a. There is a positive correlation between the respondents' environmental education gained from the private sector and their behavior about sustainability
H2: b. There is a positive correlation between the respondents' environmental education gained from the public sector and their behavior about sustainability
H3: People who already know what the European Green Deal means tend to have a more sustainable behavior.

The research was done using an online survey, which was administered only to Romanian citizens who are living in Romania via email and social media, concluding with 111 valid responses. Also, the snowball method was used in order to reach a higher number of answers. The involvement in this study was completely voluntary and promised anonymity. The questionnaire was the data collection instrument and it was divided into three sections. The first section was dedicated to the socio-demographic characteristics. The second one was composed of multi-item measures on a six-point Likert scale (from 1 totally disagree to 6 totally agree), collecting information regarding the impact of the European Green Deal promotion by the private and public sector, evaluating as well, the Romanians' behavior after the interaction with one of the advertisements. The third section had three questions and focused on the warranty-return system existing in Romania.

The structure and information about the sample are presented in Table no. 3. The majority of the respondents have a higher education, 62,2% have a Master's degree and 27% have a Bachelor's

degree, while only 8,1% have only a high school finished. Most of the respondents were female (60,4%) and 84,7% were employed. When it comes to age, most of them (42,3%) are between 25-34 years old, 27% being under 25 years old and only 1,8% are between 55-65 years old.

Table no. 3. Socio-demographic characteristics of the respondents

Characteristics		**Respondents (N = 111)**	**Percent**
Education	High School	9	8,1
	Bachelor's degree	30	27
	Master's degree	69	62,2
	PhD	3	2,7
Gendeer	Male	44	39,6
	Female	67	60,4
Ocupation	Employee	94	84,7
	Entrepreneur	10	9,0
	Self employed	5	4,5
	Unemployed	1	0,9
	Pensioner	1	0,9
Age	Under 25 years	30	27,0
	25-34 years	47	42,3
	35-44 years	17	15,3
	45-54 years	15	13,5
	55-65 years	2	1,8

Source: Processed by the authors based on research results

Data were collected over September 2024 and were analyzed using SPSS (Statistical Package for the Social Sciences).

3. Results and discussion

A One-Sample T-test was run to identify the satisfaction level of Romanians about the DSR, using a level of satisfaction >3. According to Table no. 4, the p-value (0.000) was lower than 0.01 (2-tailed), indicating a high statistical significance. Testing the result vs. hypothesis H1, (t=9.588), for 110 degrees of freedom indicates a significant difference in the sample mean (Mean=4.2252) from the tested value (respectively 3), concluding with the acceptance of hypothesis H1, showing that Romanians are satisfied with the DSR.

Table no. 4. One-Sample Test

			Test Value = 3					
	Mean	Std. Deviation	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
							Lower	Upper
How satisfied are you with the DSR?	4.2252	1.34627	9.588	110	.000	1.22523	.9720	1.4785

Source: Based on SPSS output

To achieve the second objective and examine the level of Romanians' environmental education based on the European Green Deal promotion by the public and private sectors, the respondents needed to respond to 20 affirmations on a six-point Likert scale from strongly disagree (1) to strongly agree (6). These 20 affirmations were broken into two variables with 10 items each. The Cronbach's Alpha reliability coefficient was identified to be 0.912 when it comes to the private sector and 0.934 for the public one, indicating also high statistical significance for all affirmations groups (Table no. 5).

Table no. 5. Reliability Coefficients (Cronbach's Alpha)

Respondents' environmental education gained from private sector	0.912
Respondents' environmental education gained from public sector	0.934

Source: Processed by the authors based on research results

According to Table no. 6, between the respondents' environmental education gained from the private sector and their behavior after the interaction with an advertisement or any promotion campaign regarding sustainability, it was found a strong positive correlation ($r=0.622$, $p<0.01$). Therefore, as the level of environmental education of respondents increases, they get to be more careful with sustainability principles, recycling, avoiding food waste, and showing more positive behavior in this direction. These results lead to the acceptance of H2a.

Table no. 6. Pearson Correlation

		Private sector	Environmental behavior
Private sector	Pearson Correlation	1	,622**
	Sig. (2-tailed)		,000
	N	111	111
Environmental behavior	Pearson Correlation	,622**	1
	Sig. (2-tailed)	,000	
	N	111	111

**. Correlation is significant at the 0.01 level (2-tailed).

Source: Based on SPSS output

The same interpretation applies in the case of the public sector, showing a slightly stronger correlation than the private sector, but nevertheless being framed in the same strong positive correlation ($r=0.641$, $p<0.01$) (Table no. 7). Also, the hypothesis H2b was accepted, showing a strong positive correlation between the two variables. The author didn't make any kind of assumption in either case and the correlation between the two variables is not a causation.

Table no. 7. Pearson Correlation.

		Public sector	Environmental behavior
Public sector	Pearson Correlation	1	,641**
	Sig. (2-tailed)		,000
	N	111	111
Environmental behavior	Pearson Correlation	,641**	1
	Sig. (2-tailed)	,000	
	N	111	111

**. Correlation is significant at the 0.01 level (2-tailed).

Source: Based on SPSS output

Finally, an independent sample test was run, and Table no.8 presents the means for each group. The Levene's Test ($F=0.732$, $p>0.05$) shows that variations of the two groups are equal. The model is statistically significant ($t=5.837$, $p<0.05$) for 109 degrees of freedom. In conclusion, the difference between the two means is (Mean Dif=1.18455) also statistically significant, being a real difference between these two groups and showing that the people who already know what the European Green Deal means tend to have a more sustainable behavior than the people who don't know what it means (Table no. 9). These results lead to the acceptance of hypothesis H3.

Table no. 8. Group Statistics

	Know about GD	N	Mean	Std. Deviation	Std. Error Mean
Respondents' environmental behavior	Yes	65	4.1585	0.99041	0.12284
	No	46	2.9739	1.13655	0.16758

Source: Based on SPSS output

Table no. 9. Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Respondents' environmental behavior	Equal variances assumed	0.732	0.394	5.837	109	.000	1.18455	0.20293
	Equal variances not assumed			5.701	88.409	.000	1.18455	0.20778

Source: Based on SPSS output

Overall, the paper offers relevant information regarding the level of environmental education possessed by Romanians, looking at the promotion of sustainability done by the two biggest sectors, private and public, and their influences on citizens' behavior. The results also highlight the importance of increasing and adapting the way Green Deal promotion is done, especially since the results showed a positive strong correlation between the promotion of Green Deal and Romanians' environmental behavior.

4. Conclusions

To achieve the desired requirements from the Green Deal agenda, besides regulations and law changes, it is also very important to inform and educate citizens about sustainability, what is required from them, how they can help, about various projects that are already being implemented or will be, etc.

At the European level, in some countries, the DSR is a very successful project, with Germany being the leading country when it comes to the return rate. Even though Romania is away from Germany's return rate, it had a very good start and evolution, and it is expected to grow more in the next year.

Therefore, this paper explores the environmental education level of Romanians, contributing to the scientific literature by showing the satisfaction of Romanians regarding DSR and the correlations between the level of sustainability education and Romanians' environmental behavior.

The results show that Romanians are satisfied with DSR, and they are using it mostly considering and feeling that they are making efforts to protect the environment. On top of that, strong positive correlations were found between the level of environmental education gained from both the private and public sectors and the Romanians' environmental behavior, suggesting that as the promotion of sustainability increases and is done better in more proper ways, reaching a lot more people, then also their behavior about environment and sustainability will increase as well. In the end, the author found that people who already knew what Green Deal meant, tended to have more sustainable habits.

Even though the results presented show only positive things, from 111 respondents, there are 46 (41,4%) who don't know what the Green Deal means, showing that there is still a lot of room for improvement, and this paper could represent an opportunity for private entities and public authorities to collaborate even better and come up with a plan to convert also the people who don't know anything about the European Green Deal into people who do, for example. More than that, both sectors should focus on the citizens by creating a better plan of sustainability promotion through more channels, targeting and reaching more people. During the advertisement campaign, people should be educated not only about the requirements of the Green Deal but also on the actions that can be taken by them in order to help the planet. Also, discussions, courses, games, or any activity specific to sustainability can be held even from the earliest ages in kindergartens and schools in order to be able to form an education about sustainability from the beginning of people's lives, thus forming a system.

The research provided valuable insights and can serve as a starting point for future academic research related to education and the Green Deal, but it would be useful to extend the sample of the study. Also, from the author's perspective, the correlations between the level of environmental education gained from the private and public sectors and Romanians' sustainability behavior could be further studied.

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Structural and analytical studies on some complexes of Pd^{2+} ions with asymmetric α-dioximes

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Abstract. Starting from the favorable analytical properties of α-asymmetric dioximes in the chemical analysis of certain transition metal ions, new methods for quantitative determination of Pd^{2+} with aliphatic and alkyl-aryl dioximes were developed. A comparative study was conducted on the selectivity and sensitivity of the color and precipitation reactions of the analyzed α-asymmetric dioximes, investigating how the nature of the R and R' radicals linked to the dioxime group influences the physico-chemical properties, on the one hand, of the ligands and the complexes formed, and, on the other hand, influences their solubilities and gravimetric factors. The experimental data carried out have highlighted the increased sensitivity and selectivity of the color reactions of asymmetric α-dioximes with Pd^{2+} ions. This is why new gravimetric and spectrophotometric methods have been developed for the determination of these cations in the form of asymmetric dioximates.

Keywords: structural characterization, complexes, dioximes, analytical applications

1. Introduction

Among the various and diverse applications of asymmetric dioximes in chemical analysis, it is worth mentioning their widespread use as extraction agents in various sampling processes. Asymmetric dioximes hold special importance in bioanalysis. They have allowed for the elucidation of many structural aspects and synthesis mechanisms of biological macromolecules [1,2].

It should be noted that dioximes are used in several modern separation techniques, such as chromatographic methods (GC, HPLC), used to remove traces of transition metals from various reagents. Adding dioximes to the stationary phases used in chromatographic techniques substantially contributes to increasing separation resolution through enhanced selectivity [3,4]. Modern chromatographic methods use various oximes for the recovery and concentration of metals from the mixtures in which they are found. Ion-exchange resins have been obtained through polycondensation or copolymerization processes involving unsaturated hydrocarbons, aldehydes, and ketones, resulting in the formation of oxime groups in the presence of hydroxylamine or under isonitrosation conditions. Columns filled with such resins are currently being used with increasingly promising results for the separation and concentration of precious metals from the ocean water or from the thermal power plant ashes [5,6,7].

In the purification of reagents, for example, by removing traces of transition metals from the 3d and 4d group, chromatographic columns with filler containing both α-ketoxime and α-dioxime are sometimes used [8,9]. Thin-layer chromatography (using layers of silica gel and aluminum oxide in various pretreated ratios) allows for the separation and identification of certain transition metals from biological samples. Specific reagents, such as α-dioxime, α-ketoxime, hydroxy-oxime etc. are contained in the mobile phase or in the developing solutions. Generally, the obtained R_f values have values above 0,1-0,2 allowing for objective analytical interpretations [10,11].

The separation and determination of trace metals, especially in biological samples and in the study of the mechanisms of biochemical processes, is of a highly important and current to which the class of dioxymic chelates will contribute in the future [12,13].

2. Experimental part

From a structural perspective, the class of oximes is characterized by the rigidity of the azomethine bond (> C = N -), which restricts the free rotation of the C and N atoms around the bond axis. As a result, most oximes exhibit a certain degree of asymmetry in terms of the distribution of electron density in the respective molecule. In the case of the combinations studied in this work, the most pronounced molecular asymmetry is observed in asymmetric α-dioximes and their complexes. Complexes of some bivalent metals of the type: $[M(Diox.H)_2]$, (M = Ni, Pt, Pd) have a stable square-planar structure, with a group MN_4 in a plane, stabilized by two intramolecular hydrogen bonds O-H...O (Fig. 1).

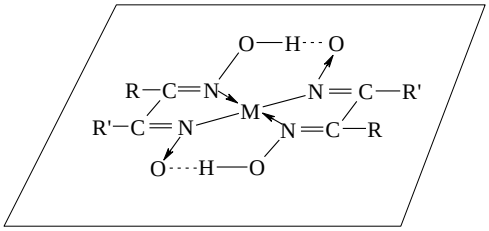


Figure 1. The square-planar structure of the bivalent metal complexes with asymmetric dioximes, $[M(Diox.H)_2]$.

The radicals R and R' in the structure of dioxime complexes can be different aliphatic, alicyclic, aromatic, or heterocyclic radicals. The degree of symmetry decreases as the difference in the nature and geometric structure of the R and R' groups increases [14,15]. The use of asymmetric α-dioximes in coordination and analytical chemistry raises several structural issues.

In the case of square-planar and octahedral complexes, new isomeric combinations can be formed. For planar derivatives, there is geometric isomerism known as ”cis-trans” isomerism. In ”cis” isomers, the two groups R and R' occupy adjacent positions in the molecule, and there is local C_{2V} symmetry around the central metal atom. In the ”trans” isomer, the R and R' groups are situated at opposite corners of the square. In this case, the local symmetry will be C_{2h}. The reduction in symmetry in the case of complexes with asymmetric α-dioximes sometimes leads to the splitting of bands in the UV-VIS spectra of the complexes [16,17].

Another result of reduced symmetry is the possibility of forming optically active isomers. During syntheses, these isomers may sometimes arise in a pure state, but their formation in various molecular ratios is more likely. Using classical separation methods, these isomers generally cannot be isolated in a pure state because most of their physical and physicochemical properties are very similar (solubility, certain spectroscopic data: IR, RAMAN, thermal properties etc.). Regarding the identity and the purity of the obtained products, ^{1}H, ^{13}C, and ^{15}N NMR spectra, measurements of dipole moments and Mössbauer spectra can provide certain useful data [18,19].

2.1. Materials and method

The quantitative determination of Pd^{2+} has been developed over time or a series of gravimetric, volumetric and physico-chemical methods. Asymmetric dioximes have been relatively little studied in terms of the possibilities of their use for Pd(II) dosing. Here below are the experimental results of gravimetric determinations in which, for the dosage of Pd^{2+} ions, two asymmetric alkyl-aryl dioximes, namely: methyl-benzyl-dioxime and methyl-phenyl-dioxime, and two asymmetric aliphatic dioximes, namely: methyl-ethyl-dioxime and methyl-isopropyl-dioxime (propoxime), were synthesized and used as precipitation reagents. Four Pd^{2+} dioximates were precipitated in the methods using asymmetric dioximes of alkyl-aryl and alkyl dioximes: [Pd(methyl-benzyl-diox.H)$_2$], [Pd(methyl-phenyl-diox.H)$_2$], [Pd(methyl-ethyl-diox.H)$_2$] and [Pd(propox.H)$_2$].

Gravimetric determination of Pd^{2+}

2–25 mg of Pd^{2+} in about 50 ml of water is acidified with dilute hydrochloric acid to pH = 2- 4 and heated in a water bath at 80–90ºC. Then add 15 ml of 1% dioxime solution in ethyl alcohol. After 30 min. cool the glass and let it rest for 2-3 hours, then filter the yellow-orange microcrystalline precipitate on a G3 glass filter crucible. The precipitate is washed with warm water and dried in an oven at 160-180ºC. The results of the gravimetric determinations and their statistical processing are presented in Table 1 and Table 2.

Table 1. Gravimetric determination of Pd^{2+} with asymmetric alkyl-aryl dioxime in the form of [Pd(methyl-benzyl-diox.H)$_2$] and [Pd(methyl- phenyl -diox.H)$_2$]

No	Pd^{2+} taken into analysis (mg)	Precipitated mass [Pd(methyl–benzhyl–diox.H)$_2$] (mg)	Pd^{2+} found (mg)	Error		Precipitated mass [Pd(methyl-phenyl -diox.H)$_2$] (mg)	Pd^{2+} found (mg)	Error	
				mg	%			mg	%
1.	2,4	11,02	2,39	–0,01	0,42	9,85	2,41	+0,01	0,42
2.	4,8	22,05	4,78	–0,02	0,42	19,53	4,78	–0,02	0,42
3.	9,6	44,39	9,62	+0,02	0,21	39,34	9,63	+0,03	0,31
4.	14,4	66,57	11,43	+0,03	0,21	58,61	14,35	–0,05	0,35
5.	19,2	88,37	19,16	–0,04	0,21	78,72	19,27	+0,07	0,36
6.	24,0	110,98	24,06	+0,06	0,25	97,89	23,96	–0,04	0,16
Statistical data		M = 490,78; f = 0,2168; $\bar{X} = 9{,}61$; $S^2 = 6{,}33\cdot10^{-4}$ $S = 2{,}51\cdot10^{-2}$; t = 0,40; $t_{n-1,\alpha} = 2{,}26$; α = 95%, $\bar{X} - t\cdot s < A < \bar{X} + t\cdot s$ 9,58<9,60<9,61				M = 434,68; f = 0,2448; $\bar{X} = 24{,}01$; $S^2 = 7{,}77\cdot10^{-4}$ $S = 2{,}79\cdot10^{-2}$; t = 0,36; $t_{n-1,\alpha} = 2{,}26$; α = 95%, $\bar{X} - t\cdot s < A < \bar{X} + t\cdot s$ 23,99<24,00<24,02			

Table 2. Gravimetric determination of Pd^{2+} with aliphatic asymmetric α–dioxime in form of [Pd(methyl-ethyl-diox.H)$_2$] and [Pd(propox.H)$_2$]

No	Pd^{2+} taken into analysis (mg)	Precipitated mass [Pd(methyl-ethyl-diox.H)$_2$] (mg)	Pd^{2+} found (mg)	Error		Precipitated mass [Pd(propox.H)$_2$] (mg)	Pd^{2+} found (mg)	Error	
				mg	%			mg	%
1.	2,4	8,24	2,39	–0,01	0,42	8,94	2,41	+0,01	0,42
2.	4,8	16,61	4,82	+0,02	0,42	17,69	4,77	–0,03	0,63
3.	9,6	33,15	9,62	+0,02	0,21	35,76	9,64	+0,04	0,42

No	Pd^{2+} taken into analysis (mg)	Precipitated mass [Pd(methyl-ethyl-diox.H)$_2$] (mg)	Pd^{2+} found (mg)	Error		Precipitated mass [Pd(propox.H)$_2$] (mg)	Pd^{2+} found (mg)	Error	
				mg	%			mg	%
1.	2,4	8,24	2,39	–0,01	0,42	8,94	2,41	+0,01	0,42
4.	14,4	49,70	14,42	+0,02	0,14	53,30	14,37	–0,03	0,21
5.	19,2	65,99	19,15	–0,05	0,26	71,14	19,18	–0,02	0,10
6.	24,0	82,46	23,93	–0,07	0,29	89,24	24,06	+0,06	0,25
Statistical data		M = 366,6; f = 0,2902; $\bar{X} = 14{,}41$; $S^2 = 6{\cdot}10^{-4}$ S = $2{,}45{\cdot}10^{-2}$; t = 0,41; $t_{n-1,\alpha} = 2{,}26$ α = 95%, $\bar{X} - t \cdot s < A < \bar{X} + t \cdot s$ 14,39<14,40<14,42				M = 394,69; f = 0,2696; $\bar{X} = 19{,}21$; $S^2 = 9{,}22{\cdot}10^{-4}$ S = $3{,}04{\cdot}10^{-2}$; t = 0,33; $t_{n-1,\alpha} = 2{,}26$ α = 95%, $\bar{X} - t \cdot s < A < \bar{X} + t \cdot s$ 19,19<19,20<19,22			

Spectrophotometric determination of Pd^{2+} with asymmetric alkyl-aryl dioximes

For the spectrophotometric determination of Pd^{2+} ions, two asymmetric alkyl-aryl dioximes: methyl-benzyl-dioxime and methyl-phenyl-dioxime, were used as precipitation reagents in the conducted determinations.

Synthesis of Pd (II) dioximates and spectrophotometric analysis

A quantity of 2-20 mg of Pd^{2+} in a 50 ml aqueous solution was taken for the procedure, and it was precipitated in an acidic medium with an excess of 1% dioxime in alcoholic solution. The cooled mixture can be extracted with acetone or chloroform, and the extraction is repeated 3-4 times with 10 ml of organic solvent each time. The organic phase was transferred to a 50 ml calibrated ballon bottle, and it was brought up to the mark with the same solvent used for extraction. [20]

The absorbance of the solutions was measured at 425 nm against pure solvent using a UV-Vis spectrophotometer Cintra 101 GBC. Calibration curves for the spectrophotometric determination of Pd^{2+} with the asymmetric dioximes, methyl-benzyl-dioxime and methyl-phenyl-dioxime, are presented in Figures 2 and 3.

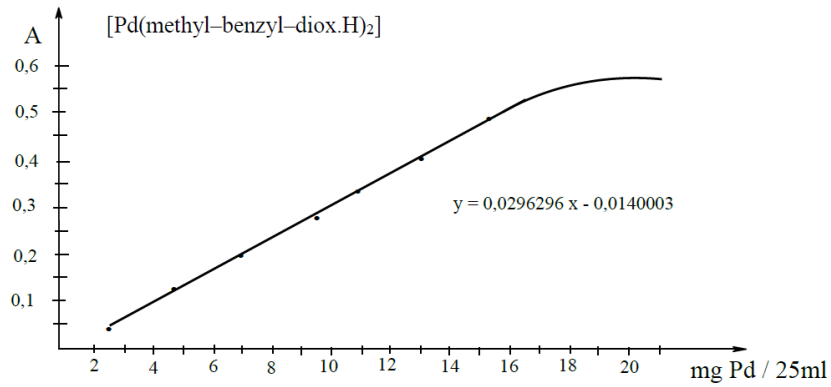


Figure 2. Spectrophotometric determination of Pd^{2+} by precipitation in the form of [Pd(methyl–benzyl–diox.H)$_2$].

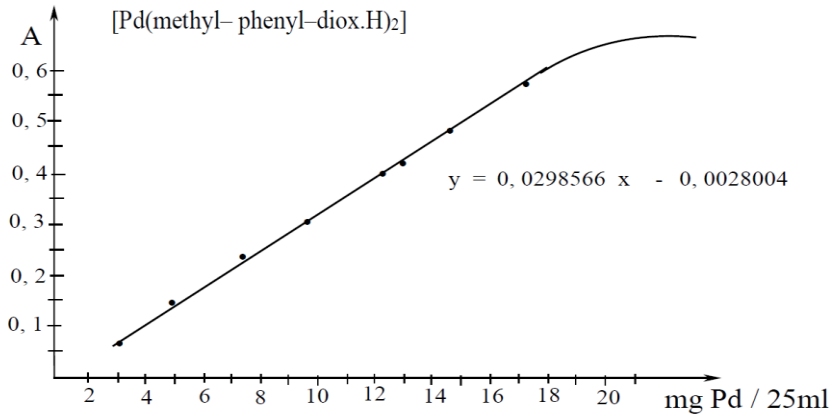
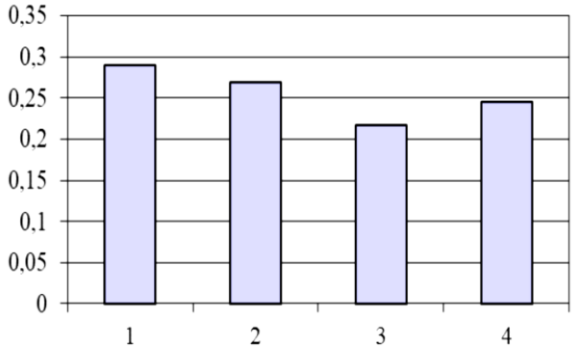


Figure 3. Spectrophotometric determination of Pd^{2+} by precipitation in the form of $[Pd(methyl– phenyl–diox.H)_2]$.

2.2. Results and discussions

In the gravimetric determination of Pd^{2+} with asymmetric dioximes, a comparative study of its quantification using asymmetric aliphatic and alkyl-aryl dioximes shows a more favorable value of gravimetric factors when using alkyl-aryl dioximes as precipitation reagents (Fig. 4).



Determination of Pd^{2+} by precipitation:
1. methyl-ethyl-dioxima;
2. methyl-i-propyl-dioxima;
3. methyl-benzyl-dioxima;
4. methyl-phenyl-dioxima

Figure 4. Representation of gravimetric factor values at determination of Pd^{2+} with asymmetric dioximes.

a) Comparing the gravimetric factors of the analyzed compounds, it is evident that the most sensitive form of Pd^{2+} determination through the gravimetric method is $[Pd(methyl-benzyl-diox.H)_2]$.

b) The statistical analysis of the data resulting from the gravimetric analysis indicates that the most accurate and reproductible determinations of Pd^{2+} were those performed with methyl-benzyl-dioxime.

The experimental data obtained from the spectrophotometric analysis of Pd^{2+} ions in the form of new complex combinations, such as those with asymmetric alkyl-aryl α-dioximes, indicate good analytical sensitivity and selectivity. The statistical analysis of the spectrophotometric data obtained in the case of Pd^{2+} determination with the previously mentioned asymmetric dioximes is presented in Tables 3 and 4.

Table 3. Statistical data of Pd^{2+}spectrophotometric determination as [Pd(methyl-benzyl-diox.H)$_2$]

No	x	x^2	y	y^2	xy	x+y	$(x+y)^2$
1.	2,16	4,6656	0,07	0,0049	0,1512	2,23	4,9729
2.	4,32	18,6624	0,13	0,0169	0,5616	4,45	19,8025
3.	6,48	41,9904	0,20	0,0400	1,2960	6,68	44,6424
4.	8,64	74,6496	0,27	0,0729	2,3328	8,91	79,3881
5.	10,80	116,6400	0,33	0,1089	3,5640	11,13	123,8769
6.	12,96	167,9616	0,44	0,1600	5,1840	13,36	178,4896
7.	15,12	228,6144	0,47	0,2209	7,1064	15,59	243,0481
Total	60,48	653,1840	1,87	0,6245	20,1960	62,35	694,2005
$\bar{x} = 8,64$; $\bar{y} = 0,27$; $\sigma_x = 4,32$; $\sigma_y = 0,128$; $r = 1$ $y = 0,0296296\ x - 0,0140003$; $x = 0,472500 + 33,750000\ y$							

From Tables 3 and 4 it is observed that the value of r = 1 calculated from statistical data corresponding to the two spectrophotometric dosages of Pd^{2+} with methyl-benzyl-dioxime and methyl-phenyl-dioxime shows that the results obtained are reproductible, and the error is negligible.

Table 4. Statistical data of Pd^{2+} spectrophotometric determination as [Pd(methyl-phenyl-diox.H)$_2$]

No	x	x^2	y	y^2	xy	x+y	$(x+y)^2$
1.	4,44	5,9536	0,07	0,0049	0,1708	2,51	6,3001
2.	4,88	23,8144	0,14	0,0196	0,6832	5,02	25,2004
3.	7,32	53,5024	0,22	0,0484	1,6104	7,54	56,8516
4.	9,76	95,2576	0,29	0,0841	2,8304	10,05	101,0025
5.	12,20	148,8400	0,36	0,1296	4,3920	12,56	157,7536
6.	14,64	214,3296	0,43	0,1849	6,2952	15,07	227,1049
7.	17,08	291,7264	0,51	0,2601	8,7108	17,54	309,4081
Total	68,32	833,5040	2,02	0,7316	24,6928	70,34	883,6212
$\bar{x} = 9,78$; $\bar{y} = 0,28$; $\sigma_x = 4,88$; $\sigma_y = 0,14$; $r = 1$ $y = 0,0298566\ x - 0,0028004$; $x = 0,09378170 + 33,4934798\ y$							

The concentration range in which Lambert Beer law is verified and the value of the molar absorption coefficient in the case of Pd^{2+} determinations with the alkyl-aryl asymmetric dioximes: methyl-benzyl-dioxime and methyl-phenyl-dioxime are shown in Table 5.

Table 5. Linear concentration range and value of the molar absorption coefficient in Pd^{2+} determinations with alkyl-aryl asymmetric dioximes

No	The metal complex studied	Linear concentration range (mg Pd)	Molar absorption coefficient ε ($L \cdot cm^{-1} \cdot mol^{-1}$)
1.	[Pd(methyl–benzhyl–diox.H)$_2$]	0,0864–0,6048	381,40
2.	[Pd(methyl– phenyl–diox.H)$_2$]	0,0976–0,6832	324,489

The mathematical equations established through linear regression that show the relationship between the measured absorbance and the concentration of Pd^{2+} in the analyzed sample, in the case of quantification as [Pd(methyl-benzyl-diox.H)$_2$], are as follows:

$$1) \quad y - \bar{y} = r\frac{\sigma_y}{\sigma_x}(x - \bar{x})$$

$$y = 0{,}0296296\ x - 0{,}0140003$$

$$2) \quad x - \bar{x} = r\frac{\sigma_x}{\sigma_y}(y - \bar{y})$$

$$x = 0{,}472500 + 33{,}750000\ y$$

From the statistically processed data presented in Table 4, the relationship between absorbance and the concentration of the active product in the sample (mg), as determined by linear regression, can be established in the case of quantification of Pd^{2+} as [Pd(methyl-phenyl-diox.H)$_2$], given by the following equations:

$$1) \quad y - \bar{y} = r\frac{\sigma_y}{\sigma_x}(x - \bar{x})$$

$$y = 0{,}0298566\ x - 0{,}0028004$$

$$2) \quad x - \bar{x} = r\frac{\sigma_x}{\sigma_y}(y - \bar{y})$$

$$x = 0{,}09378170 + 33{,}4934798\ y$$

The precision and reproducibility of the spectrophotometric methods developed for the quantification of Pd^{2+} with asymmetric alkyl-aryl α-dioximes highlight the fact that these reagents can be successfully used for analytical purposes, being sensitive and selective in such determinations.

3. Conclusions

Theoretical and experimental research aimed to highlight the possibilities of using aliphatic and alkyl-arylic α-dioximes as precipitation and determination reagents for Pd^{2+} ions in analytical practice. The statistical analysis of the data resulting from the gravimetric analysis of the complexes: [Pd(methyl-ethyl-diox.H)$_2$], [Pd(propox.H)$_2$], [Pd(methyl-benzyl-diox.H)$_2$] and [Pd(methyl-phenyl-diox.H)$_2$], as well as the comparative study of the gravimetric factors of the analyzed complexes, indicates that the most precise and reproducible determinations of Pd^{2+} were those performed with methyl-benzyl-dioxime. The applications of spectrophotometric methods for quantifying Pd^{2+} ions in the form of new complex combinations, such as [Pd(methyl-benzyl-diox.H)$_2$] and [Pd(methyl-phenyl-diox.H)$_2$], have proven to be methods with good analytical sensitivity and selectivity.

Analytical reagents from the class of asymmetric α-dioximes form sparingly soluble precipitates with Pd^{2+} in water, exhibiting favorable physico-chemical properties for analytical determinations.

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Manipulation in Negotiations: The Hidden Costs of the "Easy" Victory

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Abstract. Negotiation is a dynamic process where influence plays a key role. This article examines the contrasting approaches of manipulation and ethical persuasion, focusing on their characteristics, implications, and long-term impact. Manipulation, which exploits emotional and cognitive vulnerabilities through deceptive tactics, often delivers short-term gains but undermines trust, collaboration, and reputation. In contrast, ethical persuasion emphasizes transparency, mutual respect, and sustainable relationships. The article explores the historical evolution of manipulation, from ancient rhetoric to its modern manifestations in digital contexts, highlighting the risks and relevance of these practices. It also examines the hidden costs of manipulation, including trust erosion, relational damage, and legal and reputational risks. As a solution, the Harvard Method of principled negotiation is presented as an effective framework for achieving equitable and durable outcomes. This approach emphasizes focusing on interests rather than positions, using objective criteria, and separating people from the problem. Active listening and empathy further enhance this process, fostering mutual understanding and preventing conflict escalation. In an interconnected world, ethical negotiation strategies are vital for long-term success. By contrasting manipulation and persuasion, the article provides insights into cultivating trust, collaboration, and integrity in negotiations.

Keywords: *negotiation, manipulation, ethical persuasion, trust, long-term relationships*

1. Introduction

Negotiation, as a complex and dynamic process, involves various forms of influence, ranging from ethical persuasion to covert manipulation. While persuasion fosters transparency, mutual respect, and shared benefits, manipulation seeks unilateral advantages, often at the expense of others. (Cialdini, 2001; Perloff, 2010) In today's interconnected global landscape, where interpersonal and business relationships are increasingly intertwined, distinguishing between these two approaches is essential.

This analysis examines the concept of manipulation, tracing its historical evolution from the rhetoric of ancient Greece to the digital influences of the modern era. (Platon, 2008; Aristotel, 2010; Allcott & Gentzkow, 2017)It highlights the risks and costs associated with manipulative tactics, such as the loss of trust, damaged relationships, and legal or reputational repercussions. (Gino & Pierce, 2010; Lewicki & Robinson, 1998; Robinson et al., 2000).

In contrast, principled negotiation, inspired by the Harvard Method, is presented as an ethical and effective framework for achieving sustainable agreements. (Fisher, Ury, & Patton, 2011) This approach emphasizes active listening, empathy, the use of objective criteria, and the separation of people from the problem. It underscores the importance of mutual respect and transparency in building strong relationships and finding lasting solutions. (Shell, 2006; Drollinger et al., 2006).

Through this lens, the analysis showcases how negotiators can sidestep the pitfalls of manipulation and foster trust and collaboration, promoting a paradigm shift from confrontation to cooperation. (Reiss & Mitkidis, 2019).

2. Purpose and relevance of the article

This article provides an in-depth exploration of the differences between manipulation and persuasion in the context of negotiations, offering a detailed analysis of the impact these practices have on relationships and outcomes. Its primary goal is to clarify the concepts, highlight their historical and ethical implications, and promote constructive and sustainable approaches. In an increasingly complex and interconnected world where influence is a constant, the article emphasizes the necessity of understanding these dynamics and acting with integrity. (Lewicki & Robinson, 1998; Gino & Pierce, 2010).

By examining the historical evolution of manipulation, the article sheds light on how influence techniques have been utilized across various eras and cultural contexts. From the rhetoric of ancient Greece to the emotional manipulation of the digital age, the analysis highlights the transformations this practice has undergone and its continued relevance. (Platon, 2008; Aristotel, 2010; Allcott & Gentzkow, 2017).

The article also addresses the hidden costs of manipulation, such as the loss of trust, damaged relationships, and legal risks. These aspects are significant in any negotiation context, whether professional, political, or personal. In addition to highlighting these risks, the article advocates for ethical solutions grounded in clear principles, such as the Harvard method. (Fisher, Ury, & Patton, 2011).

The relevance of the article lies in its practical and theoretical contributions, offering readers valuable tools to identify and avoid manipulative tactics. It also underscores the importance of negotiation approaches based on mutual respect, transparency, and collaboration. In a society where reputation and durable relationships are increasingly valued, ethical negotiation practices are essential for long-term success. (Reiss & Mitkidis, 2019).

This article is aimed at both practitioners and individuals seeking to better understand the complexity of the negotiation process, contributing to the development of a balanced perspective between efficiency and ethics.

3. Manipulation and the Fine Line Between Persuasion and Manipulation

3.1. The Concept of Manipulation and Negotiation

Manipulation is regarded as a form of covert and unethical social influence, where an individual or group seeks to compel another to act against their own interests by exploiting emotional or cognitive vulnerabilities and presenting distorted or false information. Its primary objective is to secure a unilateral advantage with little or no concern for the consequences on the other party (Knapp & Daly, 2011; Gelfand et al., 2013).

In the context of negotiation, defined as the process by which two or more parties seek to reach an agreement with differing interests or resources, the psychological definition of manipulation aligns closely with specific tactics often observed. Parties may employ hidden strategies, emotional pressures, and distorted information to gain disproportionate advantages. Such behaviors disregard the genuine interests of the other party, often damaging trust and long-term relationships (Knapp & Daly, 2011; Gelfand et al., 2013).

3.2. The Historical Evolution of Manipulation: From Antiquity to the Digital Age

Manipulation is not a modern phenomenon but can be traced back to ancient times, manifesting in various forms and methods depending on the socio-cultural context and available tools. Historians and researchers have identified numerous examples illustrating how manipulation has evolved over the ages.

In Ancient Greece, the art of persuasion and verbal manipulation was extensively studied and considered essential in political and social life (Plato, Gorgias; Aristotle, Rhetoric). The Sophists, represented by thinkers like Protagoras and Gorgias, specialized in constructing arguments and oratory techniques to convince audiences, often irrespective of the objective truth. While celebrated for their intellectual agility and rhetorical expertise, the Sophists were criticized by philosophers such as Socrates and Plato for employing deceptive arguments and techniques that could distort reason and moral values (Plato, 2008). Significant example: Public debates in the Athenian Agora, where skilled rhetoricians used linguistic refinement to sway public opinion toward their own goals (Aristotle, 2010).

During the Medieval Period, manipulation predominantly found expression in political and religious spheres. Secular and ecclesiastical leaders employed strategies to legitimize their authority and maintain social cohesion (Althoff, 2004). Rituals, sacred texts, and symbolic acts were used to influence mass perceptions and secure loyalty to leaders. Significant example: Religious sermons and rituals were often utilized to justify political or military campaigns. Clergy, bishops, and even popes leveraged their spiritual status to impose or validate actions, crafting a favorable image of the leader or cause (Southern, 1970).

In the Modern Era, with the development of mass communication (print media, radio) and the centralization of power in nation-states, manipulation became more sophisticated and systematic (Ellul, 1965). Political leaders like Adolf Hitler and Joseph Stalin used propaganda as a tool for control and indoctrination, shaping the attitudes and beliefs of entire populations. Manipulative methods included strict control of information, extensive use of slogans, and imagery designed to evoke strong emotional reactions. Significant example: The Nazi Propaganda Ministry, led by Joseph Goebbels, implemented mass communication strategies through radio and cinema to create an idealized image of the state and its supreme leader (Kershaw, 2001).

In the Digital Era, manipulation has reached unprecedented levels with the advent of the internet and social media. The ability to create and distribute viral content, combined with instant global access, has amplified the prevalence of disinformation and emotional manipulation (Allcott & Gentzkow, 2017). Platforms like Facebook, Twitter, and TikTok act as accelerators for spreading distorted information, influencing electoral behavior, consumer preferences, and social attitudes. Significant example: In modern electoral campaigns, political marketing experts utilize targeted advertising, emotional messaging, and bot accounts to steer debates, fragment public opinion, and manipulate perceptions of candidates or major issues (Wardle & Derakhshan, 2017).

3.3. Key Psychological Elements of Manipulation

A. **Exploiting Emotional or Cognitive Vulnerabilities**

In negotiations, one party may exploit the fears or emotional insecurities of the other (e.g., fear of failure, lack of self-confidence) to convince them to accept less favorable terms. This aligns with the psychological definition of manipulation as hidden influence with no genuine concern for the other's well-being.

B. **Providing Distorted Information**

Rather than presenting an accurate and comprehensive picture, a manipulative negotiator may omit, distort, or conceal critical data (e.g., true costs, risks, or alternatives). This tactic alters the other party's perception of reality, leading them to make decisions contrary to their best interests.

C. **Seeking Unilateral Advantage**

Manipulation often reflects a disregard for the consequences on the other party, focusing solely on maximizing personal gain. In negotiations, this translates into prioritizing self-interest at the expense of trust and long-term relationships.

D. **The Hidden Costs of "Victory"**

While manipulative strategies may yield immediate gains, behavioral psychology suggests that such tactics often lead to long-term consequences, including damaged relationships, compromised trust, and reputational harm. The imbalance between short-term benefits and long-term fallout underscores the unsustainable nature of manipulative behavior.

By examining manipulation in its historical, psychological, and practical dimensions, this section sets the stage for contrasting these tactics with ethical approaches, highlighting the importance of integrity and transparency in negotiation processes.

3.4. Ethical Persuasion vs. Manipulation

Persuasion is defined as the process through which an individual (or group) uses communication and reasoning skills to influence another person's attitudes, beliefs, or behaviors without resorting to unethical pressure, deceit, or exploitation of vulnerabilities (Cialdini, 2001; Perloff, 2010). This type of influence is built on:

- **Solid arguments and evidence:** Persuasion draws its strength from facts and data, avoiding lies or the deliberate omission of critical information.
- **Respect for the audience and transparency:** The goal is not emotional manipulation but the honest presentation of ideas and advantages, enabling the audience to make informed decisions.
- **Mutual benefits:** Ethical persuasion focuses on creating a "win–win" scenario, maintaining a climate of respect and integrity.

Table 3.1: Ethical Persuasion vs. Manipulation in Negotiations

Characteristic	Ethical Persuasion	Manipulation
Definition	Relies on real arguments and evidence to convince, without hiding intentions or relevant information.	Utilizes distorted, hidden, or false information to exploit vulnerabilities and gain an unfair advantage.
Intent	Aims to promote solutions that benefit both parties and uphold moral integrity.	Seeks unilateral benefits, even at the cost of violating ethical norms or harming the other party.
Influence methods	Uses logical arguments, verifiable facts, and transparency. Encourages active listening and mutual respect.	Applies psychological, emotional, or time pressure, omits information, or uses deception to dominate.
Interpersonal relationships	Builds trust, respect, and collaboration, fostering long-term partnerships.	Generates suspicion and resentment, often damaging future relationships.
Immediate vs. long-term outcomes	May take longer to achieve results but ensures a solid foundation for repeated and enduring collaborations.	Often yields quick results but damages credibility and trust, making future partnerships unlikely.
Type of information used	Transparent, complete, and verifiable, including potential risks or limitations.	Incomplete, omitted, or fabricated to mislead and conceal disadvantages.
Ethical consequences	Maintains reputation and integrity, strengthening personal or organizational trustworthiness.	Risks legal repercussions, moral criticism, and the loss of trust and business opportunities.
Emotional approach	Encourages empathy and mutual understanding; manages emotions with respect and honesty.	Exploits emotions (e.g., fear, guilt, pride) to coerce concessions through subtle or overt threats.
Conflict resolution	Seeks fair solutions that address real needs and interests of both parties.	Escalates conflicts deliberately to exert pressure and secure disproportionate concessions.
Dialogue approach	Invites open communication and questions, fostering transparent negotiations.	Evades or blocks questions, offering vague responses to maintain control and limit alternatives.

The distinction between ethical persuasion and manipulation emphasizes that approaching negotiations with transparency and integrity ensures trust and collaboration in the long term. While

persuasion aims to create mutually beneficial outcomes, manipulation seeks short-term gains at the cost of honesty and relationship-building. As such, ethical negotiation practices not only preserve credibility but also strengthen the foundation for sustainable partnerships.

4. The Hidden Costs of the "Easy" Victory

4.1. Loss of Trust and Tarnished Reputation

While manipulation can yield immediate gains, these outcomes often lack a solid foundation and are quickly undermined by long-term negative consequences. In negotiations, trust is a cornerstone, acting as the glue that sustains functional relationships and facilitates enduring partnerships. Once a negotiating partner realizes they have been deceived, their perception of the manipulator's integrity changes drastically, casting doubt on any future collaborations.

Studies by Gino and Pierce (2010) emphasize that negotiators who resort to manipulative tactics are often perceived as dishonest and morally unscrupulous over time. This perception leads to a significant erosion of trust not only from current partners but also from potential collaborators who may learn about unethical behavior through recommendations or professional networks. Moreover, in a digitally connected world, a compromised reputation spreads quickly, becoming a substantial obstacle for future projects or contracts.

Beyond relational impacts, a tarnished reputation has economic consequences. Business partners may become more cautious, demanding stricter contractual clauses and additional checks, increasing transaction costs and complicating future agreements. Additionally, a climate of distrust can prompt other parties to seek alternative suppliers or partners, potentially terminating existing contracts out of fear of hidden risks.

In conclusion, while manipulation might offer an "easy" victory, it is far from sustainable. The absence of an ethical foundation undermines business relationships and results in significant reputational and financial costs, often irreparable. Negotiators aiming to maintain relevance and credibility in a competitive environment should avoid manipulative practices and instead invest in fostering trust and transparency.

4.2. Relationship Deterioration and Internal Tensions

When one party employs manipulative strategies, the stability of the negotiation relationship erodes, being built on a foundation devoid of trust. Trust, as the central element sustaining long-term collaboration, hinges on the belief that each party acts in good faith, adhering to basic ethical principles. In its absence, interactions can quickly devolve into a cycle of suspicion and excessive caution.

Lewicki and Robinson (1998) argue that negotiators who manipulate their counterparts create an isolation effect over time. Clients, suppliers, and collaborators, both current and prospective become reluctant to engage with individuals or organizations known for unethical practices. As a result, the costs extend beyond losing a single agreement, potentially creating a vicious cycle: a damaged reputation limits opportunities, which may lead to even more defensive and manipulative behavior in future negotiations.

Gino and Pierce (2010) further highlight that individuals who feel deceived tend to generalize the unethical behavior of their counterpart as indicative of their overall character. This perception eliminates any chance of future collaboration and often spreads negative feedback through professional networks.

The effects of manipulation are not confined to direct business interactions. Gelfand et al. (2013) note that cultural factors can exacerbate the backlash against unethical behavior. In certain environments, reactions to manipulation are particularly severe, leading to the rapid dissemination of information about unethical conduct through word of mouth, social media, or professional platforms. Once tarnished, a reputation is difficult to restore, resulting in heightened caution from all stakeholders.

Over time, deteriorating relationships negatively affect not only the morale of the teams involved but also financial performance:

- Monitoring and drafting detailed contracts become costlier to ensure minimum protection against unethical practices.
- Joint projects are carried out under strained conditions, increasing the likelihood of failure.
- Negotiation partners may choose more trustworthy competitors, even if their offers are less attractive financially in the short term.

Thus, although manipulation might provide an immediate advantage, its long-term costs are hard to overlook. In a competitive context, trust capital and reputation become increasingly valuable, serving as critical assets for establishing durable business relationships. Any deviation from ethical principles in negotiations risks causing irreparable damage to relationships and public image.

4.3. Legal and Ethical Risks

When manipulation crosses the boundary into illegality, such as falsifying documents, presenting inaccurate financial data, or engaging in fraud negotiators face tangible legal risks. In many jurisdictions, contract and civil liability laws impose severe sanctions for deceit. In extreme cases, manipulative behavior can lead to criminal charges for fraud or document falsification. These scenarios can arise not only in commercial contracts but also in mergers and acquisitions, public tenders, or strategic partnership negotiations (Robinson, Lewicki, & Donahue, 2000).

Ethical risks can be equally severe. Many organizations and professional associations (e.g., bar associations, financial consultancy bodies, regulatory organizations) enforce strict codes of conduct. Violations, such as intentional misinformation or corrupt practices can result in professional sanctions, ranging from warnings to exclusion from professional organizations. In the corporate world, adherence to ethical governance principles, like those promoted by ESG standards (Environmental, Social, and Governance), is increasingly vital for attracting investments and maintaining stakeholder trust.

Beyond immediate penalties, potential lawsuits or public scandals can trigger reputational crises, drastically undermining the trust of business partners, shareholders, and clients. In an era of heightened transparency and rapid information flow, any allegations of illegal or unethical conduct can quickly spread through mass media and social networks, causing reputational damage that is challenging to repair.

Key legal grounds for voiding or nullifying contracts obtained through manipulation include:

- Defective Consent (Fraud or Deception): Many civil codes (e.g., Art. 1.214 of the Romanian Civil Code) consider fraud a valid reason for contract annulment when one party uses deceitful means to secure the other's consent.
- False Information in Official Documents: Providing inaccurate data or falsified documents can lead to contract invalidation and potential criminal charges.
- Breach of Good Faith: National and international regulations mandate good faith in contractual and commercial relationships. Violations may render agreements voidable.
- Abusive or Unconscionable Clauses: Courts may invalidate contracts with excessively burdensome terms induced through manipulation.

Pre-Contractual Liability: Manipulative practices during negotiations can lead to claims for damages or contract nullification, depending on applicable laws.

When manipulation escalates into fraud or deceit, the resulting contracts can be annulled, and culpable parties may face civil or criminal penalties. Furthermore, such unethical and unlawful behavior irreparably damages the reputations of those involved, hindering future business relationships.

4.4. Is Manipulation in Negotiations Increased over time?

Evaluating the dynamics of manipulation in negotiations over the past decades remains a challenging endeavor due to the lack of centralized statistical data and the heterogeneous ways in which legislation and specialized studies define and classify the concept of "manipulation." Existing research and reports from professional organizations provide only fragmented insights, often focusing on corporate fraud,

market abuses, anticompetitive practices (such as abuse of dominant position), or general indicators of commercial disputes. Nevertheless, several key observations can be drawn:

*A. **Digitalization and Increased Media Exposure:***

Digital platforms and media coverage of unethical behaviors create the impression that manipulation is on the rise. Social networks and instant news reports amplify the visibility of cases involving fraud or deceit (Lianos & Ivanov, 2019).

*B. **Enhanced Monitoring and Sanctions:***

Organizations such as the European Commission and the Association of Certified Fraud Examiners (ACFE) monitor and report unethical practices more rigorously, leading to increased detection and penalties for manipulative behavior.

*C. **Market Power and Manipulation Distinction:***

While companies with monopolistic power may impose stringent conditions, this behavior often falls under abuse of dominance rather than subtle negotiation manipulation.

*D. **Ethics and Professionalization:***

Many organizations are adopting ethical standards and ESG principles, promoting transparency in transactions and countering manipulative tendencies.

Although concrete evidence of a significant rise in manipulative practices is lacking, certain **phenomena**, like digitalization and increased scrutiny create the perception of greater prevalence. Simultaneously, advancements in legislation and professional ethics improve the detection and penalization of unethical behaviors, underscoring the growing importance of ethical negotiation practices.

In the absence of a robust database that reveals long-term trends, we can only assert that the phenomenon of manipulation in negotiations is being increasingly monitored and penalized, without being able to confirm with certainty a real numerical increase.

5. Alternative Approaches: Constructive and Ethical Negotiation

5.1. The Harvard Method in negotiation

The Harvard Negotiation Method (Fisher, Ury & Patton, 2011) advocates for an approach where parties focus on interests rather than positions, use objective criteria, and separate people from the problem. This perspective seeks to create a collaborative environment, avoiding destructive confrontations, and leading to sustainable, trust-based outcomes.

A. Focusing on Interests, Not Positions

Rather than fixating on rigid statements or strict demands (e.g., "I demand a salary of €5,000"), negotiators are encouraged to express their underlying interests (e.g., "I need financial security and fair compensation for my skills"). This shift helps identify fundamental needs such as security, stability, respect, or professional growth, which are easier to reconcile through creative solutions. Discussions become less rigid and more open to compromise, as each party understands the reasons behind the other's demands.

B. Using Objective Criteria

The Harvard Method emphasizes reliance on independent standards, such as industry practices, salary benchmarks, market prices, legal regulations, or collective agreements. When a deadlock occurs, negotiators can appeal to verifiable data and principles recognized by both sides, rather than resorting to force or subjective preferences. This approach reduces tensions and provides an impartial foundation for decision-making.

C. Separating People from the Problem and Managing Emotions Effectively

A fundamental principle of the Harvard Method is to "be hard on the problem, soft on the people." This means negotiators must rigorously address negotiation content (e.g., price, deadlines, responsibilities) while remaining respectful toward the other party as an individual. This approach entails active listening, recognizing involved emotions, and avoiding personal attacks. By managing

emotional impulses thoughtfully, a constructive dialogue atmosphere is maintained, increasing the chances of reaching a satisfactory agreement for all parties involved. (Fisher, Ury, & Patton, 2011)

5.2. Key Benefits of Principled Negotiation

- **Durable Agreements**: By understanding the real needs of all parties and using objective benchmarks, the final agreement tends to withstand potential future conflicts. Each party feels their fundamental interests are respected, motivating adherence to the established terms.
- **Trust and Mutual Respect**: The principle-based approach emphasizes collaboration and transparency, strengthening long-term relationships. Negotiation partners foster a climate of trust, sharing information openly and considering each other's perspectives.
- **Conflict De-escalation:** Shifting from rigid positions to interests and from personal attacks to objective criteria reduces conflict escalation. The discussion stays focused on solving the issue rather than fueling egos or determining a "winner."
- **Creative Solutions:** Free from the pressure of rigid arguments like "we must get X," parties can identify alternative options or combine resources innovatively to generate additional value. This "expanding the pie" process allows all participants to achieve greater benefits than initially expected.

By applying these principles, negotiators improve their chances of achieving equitable and lasting outcomes rooted in mutual respect, contributing to the preservation or even enhancement of professional and personal relationships.

5.3. Active Listening and Empathy

Although active listening and empathy are implicitly part of the Harvard Method (under managing emotions and separating people from problems), many experts (Shell, 2006; Drollinger et al., 2006) argue that these communication skills deserve a dedicated focus due to their significance.

Active listening involves fully concentrating on the speaker's message, clearly restating key ideas, and seeking confirmation to avoid misunderstandings. This approach prevents misinterpretations, demonstrates respect for the discussion partner, and fosters a collaborative environment.

Empathy entails recognizing and validating the emotions or concerns of the other party without judgment or dismissal. When individuals feel heard and understood, they are more likely to share relevant information about their real interests, enabling the identification of viable solutions for both sides. Empathy reduces emotional tensions and prevents disagreements from escalating into personal conflicts.

Benefits of Active Listening and Empathy

- Facilitate dialogue by clarifying concerns at specific points.
- Prevent conflict escalation by acknowledging emotions and differing perspectives.
- Build trust and encourage negotiation partners to reveal their genuine interests (Drollinger et al., 2006).

Conclusions

Manipulation and persuasion represent two fundamentally opposing approaches to influence in negotiations. While manipulation exploits emotional and cognitive vulnerabilities, seeking unilateral benefits through concealed means, ethical persuasion promotes transparency, mutual respect, and the development of sustainable relationships. This core distinction underscores the importance of understanding not only the implications of these approaches but also their long-term impact on trust, reputation, and the sustainability of both professional and personal relationships.

This article has highlighted the hidden costs of manipulative tactics, ranging from the erosion of trust and deterioration of relationships to legal risks and reputational damage. Such practices, while offering short-term gains, undermine future opportunities for collaboration and destabilize organizational climates. In contrast, principled negotiation, inspired by the Harvard Method, illustrates

how active listening, empathy, and the use of objective criteria can lead to equitable, mutually beneficial, and sustainable solutions.

In an increasingly interconnected and competitive world, integrity, respect, and transparency are vital elements for success in negotiations. Choosing an ethical approach not only enhances the quality of relationships and agreements but also builds long-term trust. Negotiators are therefore encouraged to avoid the pitfalls of manipulation and embrace strategies rooted in collaboration and mutual respect to forge strong partnerships and achieve enduring outcomes.

This conclusion reaffirms the importance of an ethical and constructive perspective in negotiations, emphasizing that true victory lies not in achieving a unilateral advantage but in building relationships and solutions that bring value to all parties involved. While there are challenges, such as the tendency to overlook deep listening in time-constrained contexts, or the impact of cultural differences on how emotions are expressed, careful adaptation can address these issues. Nevertheless, the benefits of an empathetic approach ranging from preventing conflict escalation to enhancing relational satisfaction remain essential.

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Children's literature as a means of pedagogical influence on the way to the emotional intelligence development of preschool children

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Abstract. The article provides a theoretical analysis of the fiction influence on the emotional intelligence and creative imagination development of preschool children. The paper reveals the peculiarities of the relationship between fairy tale therapy and emotional intelligence, which are developed in preschoolers together with reflection and creative potential. The study describes the adult's expediency giving examples of their own behaviour in various life situations when communicating with children. It is revealed that the process of developing emotional intelligence has its own characteristics, but its main structural elements begin to develop in older preschool age and are improved throughout the entire school period of study. The focus is on the fundamentals of emotional intelligence development as one of the key elements of the development of preschoolers' imagination, which include children's fiction, stories, and fairy tales. It is proven that the development of emotional potential in preschool age will help regulate their own mood and behaviour, teach how to cooperate with adults and peers.

Keywords: *children's literature, emotional intelligence, reflection, socialization, self-awareness, self-regulation, empathy, fairy tale therapy.*

Introduction

In the context of modernity, at the stage of the information society development, the determinants issue of the formation and development of each individual creative potential is particularly acute. The beginning of the XXI century is recognized by scientists as extremely productive for significant discoveries in the field of psychological and pedagogical research, it was during this period that scientists managed to more thoroughly investigate the role of emotional intelligence in the life of each individual. The work of researchers in the past allows us to define emotional intelligence as the ability to social adaptation, the ability to use, understand the emotions of others. Emotional intelligence is a tool for human self-regulation, stress reduction, effective communication, showing empathy for other people, the ability to respond to life's challenges and resolve conflicts.

1. Analysis of recent research and publications

According to the observations of Dr. J. Gottman, who in the book "Emotional intelligence of the child. A practical guide for parents" found that parents who show compassion and empathy in their interactions with children, thereby help them fight their own negative feelings, and contribute to a better values assimilation and the spiritually enriched personalities growth [3].

Modern scientist in the field of psychology V. Zarytska in her works interprets the concept of emotional intelligence as a tool for understanding the environment, social relationships, and one's own inner world. It develops simultaneously with such vital psychological concepts as reflection, introspection, emotional competence, identification, and self-analysis [4].

L. Burkova believes that emotional intelligence is an extremely important manifestation of an individual's mental activity, as it has a dual functionality. On the one hand, it helps to interact with the inner world and counteract one's own conflicts, on the other hand, it contributes to the process of socialization, adaptation in society, helps to interact with others through effective communication and a clear analysis of the interlocutor emotions [1].

Thus, emotional intelligence is a way and form of behaviour and a person's attitude towards himself/herself and others. This is the ability to accurately determine and analyse the emotions expressed by others, as well as to predict their consequences. Therefore, it is important for each individual to understand not only his own feelings, but also the emotions of other people, which are often associated with both internal and external manifestations of behaviour. The emotional intelligence of both adults and children can be developed through painting, art, literature and game.

2. Formulation of the objectives of the article

The purpose of the article is to carry out a theoretical analysis of the emotional intelligence phenomenon in the context of the development of preschool children creative imagination, to substantiate the influence of children's literature on the development of emotional intelligence and creative potential, to identify the relationship between the emotional intelligence of preschool children and their ability to reflect.

3. Presentation of the main material

The main task of children's literature, which contributes to the development of emotional intelligence and reflection in preschool age, is the continuous contemplation of the world around the child on the basis of his/her creative potential development. The early manifestations of child's mental activity should be provided with information in an arbitrary form, for example, fairy tales. This will help him/her develop associative thinking, form axiological guidelines. In preschool age, the child needs constant saturation with new information, which will initially serve as a kind of basis for world perception, and in the future will contribute to the development of creative imagination.

It is also worth mentioning that the development of creative imagination is impossible without improving sensory-figurative thinking, which is an integral part for the formation of a child's creative potential. Informative accumulation allows a child to cope more easily with intrapersonal conflicts and the future crisis associated with the child's beginning to attend school. The process of developing emotional intelligence has its own characteristics, but its main structural elements begin to develop in senior preschool age and are improved throughout the entire school period of study. It's already in the senior grades, a child-adolescent has the opportunity to achieve such a high level of emotional intelligence development that in adulthood he/she can successfully continue his/her studies and establish communication with unfamiliar people in new social conditions.

The child's ability to distinguish himself/herself in the world begins from the moment of his/her integration into society. The formation of a preschool child's own "I" depends entirely on the influence of the cultural heritage of the environment in which he/she grows. Not only success, but also the pace of the socialization process depends on it. From early childhood, adults begin to introduce a child to the world of fairy-tale heroes. Because it is a fairy tale, due to its accessibility for understanding, that allows a child to be as a part of society, instils axiological guidelines, explains the comparison of the

positions of "good" and "evil". It is worth noting the influence of this type of creativity as a form of psycho-emotional guideline for an individual, which allows a child to distinguish between both positive and negative manifestations and actions on the example of fairy-tale heroes.

Fairy-tale therapy is a direction in practical psychology that, using the metaphorical resources of a fairy tale, allows people to develop self-awareness and build special interaction with each other for a further full life [5]. Fairy-tale therapy is a relatively new direction, but one of the most effective methods of psychological help and support, since the first stories appeared simultaneously with the emergence of language. Stories and tales were created on the basis of repeatedly told by people in order to transfer and assimilate knowledge, experience, examples of man and nature interaction. The mankind experience, examples of feelings, heroes' actions, options for interaction with the outside world i.e. all this was and is the ontogenesis of the word and language, with this help the society created a fairy tale as a means of therapy. Fairy tale therapy is also a system of education allowing you to didactically form ideas about basic life values. It is also worth analysing the deep connection between a fairy tale and the human subconscious. Stories and narratives used in fairy tale therapy are saturated with symbols, images and metaphors, which in turn encourage the listener to make associations i.e. this is one of the fairy tale therapy functions, which allows you to realize what the consciousness has pushed into the subconscious and what it has refused, that is, its self-awareness develops. Gradually, everything acquires signs of control and is naturally integrated into a person's real experience, therefore, the self-regulation process occurs. In stories, based on examples of the heroes' actions, one's own experience is acquired, which is integrated into the human consciousness and will further contribute to the development of social sensitivity, the ability to regulate relationships, and the development for new ways of interacting with oneself and the world around them. Therefore, it is difficult to overestimate its significance in the education of preschool children.

The fairy tale key functionality is the reproduction of the associative process and the improvement of creative imagination, which arises through the individual analysis of the main characters and the fairy-tale world interaction (sensory and figurative perception of the story by the child). In the process of illustrations examination, associative thinking and the ability to compare is developed. Comparing himself with the main character, the child is able to program himself at an unconscious level in terms of positive or negative behavioural guidelines. In other words, he/she takes an example, imitates actions, learns to recognize morality and immorality. This process is quite complex, but embodies the first steps towards the intellectual improvement of the individual.

The ability to identify with the heroes of a fairy tale allows a child to associate good with good deeds in his/her early years, and evil with villainy, injustice, cruelty. Thus, with the help of fairy tales, he/she tries to understand such moral maxims of society as responsibility, nobility and generosity from an early age. Therefore, preschool children in real life try to reproduce the fairy tale hero's behaviour through the game. Returning to the analysis of the fairy tale functionality and the isolation of the main influence of fiction on children, it is advisable to note that this type of creativity allows a child, using his own attention and imagination, to analyse and compare the actions of the story heroes, to establish cause-and-effect relationships between the actions of the characters, and to learn to draw his/her own conclusions. This type of intellectual load is able to develop mechanisms for self-awareness and identification. If a child copes with the identification process quickly enough, then the reflection beginnings appear only in preschool age. That is why it is worth devoting more time to fairy tales and fiction, this is a kind of investment in the individual future.

According to Ya. Ponomaryev, reflection is one of the main characteristics of creativity, when a person becomes an object of control for himself/herself. Reflection is like a mirror that reflects all personal changes. In this context, reflection is the main means of self-development, a condition and a way of transforming mental abilities. The child is not sufficiently aware of his/her own mental operations and therefore is not able to fully master them. He/she is not yet fully capable of in-depth analysis and introspection. Only under the influence of discussions, contradictions and objections does the child try to find other, more complex ways to transform information. In addition, researchers

explain the reflection concept as the ability of the subject to "isolate, analyse and correlate his own actions with the objective situation". In this case, reflection is considered in its intellectual aspect.

In general, scientists distinguish four main types of this psychological phenomenon i.e. cooperative, communicative, personal, intellectual.

What is important in all of the above concepts is that in their totality they determine the diversity of contents that act as objects to which reflection can be directed. This phenomenon is best observed on children's literature example: fairy tales develop the child's ability to formulate certain beliefs about the inner world of fairy tale characters, explain the reasons for their actions i.e. this is communicative reflection; fiction allows us to analyse the relationships system using the example of the interaction of characters i.e. cooperative reflection; the properties, qualities, behavioural characteristics, and status of a fairy tale character are attributed to personal reflection; another function of children's stories is the development of the individual's intellectual abilities, which are manifested in the process of solving various problems and the ability to analyse.

Fiction stories processing by preschool children helps to improve brain activity. Discovering the world of books, the child begins to get acquainted with the norms of society, becomes more mobile in making socially responsible decisions, therefore, has every chance of going through the socialization process more dynamically. It is worth noting that the influence of fairy tales on the child is quite abstract in nature, but this influence is quite noticeable. After all, from an early age, a child who tried to find answers to his/her own questions in fiction, at a more mature age, copes more easily with the tasks of adult life. A creative approach to solving tasks that the child is accustomed to from an early age will contribute to the more appropriate use and development of his/her own creative potential in the future.

In most cases, the driving force and source of personality development is his/her creative potential. This problem was highlighted in the works of such scientists as V. Andrushchenko, M. Boychenko, V. Zablotsky, M. Mykhalchenko, etc. They reveal the very concept of the individual creative potential, considering it at the level of studying the potential and actual characteristics by a person. The main idea in the works of scientists is that creative potential is interpreted as a form of the individual creative activity. Creative potential is a dynamic structure that includes a complex of creative inclinations that manifest themselves in the individual creative activity and is driven by creativity. Creative activity on the culture general scale leads to the uniqueness of a person in the cultural and historical aspect and his/her phenomenality. Thus, the person himself/herself is a culture phenomenon himself/herself and as a result, his/her creativity becomes important in a wide social space. The creative uniqueness of such a person is both a condition and a result of the creative process. In addition, under such a condition, there is a possibility of a person's conscious choice for a creative life position and the development of his/her creative potential.

4. Research Methods

Analysing the works of the above-mentioned scientists, we assume that creative abilities are closely related to intelligence. The theory is reinforced by the concept of ten thousand hours of work by M. Gladwell. The famous modern American sociologist in his book "Geniuses and Outsiders" describes the phenomenon of successful people who have become virtuosos in their field through constant improvement, hard work and introspection. The author emphasizes the importance of systematic work as a professionalism and genius guarantee, giving the example of such famous people as B. Gates, B. Joy, R. Oppenheimer, W. Mozart, P. McCartney.

The assumption is that to achieve success in any area of life and to achieve a high level of skill with the status of a world-class expert, about one hundred thousand hours of practice are required. And this condition applies to all professions without exception. Ten thousand hours is about three hours of work per day, or twenty hours per week for ten years. This does not explain why some people find classes more useful than others, but so far there is no known case when the highest level of skill would

be achieved in less time. It seems that this is exactly how much time the brain needs to absorb all the necessary information. M. Gladwell's idea is to adapt a person to a systematic mental load, which later allows him to be more successful in his chosen professional field of activity [2].

A child who is accustomed from an early age to perceive and process a relatively large amount of information, subsequently expands these boundaries to the point of creating his/her own creative product of imagination. The American researcher considers the concept of genius not to be an innate gift, but success, which is due to hard work, systematic improvement, and constant intellectual enrichment. It is worth noting this as the main condition for success. If the mental activity of an individual from preschool age has a systematic progressive character, then in adulthood it will have a number of advantages, in particular, competitiveness, which is significantly noticeable among peers.

Therefore, if a child's attention, imagination, memory, and thinking are developed from an early age, then he or she will be suitable for more intensive intellectual work in the future. The fundamental basis of these abilities for an individual is his or her understanding of social processes, cause-and-effect relationships, and norms of behaviour that are embedded in the distorted form of the fairy-tale world.

5. Conclusion

Thus, we can conclude that at the current stage of society's development, in the period of information technologies rapid development, the personal potential development, self-improvement and work on oneself are extremely important. In the field of psychological science, it is known that the most effective is the individual development of the preschool children intellectual potential, because the persistent mental activity of children will definitely come in handy during the socialization process. Modern science is trying to more thoroughly investigate mental activity at the early stages of the formation of individual properties of intelligence. Thanks to the fruitful efforts of scientists, we understand the interdependence of the success of the individual and emotional intelligence, creative potential, reflection and introspection. The earlier a child begins to realize himself/herself, feel his/her own unique inner world, work on mistakes, develop an immanent (internal) moral core, the easier the process of socialization and successful adaptation in society. The child's fascination with fairy tales can play a key role in the independence of socially responsible decisions made by him/her, because a fairy tale with its moral central message strengthens the moral and ethical guidelines of the individual. Thanks to the development of reflection and introspection, the child learns to analyse the problems of the fairy tale world at a theoretical level, transfer this knowledge to reality and apply it in practice, because many fairy tales have an educational, training and cognitive nature, often demonstrate examples of socially desirable behaviour, for example, familiarization with ethical norms.

Instead, emotional intelligence is a more comprehensive concept that includes not only self-awareness, but also an understanding of the interlocutor’s emotions and feelings. The ability to quickly and skilfully read the mood of others helps a child in the process of resolving various life situations and establishing socially important contacts.

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Considerations regarding the management and protection of the „Monumental ensemble created by Constantin Brâncuși in Târgu-Jiu”

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Abstract. This paper presents aspects related to the importance of the "Monumental Ensemble created by Constantin Brâncuși in Târgu-Jiu" for national and universal cultural heritage, in the context in of its inclusion on the UNESCO World Heritage List starting with 2024. In accordance with national and international provisions on the preservation of national and universal cultural heritage, the paper highlights the necessary measures to be adopted by institutions with relevant competencies, both at central and local levels, for the optimal management and protection of the ensemble, considering its inestimable value for national and universal cultural heritage. The optimal valorization of the "Monumental Ensemble created by Constantin Brâncuși in Târgu-Jiu" can contribute to strengthening Romania’s international profile.
Keywords: *Monumental ensemble, Constantin Brâncuși, heritage, management, protection*

1. General considerations regarding National Cultural Heritage

The National cultural heritage represents an „essential resource for Romania’s identity and for the development of a society of peace and stability, based on respect for human rights, democracy, and the rule of law," especially in the context of emerging unconventional threats that undermine the role of the national state and its defining values. [1]

The preservation of national cultural heritage represents a fundamental obligation of any modern state, considering values, beliefs, knowledge, and traditions, through the institutions with responsibilities in the field —such as the National Heritage Institute, County/Municipality of Bucharest Directorates for culture, subordinated museum institutions, national/local administrative authorities, institutions in the fields of national security and public order etc—regardless of its form of expression: archaeological heritage (sites, vestiges, etc.), immovable heritage (monuments, ensembles, sites), movable heritage (museums, archives, collections, etc.), or intangible heritage (crafts, games, rituals, etc.). [1]

The importance of cultural heritage is also reflected in the international regulatory frameworks governing this issue, such as: The Paris Convention (16.11.1972) on World Cultural and Natural Heritage [2]; The Hague Convention for the Protection of Cultural Property in the Event of Armed Conflict (adopted on 14.05.1954) [3]; The Protocol for the Protection of Cultural Property in the Event of Armed Conflict (adopted on 14.05.1954) [4]; The Second Protocol to the Hague Convention (adopted on 26.03.1999) [5]; The Convention on the Protection of the Underwater Cultural Heritage (adopted in

Paris, on 02.11.2001) [6]; The Convention for the Safeguarding of the Intangible Cultural Heritage (adopted in Paris, on 17.10.2003) [7]. Of particular significance is the *Convention concerning the Protection of the World Cultural and Natural Heritage*, adopted by UNESCO in 1972 and ratified by Romania in 1990, which laid the foundation for the World Heritage List, "a list of cultural and natural heritage assets deemed to have outstanding universal value." [8]

In Romania, Law no. 182 of October 25, 2000 (republished) [9]—which establishes the legal framework for movable national cultural heritage as part of the national cultural heritage, Law no. 564 of 2001 for the approval of Government Ordinance no. 47/2000 regarding the approval of certain measures for the protection and management of cultural heritage assets listed on the World Heritage List [10], Law no. 422 of 2001 (republished) [11]—which regulates the general legal framework of historical monuments and Law no. 378 of 2001 on the protection of archaeological heritage and the declaration of certain archaeological sites as areas of national interest [12], as well as Government Decision no. 857/2021 for the approval of the framework regulation and the composition of UNESCO organizing committees [13], are just a few of the normative acts that regulate the issue of protecting national cultural heritage sites. The aforementioned normative acts align with the policy of conservation, recovery, and protection of cultural heritage found in the consolidated version of the European Union treaties, which stipulates the need to strengthen the cultures of member states by enhancing their national cultural heritage.

2. The universal dimension of the "Monumental ensemble created by Constantin Brâncuși in Târgu-Jiu"

The Sculptural Ensemble of Târgu-Jiu, created by Constantin Brâncuși, extends along a west-to-east axis that crosses the city of Târgu-Jiu, starting from the banks of the Jiu River in the Central Park of Târgu Jiu, where the works carved in stone are located —Table of Silence, Alley of Chairs, and the Gate of the Kiss—are located. It continues along the Avenue of Heroes, where the Saints Apostles Church is situated, followed by the Endless Column, made of brass-clad cast iron and steel, standing in the middle of the park that bears the same name. [14]

The process of inclusion in the World Heritage List of the Sculptural Ensemble of Târgu-Jiu realized by Constantin Brancuși was started on March 1, 1991 when the ensemble was placed on the tentative list. In 2011 steps were taken to prepare the nomination file. On February 20, 2011, the Local Council of Târgu-Jiu passed a resolution to start the procedures for the inclusion of the Monumental Ensemble "Avenue of Heroes" on the UNESCO World Heritage List.

However, the Romanian state later withdrew the nomination in 2015 following an evaluation report by ICOMOS experts. Subsequently, in 2016, the National Heritage Institute Institute commissioned expert Barry Gamble for the preparation of the new nomination file, which was submitted in January 2018. In March 2018, the UNESCO World Heritage Centre announced that the nomination file met the technical compliance criteria. [15]

Under the title "Monumental Ensemble created by Constantin Brâncuși in Târgu-Jiu", it was inscribed on the UNESCO World Heritage List following Decision 46 COM 8B.24, adopted by the UNESCO World Heritage Committee (WHC) on July 27, 2024, thus recognizing the ensemble's outstanding universal value. It is regarded as "an exceptional work, a fusion of monumental abstract sculpture, landscape architecture, engineering and urban installation that offers a sequential commemorative experience on an urban scale, carrying powerful symbolic meaning and marking an artistic expression of great strength and purity on multiple levels: artistic, symbolic, and spiritual." [16] Given these circumstances, coherent measures must be adopted to ensure the management and protection of the "Monumental Ensemble created by Constantin Brâncuși in Târgu-Jiu", seen as a strategic resource that provides the local communities and Romania with economic, social, and cultural capital, essential for asserting the country's position on the international stage.

3. Institutional responsibilities in the management and protection of the monumental ensemble

The Ministry of Culture is responsible, according to Government Ordinance No. 47/2000 on the approval of protection and management measures for cultural heritage assets listed on the World Heritage List, as well as Government Decision No. 857/2021 for the approval of the framework regulation and the composition of UNESCO organizing committees, to initiate the establishment of the UNESCO Organizing Committee (COU). The aim of this structure—comprising representatives of authorities and institutions with competencies in the field, the property owner, the local community, and experts—is to oversee the fulfillment of the Romanian state's obligations regarding the management and protection of the Monumental Ensemble created by Constantin Brâncuși in Târgu-Jiu [17]. Additionally, ministry officials may collaborate with local public administration authorities and public institutions responsible for cultural heritage protection to implement cultural policies initiated by the ministry.

The National Institute of Heritage, a subordinate entity of the Ministry of Culture, is authorized—based on its methodological and scientific role in the management and protection of World Heritage sites as conferred by the aforementioned national legislation—to propose the designation of specialists from museum institutions and academia for inclusion in the COU. It is also responsible for making recommendations on the methodology for selecting local community representatives in the COU [18].

The Prefecture of Gorj County has responsibilities regarding the implementation of the Government Decision that defines the role of decentralized institutions in the organization and protection of the Monumental Ensemble created by Constantin Brâncuși in Târgu-Jiu. These institutions include the County Directorate for Culture, structures of the Ministry of Internal Affairs, etc. [19].

The Gorj County Council is responsible for initiating the activities necessary for establishing the COU. It is also the institution that drafts the regulations for selecting the three community representatives through a procedure that adheres to principles of transparency. Additionally, the council establishes specialized departments or positions within its own structure or, if necessary, assigns specific service duties related to the protection of cultural heritage assets listed in the World Heritage List (LPM) [20].

The Gorj County Directorate for Culture is responsible for fulfilling legal obligations related to the protection of national cultural heritage. It collaborates with public authorities and specialized institutions to ensure the conservation and promotion of this heritage, applying the relevant legal provisions accordingly. Together with local authorities, it ensures the implementation of the "Heritage Property Listed in the LPM" emblem and oversees its maintenance by the owner [21].

The Constantin Brâncuși Research, Documentation, and Promotion Center has the primary objective of preserving and promoting the Monumental Ensemble " Avenue of Heroes " in Târgu-Jiu, an internationally recognized masterpiece of artistic and historical value. In addition to this mission, the center actively participates in disseminating information and promoting both local and national tourism, thus facilitating public access to this exceptional cultural heritage. One of the center's essential roles is the protection and preservation of the Monumental Ensemble " Avenue of Heroes " against risk factors, whether natural or human-induced. Climate change, pollution, and other external factors can threaten the integrity of the monument, making continuous monitoring and maintenance essential. By assessing risks and identifying appropriate solutions, the center's experts ensure the transmission of cultural heritage to future generations [22].

The Constantin Brâncuși University of Târgu-Jiu, a higher education institution named after the great sculptor can nominate to the EOC researchers or teachers who have carried out research on the history of the monument inscribed in the LPM. Additionally, the university can contribute to the drafting of specialized studies outlining the measures that need to be taken by the institutions with competence in the field in order to optimally manage and protect the ensemble, given its inestimable value for the national and universal cultural heritage.

The Târgu-Jiu Municipality, the administrative-territorial unit where the Monumental Ensemble created by Constantin Brâncuși in Târgu-Jiu is located, is responsible for finalizing the Zonal Urban Plan for the Monumental Ensemble " Avenue of Heroes ", while simultaneously updating the General

Urban Plan of Târgu-Jiu. Additionally, the Management and Protection Program for the Monumental Ensemble must be updated in parallel with the integration—together with the COU—of an appropriate Interpretation Plan. Furthermore, a project must be developed to mark the Monumental Ensemble with specific UNESCO World Heritage signs, including its proper road signage [23].

To protect cultural heritage assets listed in the LPM and ensure compliance with legal provisions in this field, local public administration authorities collaborate with organizations and public institutions responsible for the protection of cultural heritage assets, implementing and respecting their decisions [24].

National intelligence agencies have the role, as established by the documents that regulate their activity, to assist, from an informational point of view [25], the decision-making process exercised by those responsible for national identity values, namely "national cultural heritage, subject to a combination of erosive factors, objective or subjective, which may jeopardize the identity cohesion of society" [26].

This proactive approach is necessitated by societal transformations, where globalization has facilitated the emergence of new risk factors and threats to the identity of states [27]. Thus, protecting national cultural heritage is a fundamental element in maintaining the identity standards of any state entity, scientifically proving its origins and continuity within a specific physical and cultural space. . In this context, intelligence agencies have the mission to be aware of national security issues [28], specifically the identification, prevention, and counteraction of actions that may harm national cultural heritage, carried out by members of domestic or transnational criminal organizations [29], including with the "support" of certain authorities directly or indirectly involved in the phenomenon [30].

The Romanian Police, through the Criminal Investigations Directorate, is authorized to carry out specific activities to protect national cultural heritage from actions undertaken by interested individuals, such as "the theft of heritage or religious objects from archaeological sites, churches, monasteries, and hermitages, from private homes and collections, museums, or public collections," as well as other "criminal acts affecting historical monuments or their protected areas" [31], in which elements of organized crime are involved, both nationally and transnationally.

The national legislative framework grants the Criminal Investigations Directorate authority over organizing, coordinating, guiding, and evaluating activities related to combating "crimes against persons, property, authorities, etc.," including those aimed at protecting national cultural heritage, particularly those involving sophisticated methods and causing significant damages. The directorate is also responsible for recovering stolen cultural assets and ensuring cooperation through EUROPOL, as well as coordinating nationwide efforts to combat crimes against cultural heritage, particularly those committed by organized itinerant criminal groups [32].

4. Conclusions

Given that national cultural heritage represents an "essential resource for Romania's identity and for the development of a society based on peace and stability, respect for human rights, democracy, and the rule of law" [1], its preservation is a fundamental duty of Romania as a democratic state aligned with modern global values.

The importance of the Monumental Ensemble created by Constantin Brâncuși in Târgu-Jiu for both universal and national culture, through its inclusion in the UNESCO World Heritage List, necessitates the adoption of coherent measures for its management and protection by the institutions responsible at both central and local levels. These measures aim to valorize the ensemble as a strategic resource that encompasses economic, social, and cultural capital, essential for the country’s international recognition. For the management and protection of the Monumental Ensemble created by Constantin Brâncuși in Târgu-Jiu, a crucial role belongs to the local public administration authorities who must initiate cooperation measures with public bodies and institutions responsible for the protection of cultural heritage assets, in order to enhance the exceptional value of the ensemble.

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Exploring the primary drivers of innovation in fintech start-ups: a case of Sasai

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Abstract. The traditional financial services business has seen rapid change as a result of the digital transformation brought about by the fourth industrial revolution, which has given rise to sophisticated technology-enabled financial services, or fintech. Because of its disruptive nature, fintech is rapidly gaining popularity all around the world. This movement is mostly supported by participants who are underserved by traditional financial service providers. Global investments in fintech are growing rapidly each year because to the increased interconnection brought about by the digital revolution. The word "fintech" describes a wide range of innovative applications in a variety of services, including insurance, asset management, payments, and financing. The literature and visualization research do not adequately address the role of financial regulations, the impact of fintech advancements in payments and financial services, or their future trajectory. The creation of an innovation management framework for Fintech start-ups in Zimbabwe was examined in the study. The objective was to assess the elements that help Zimbabwe's constantly expanding economy produce creative solutions. There were 650 people in the research population, resulting in a sample size of 250. A 50% response rate was obtained by distributing the questionnaires over an internet link. It was found that some of the main factors driving innovation in Zimbabwe's start-ups are customer demand, appropriate regulatory pressures, and technology improvements. Second, this simple method allows us to think about innovation from a wide angle even though it is micro-focused. The study's findings broaden our knowledge of fintech developments in the financial services industry and highlight how crucial these innovations are to figuring out how businesses will develop going forward. The study's conclusions have implications for scholars who might utilize them as a reference to develop a thorough mapping and a comprehensive comprehension of fintech advances.
Keywords: *fintech; innovations; payments; financing; financial services*

Introduction

Fintech has affected overall economic growth in a number of countries. New generation businesses in retail trade and investment banking have successfully merged the power of the internet with user-friendly smartphones. Banking applications have reduced banking procedures and made banks more accessible online than through traditional channels, allowing customers to conduct digital transactions (Wang 2021). In an environment that has emerged as a result of the fourth industrial revolution, more disruptive and digitally transformational technologies—like the Internet of Things, extended reality, artificial intelligence, etc.—are altering our way of life (Schulte and Liu 2018).

This change has also affected the financial sector, resulting in the rise of fintech, which is primarily defined by the introduction of technical advancements that aid in the creation of novel, lucrative ventures pertaining to financial services (Stern et al. 2017). Fintech is defined as financial services supported by

technology that leverage integrated IT to enhance critical performance, according to Wonglimpiyarat (2017a). Fintech produces quick revenue, offers high-quality service, and lowers costs than traditional financial services, which reorganizes the financial sector and stabilizes the financial system (Shin and Choi 2019). Technology integration, forecasting, and process efficiencies in various finance activities serve as proof of the financial services industry's quick transition from the inquiry to the application stages (Kou 2020).

Fintech companies are typically small-equity start-ups, made up mostly of SMEs with a strong understanding of a new product or how to enhance an already-existing service (Saksonova and Kuzmina-Merlino 2017). Innovation has improved profitability by changing the performance and output of several sectors. Arner et al. (2016) reviewed the literature on the history of fintech and came to the following conclusions: fintech 1.0 (1866–1967) was the shift from analog to digital practices; fintech 2.0 (1967–2008) was the expansion of conventional digital financial services that led to the digitalization and globalization of finance; and fintech 3.0 (2008–present) is about making digital financial services accessible to everyone.

In the wake of the 2008 global financial crisis, the importance of financial services expanded. Up until that point, traditional financial services represented a stronghold for stable corporate environments and secure jobs (Gomber et al. 2018). According to Saksonova and Kuzmina-Merlino (2017), the rise of fintech companies was driven by two factors: technological advancements that improved performance, customer experience, and convenience on the one hand, and the limitations of the traditional banking system that put customers in dangerous situations on the other (Gassot et al. 2016; Haddad and Hornuf 2019; Haikel-Elsabeh et al. 2016; Soulé 2016).

The diverse needs for finance have not been met by traditional sources of funding. While crowdfunding, peer-to-peer lending, microfinance, venture capital, crowdfunding, SME stock exchanges, and other financial innovations may have originated in one region of the world, they swiftly spread throughout the world (Drummer et al. 2017; Ibrahim 2018). But as fintech continues to grow and innovate, numerous previously undiscovered possible solutions to issues facing the financial services sectors are becoming apparent (Lu 2018). Fintech's quick rise to prominence and spread to unbanked areas have been made possible by the Internet, which has made financial services more easily accessible to the general public (Popkin 2019). A current comprehensive evaluation is required for

Innovation management is becoming more and more important in Zimbabwe for new enterprises to succeed. There is a strong entrepreneurial spirit in the nation, as evidenced by the increasing number of people and groups entering a variety of industries, including as renewable energy and e-commerce (Shadow, 2020; Kakpovi, 2023). Zimbabwe has particular regional difficulties, such as complicated regulations and little economic resources (Mashavira, 2020). Novel strategies are required to overcome these obstacles and continue to expand. In the nation, startups frequently function in resource-constrained settings where effective resource allocation is essential (Vakirayi, 2020; Siwale, Thondhlana, and Madziva, 2021).

Innovation management techniques aid in optimizing impact, cutting waste, and making effective use of scarce resources. Zimbabwe's market conditions also necessitate that start-ups possess a high degree of adaptability (Karambakuwa, 2021; Manyangadze, 2021). It is critical to have the flexibility to adjust course, improve tactics, and react quickly to shifting market conditions (Karambakuwa and Bayat 2022). The structure that innovation management offers for consistently coming up with and putting new ideas into action is crucial in a local environment that is changing quickly.

But even with these focused insights into the Fintech scene in Zimbabwe, there is still a lack of frameworks for innovation management. Although the local studies have shown potential and problems unique to Zimbabwe, they haven't yet produced a comprehensive framework for innovation management that is appropriate for the requirements of Fintech start-ups operating there. This vacuum is a serious shortcoming in the corpus of information now available, depriving investors, policymakers, and Fintech entrepreneurs in Zimbabwe of a clear road map for managing innovation effectively in a quickly changing and exceptionally difficult local context.

One major obstacle that EcoCash, a well-known player, has is the lack of a specific local payments API (Masarakufa, 2019). This restriction makes creative workarounds necessary for companies that operate in the nation and makes it more difficult for EcoCash to be seamlessly integrated with other services. Moreover, regulatory obstacles present a challenging balance between promoting innovation and adhering to the changing regulatory environment. EcoCash always places a high premium on strong security measures to protect customer funds and sensitive data.

Another notable platform, Sasai, has difficulties becoming widely used even if it has potential. Achieving a critical mass of users and defeating competitors are seen as crucial objectives. Building customer trust and maintaining continuously dependable service delivery remain ongoing problems, but improving the user interface, functionality, and overall experience stands out as a crucial tactic to boost Sasai's appeal (Dzoma, 2021).

Though platforms such as Ecocash and Sasai have brought attention to the growing importance of Fintech in Zimbabwe, there is still a critical research gap regarding the lack of a complete innovation management framework designed with Fintech start-ups in mind. Although focused research has illuminated obstacles and prospects in Zimbabwe's Fintech scene, there is a lack of a comprehensive framework that can direct and maximize innovation management tactics for Fintech business owners in the country.

The distinct features of the Fintech ecosystem in Zimbabwe, such as its quickly changing market, economic limitations, and regulatory intricacies, highlight the research vacuum in a particularly striking way. Fintech entrepreneurs, authorities, and investors lack a clear roadmap for managing the complex problems of the local environment due to the lack of a customized innovation management framework. Thus, by offering a context-specific manual for efficient innovation management in Zimbabwe's dynamic Fintech scene, the proposed research, which focuses on creating an innovation management framework for Sasai Fintech, seeks to close this crucial gap.

Literature discussion

Within the field of innovation management, academics have delved deeply into the complex dynamics of promoting innovation in modern firms, particularly in the highly competitive financial technology (Fintech) sector. This literature review critically analyzes prior research in order to give a comprehensive overview of the body of knowledge previously known in the field and to set the stage for the proposed study, which intends to establish an innovation management framework specifically for Sasai Fintech in Zimbabwe.

The ever-changing demands of the business environment continuously shape the dynamic landscape of innovation management strategies. Afuah (2020) highlights the necessity of continuous research in strategic planning and technology management, emphasizing the need for flexible frameworks. Building on Afuah's observations, this study draws emphasis to the nuances of innovation management within the unique Sasai Fintech context.

It's especially clear how tactics and frameworks have evolved over innovation management's historical development. The Stage-Gate Model, created by Cooper (1990), is one important early strategy that had a big impact on the landscape (Patterson, and Agarwal, 2023). According to Wynn and Clarkson (2023), this model is an organized approach to managing the innovation process, particularly when it comes to new product creation. A methodical and structured framework for directing innovation through discrete stages, each denoted by a different gate, was introduced by the Stage-Gate Model.

The Lean Startup movement, which Ries (2011) initiated, brought about a paradigm shift in the field of innovation management. In addition to changing organizational methods, this transformative approach has caused a significant reevaluation of traditional practices (Shepherd and Gruber, 2021; Kaylan et al., 2022). The Lean Startup and Agile approaches become important focal areas as this research explores the subtleties of innovation management in the context of Sasai Fintech, with significant ramifications for the field.

Chesbrough's revolutionary idea of open innovation from 2003, which has become a key advancement in the field of innovation management, is another concern in the evolution of innovation

(Beck et al, 2022; Chesbrough et al, 2024). According to Solaimani and van der Veen (2022) and Srisathan, Ketkaew, and Naruetharadhol (2023), it promotes companies to aggressively engage with external sources of innovation in order to surpass their own capabilities. Battistella, Ferraro, and Pessot (2023) claim that this strategy promotes strategic acquisitions, technology licensing, and cooperation with outside parties, all of which help to create a more porous innovation boundary. Based on the above discussion, a hypothesis is developed which explores the relationship between Fintech start-ups and the drivers of innovation.

Null Hypothesis (H0): Fintech start-ups in Zimbabwe do not significantly correlate with the key drivers of innovation.

Adopting open innovation means Sasai Fintech is changing its approach to strategically relying on outside knowledge, resources, and market intelligence to improve its capacity for innovation. According to Urbinati (2020), Chesbrough's definition of open innovation includes a variety of cooperative methods, obtaining outside technology, intellectual property, or creative solutions. Sasai Fintech can accelerate its innovation goal by establishing a dynamic ecosystem through the integration of various techniques.

The most revolutionary advance of them all has emerged in recent years: the integration of machine learning and artificial intelligence (AI) into innovation management. The analysis of large data sets, pattern recognition, and well-informed decision-making for innovation strategies are made easier by AI-powered solutions from platforms such as H2O.ai and DataRobot (Śmietanka, Koshiyama, and Treleaven, 2021; Aldoseri, Al-Khalifa, and Hamouda, 2023; L'Esteve, 2023). Moreover, AI-powered solutions automate repetitive jobs, freeing up innovation managers to focus on higher-value duties.

A number of reasons, including the government's encouragement of entrepreneurship, easier access to technology, and the youthful and highly educated population of Zimbabwe, have contributed to the country's recent boom in start-up businesses. Makate et al.'s research (2019), which examines innovative skills in Zimbabwe's unorganized sector, highlights the significance of innovation in the country's economic environment. Their research highlights the inventiveness and tenacity of informal actors, providing insightful information about potential adaptable tactics for Sasai Fintech.

Null Hypothesis (H0): The growth and success of Fintech start-ups in the Zimbabwean market are not significantly impacted by innovation management practises.

It has been determined that a number of variables are essential for fostering innovative capacities in Zimbabwe's startup businesses. In order to foster innovation capabilities in Zimbabwe's start-up firms, Chiwenga (2021) highlights the significance of government support, funding accessibility, mentorship and networking opportunities, and a supportive business environment. Additionally, they offer instances of prosperous startups that have incorporated these elements, such EcoFarmer, a Zim-based startup that has benefited from government backing and financing availability to create creative approaches to sustainable agriculture (Murisa, 2020).

Drawing insights on the challenges and opportunities to innovation in Zimbabwe the nation that has experienced political and economic turmoil in recent years, which has hindered its ability to develop and implement innovative solutions. Gwaka, Haseki, and Yoo, (2023) noted that one of the primary challenges of innovation in Zimbabwe is the lack of access to reliable infrastructure, such as electricity and internet connectivity. This makes it difficult for organizations to adopt and implement innovative technologies and business models (Maphosa, 2021; Mthwazi, 2022). Additionally, as ascertained by Mhlanga, Shava, and Dzingirai, (2023) the country's political climate has often been unstable, which can hinder long-term investment in innovation. However, according to Togo, and Gandidzanwa, (2021) the country has a highly educated population, which can be harnessed to develop innovative solutions for local and global challenges which is a great opportunity for start-ups. Furthermore, the Zimbabwean government has shown a willingness to invest in infrastructure and technology, which can pave the way for future innovation (Mthwazi, 2022).

Null Hypothesis (H0): There is no discernible impact of Fintech start-up obstacles and hurdles in Zimbabwe on the application of innovation management practises.

Methodology

In order to give a balanced investigation of both qualitative and quantitative data, a mixed methods research methodology is used, which is in line with the study's practical aims (Dawadi et al, 2021). This strategy incorporates a variety of approaches, which enhances the findings and provides flexibility. Using a mixed methods approach, the research attempts to obtain a thorough understanding of the dynamics of innovation management in Zimbabwe's Fintech industry.

The research philosophy emphasizes pragmatism's practical perspective and welcomes it. This decision enables the study team to choose between many philosophies as needed, including positivism and interpretivism (Toyon, 2021). The paper takes a realistic approach and examines innovation management in the Fintech industry from all angles. It combines subjective viewpoints with objective measurements to ensure a comprehensive knowledge of the intricate relationship between innovation and the particular difficulties faced by Fintech start-ups in Zimbabwe.

To gather information from Sasai Fintech in Zimbabwe at a certain point in time, a cross-sectional study design is selected. A quick overview of the current innovation management procedures used by these companies is made possible by this design. It makes comparison analysis easier and provides insightful information about the parallels and divergences among Fintech startups. The research approach offers a basis for comprehending the processes of continuous innovation in the Zimbabwean Fintech ecosystem by seizing a fleeting moment.

This ensures a 50% response distribution, a 5% margin of error, and a 95% confidence level. The employees and customers make up the majority of the participants in order to guarantee a strong quantitative analysis. The aforementioned strategic distribution is consistent with the notion that sampling adequacy for quantitative research is ensured for sample sizes greater than thirty (Shafian et al, 2022). In qualitative research, the emphasis switches to reaching data saturation so that topics can be thoroughly explored (Alam, 2021). A variety of purposive sampling techniques is used to choose individuals for qualitative insights (Campbell et al, 2020).

Primarily, structured surveys are used to gather quantitative data. Sophisticated surveys are designed to capture particular facets of innovation management strategies used by Fintech startups. The purpose of these surveys is to collect standardized data points in a methodical manner by carefully crafting questions that elicit quantitative answers from respondents. The research intends to provide numerical insights and do statistical comparisons on innovation management methods in the Zimbabwean Fintech ecosystem through the use of surveys (Roberts, 2020).

The study has a sample of 250 based on the adopted criteria of Krejcie and Morgan (1970) and the same number was administered. A total of 124 were returned giving a response rate of 50%. With the right tools, quantitative data is subjected to sophisticated statistical analysis. To compile survey results, descriptive statistics such as means, frequencies, and percentages are used. Regression analysis and other inferential statistics are used to find correlations and relationships in the quantitative data. The study examines the relationships between many factors using statistical methods, offering important new understandings into the quantitative facets of innovation management in the Fintech industry in Zimbabwe.

Presentation and discussion of findings

The target population consists of 250 people, which includes Sasai Fintech's clients, management, and staff. The sample size is calculated to be 92 participants using the Raosoft sample size calculator. There are many different types of inferential statistics, and each one is appropriate for a specific study design and sample makeup. Researchers should consult the numerous texts on experimental design and statistics in order to choose the best statistical test for their particular experiment. However, most inferential statistics work on the assumption that a test-statistic result is calculated with a certain formula. That number is used along with the degrees of freedom, a sample size measure, and the rejection criteria to determine whether differences exist. This study's inferential statistics are measured using the hypothesized data and are based on each construct that has been generated in SPSS.

Testing Hypothesis 1

Null Hypothesis (H0): Fintech start-ups in Zimbabwe do not significantly correlate with the key drivers of innovation.

The hypothesis was tested using a one sample t-test, and the outcomes are displayed in the table below. A statistical hypothesis test called the one-sample t-test is used to ascertain whether the mean of an unknown population differs from a given value. We use the One-Sample z-test to determine whether a difference between a sample mean and the population mean is significant enough to be statistically significant, meaning that it is unlikely to have occurred by coincidence.

One-Sample Test

	Test Value = 0					
	t	Df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Drivers of innovation	33.575	123	.000	1.710	1.61	1.81

The study's main test, the significance test, is highlighted in red, and all of the findings have P-Values of.000, indicating that they are statistically significant. There is no deviation of the population mean from the sample, as indicated by the identical P-Value for every value. The null hypothesis, which states that there is no significant correlation between Fintech start-ups in Zimbabwe and the key drivers of innovation, is rejected based on the results mentioned above, which have a P-Value of.000. Consequently, the alternate hypothesis, which states that there is a significant correlation between Fintech start-ups in Zimbabwe and the key drivers of innovation, will remain valid.

Null Hypothesis (H0): The growth and success of Fintech start-ups in the Zimbabwean market are not significantly impacted by innovation management practises.

Testing this hypothesis was done using the analysis of variance (ANOVA) and the results are as shown below.

ANOVA

Organisational Innovation Management Practices

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	11.276	3	3.759	18.459	.000
Within Groups	24.434	120	.204		
Total	35.710	123			

The F ratio is the ratio of two mean square values. If the null hypothesis is true, you expect F to have a value close to 1.0 most of the time. A large F ratio means that the variation among group means is more than you'd expect to see by chance.

Based on the results of the hypothesis results on the ANOVA test, we reject the null hypothesis which says that the growth and success of Fintech start-ups in the Zimbabwean market are not significantly impacted by innovation management practises. Therefore the alternate hypothesis which says the growth and success of Fintech start-ups in Zimbabwe are significantly influenced by innovation management practises.

Null Hypothesis (H0): The growth and success of Fintech start-ups in the Zimbabwean market are not significantly impacted by innovation management practises.

Testing this hypothesis was done using the paired t-tests and the results are as shown below.

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	Obstacles and constraints - What is the most common obstacle or constraint faced by Fintech start-ups in Zimbabwe when implementing effective innovation management strategies	.476	.770	.069	.339	.613	6.881	123	.000

Due to the fact that the p-value is less than your significance level, the difference does not equal zero. Because our p-value (0.000) for the paired sample t-test is less than the standard significance level of 0.05, we fail to reject the null hypothesis.

Based on the results shown in the Paired Tests above, we reject the null hypothesis which says that there is no discernible impact of Fintech start-up obstacles and hurdles in Zimbabwe on the application of innovation management practises. The alternate hypothesis which says that the obstacles and difficulties Zimbabwean Fintech firms encounter have a major impact on how innovation management techniques are put into practise.

Without a doubt, the development of financial technology marks a critical turning point in technological advancement. Compared to industrialized nations, Asian nations like China are leading the way in fintech innovation. According to Kurniawati (2019), internet technology has greatly benefited Asian nations, especially those with high incomes. The Financial Stability Board (FSB) originally defined fintech as a financial innovation powered by technology that develops new applications, processes, business models, or products that have a big impact on the financial markets, financial institutions, or the way financial services are provided in March 2016.

Numerous academics have focused on the effects of fintech, or internet finance, on conventional banks and finance since its debut. Fintech is defined by Palmie (2020) as a detrimental innovation ecosystem that supports commercial banks' and intermediary companies' debt-end structure. Buchak et al. (2018) discovered that the growth of fintech has also increased the market share of shadow banking. Commercial banks now have significantly higher total factor productivity, operating efficiency, innovation capacity, and risk tolerance because to Fintech's innovation and technology spillover impact.

Blockchain technology facilitates safe and transparent transactions, while AI-based algorithms can improve risk management and financial analysis procedures. Big data analytics can help with personalized experiences and understanding customer behavior. Hendershott et al. (2021) provided services. Investing more in FinTech advances digital transformation and improves customer service. The banking sector and financial markets react as a result. By offering substitute solutions and expanding access to financial services, FinTechs compete with traditional financial institutions (CruzGarcía et al., 2021). Client behavior changes as a result, increasing demand for innovative financial products and services.

Conclusions and recommendations

Fintech companies have grown significantly in the last 20 years due to the rapid development of hardware and software as well as the growing convergence of information and communication technologies. Travel, entertainment, and financial services are just a few of the industries that are disrupted by new business models and organizational structures brought about by these innovations.

Furthermore, new chances to change the financial sector's operations are being created by developing digital technologies like big data, blockchain, artificial intelligence, 5G, and the Internet of Things, as well as notable advancements in data storage and administration. Fintech companies may now provide financial services more swiftly and affordably than traditional banks, and their customers can enjoy more convenient digital banking experiences thanks to the exponential rise of digital technology.

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Wastewater treatment and circulation in thermal power plants

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Abstract. Wastewater from thermal power plants comes from cooling and energy production processes. In thermal power plants, water is used to cool the plants and turbines, a process in which it heats up. After the water has been used for cooling or other processes, it becomes "wastewater" and must be managed properly to prevent pollution and protect the environment. Treating wastewater from thermal power plants is essential to prevent environmental pollution and to comply with environmental regulations. There are several technologies that can be used to treat wastewater from these plants, and their choice depends on the type and level of contamination of the wastewater. This paper analyzes how water is treated and used in a thermal power plant, each method having advantages and limitations, and the choice of technology depends on the type and concentration of contaminants, costs and regulatory requirements of each plant. Often, thermal power plants use an integrated treatment system, which combines several of these technologies to ensure process efficiency and protect the environment.
Keywords: *power plants, treatment, wastewater*

Introduction

Taking into consideration that in 2021 the share of wastewater from electricity production and distribution was quite high, a point of interest is the way in which wastewater from the production process is managed and treated. The thermal power plant, for generating electricity, uses a thermodynamic cycle for generating electricity, in which water plays an essential role.

The chemical regime of the water in the power units must be organized in such a way as to not allow damage or reduction in the operating efficiency of the equipment due to salt deposits and corrosion in the water-steam-condensate circuit, in the cooling circuits and in the heating networks.

To ensure an appropriate chemical regime, the following conditions must be met:

a. Preparation of the internal surfaces of the water-steam circuit of the boiler before putting it into operation or, as the case may be, during repairs (mechanical, chemical cleaning).

b. Removal of suspended and dissolved substances from raw water, using make-up water treatment plants, up to the values allowed for feed water.

c. Conditioning of make-up water, feed water, boiler water and steam, to avoid corrosion of internal heat exchange surfaces.

Main stages of water circulation in a power plant

1. Heating of water in the boiler
• Water is pumped into a large-capacity boiler.
• Fuel (coal, natural gas, oil or biomass) is burned in a combustion chamber, generating very high temperatures.
• The heat produced heats the water in the boiler, transforming it into pressurized steam.
2. Steam expansion in the turbine
• The superheated steam is directed to a steam turbine, where it expands and loses some of its energy.
• The steam drives the turbine blades, which are connected to an electric generator.
• The mechanical energy of the turbine is converted into electrical energy by the generator.
3. Condensation of steam in the condenser
• After passing through the turbine, the steam reaches a condenser, where it is cooled with the help of water from a cooling tower or a river.
• By cooling, the steam turns back into water.
4. Water recirculation in the circuit
• The condensed water is pumped back to the boiler by means of a feed pump.
• In this way, the cycle resumes, ensuring a continuous water circuit.

Wastewater treatment from production processes in a thermal power plant

Hydrotechnical installations

The technological water necessary for the operation of the power units is taken over by means of the following installations:
• water intake
The dam is of the spillway type and consists of independent tanks. Downstream of the dam is the energy dissipator, of the basin type. The tanks are also equipped with a rare grate at the outlet, a sand-removing decanter and the screen and grate house. The screen and grate house has 8 compartments, each equipped with two rotating screens and two grates with rotating brushes. From the intake channel, water is sent to the power plant equipment and installations through the following circuits:
- the main circuit, which represents the actual hydrotechnical circuit and has the following routes:
• from the screen and grate house, water flows by gravity to the suction basins of the cooling water pumps;
• from the suction basins through the cooling water pumps to the turbine condensers of each power unit. The cooling water channels are made of reinforced concrete with a rectangular section, one for each power unit;
• from the hot water pump station, the water is sent to the cooling towers, with natural countercurrent draft. Water cooling can be performed in a mixed or closed circuit. The degree of water recirculation in the closed cooling circuit is a maximum of 83%. When operating in a mixed circuit, the excess cooled water is sent to the Jiu River, through two discharges located on the right bank, downstream of the dam.
- the secondary circuit, from the power plant premises, to the chemical water treatment plant and to other auxiliary equipment.

Chemical water treatment process

The technological water is prepared for the quality required for power boilers in the chemical treatment plant, consisting of the following plants:
- the pretreatment plant prepares the water for the softening and demineralization plants and the water for the cooling circuit and bearing seals. The pretreated water is produced through a coagulation-decarbonation-settlement process in decanters with a capacity of 900 m3/h each and with sludge recirculation. Then, the coagulated water is mechanically filtered in horizontal quartz filters and stored in tanks.

- the softening plant consists of three Na-cationic filters. The plant is also equipped with three salt dissolution tanks, two salt solution clarification filters, recirculation/transfer electric pumps, regenerative consumption vessels, rotameters, ejectors, etc.;
- the demineralization installation consists of demineralization lines operating in parallel and with the following filtration stages:
a. the cationic stage, consisting of two filters with strongly acidic cationite;
b. the anionic stage, consisting of a filter with a weakly basic anionite and a filter with a strongly basic anionite;
c. finishing stage, consisting of mixed bed filters with internal regeneration. Regeneration of ionic filters is carried out in equipment with hydrochloric acid solution (8÷10%) for H-cationic filters and with sodium hydroxide solution (3÷4%) for anionic filters. The chemical treatment plant also contains the associated chemical reagents for regeneration. The dosing of chemical reagents is carried out through a consumption-ejector vessel system. The regeneration of ion exchanger masses results in acidic and alkaline waters that are collected, homogenized and neutralized in special tanks. The conditioning of the steam boiler feed water is carried out with a dosing installation for ammonia solution (5%). This consists of dosing and storage vessels. The main condensate resulting from the power unit is prepared in a chemical treatment plant included in the thermal circuit between the condensate pumps of stage I and stage II. The main condensate treatment plant consists of two filtration stages:
- H-cationic stage with 4 filters with strongly acidic cationic mass;
- finishing stage with 4 mixed bed filters, with external regeneration of ion exchangers. It is equipped with its own chemical reagents for regeneration and its own wastewater discharge plant.

Considering the processes and requirements necessary for the proper functioning of hydrotechnical installations, thermal power plants have developed technical operating regulations regarding the chemical regime of water and steam in power and thermal power plants, where the limit values of the physico-chemical indices in the water and steam circuits are established in order to:
• avoid corrosion of the components of the water and steam circuits;
• eliminate the danger of deposit formation that would lead to major shortcomings in the boiler system.
• produce technically clean energy steam for safe operation and at the nominal parameters of the turbines.

Chemical control
The chemical control carried out within the plant must ensure:
a. determination of the quality of water and steam, reagents and composition of deposits;
b. recording the condition of water treatment equipment and thermomechanical equipment in terms of corrosion and scale deposits;
c. recording any violations of the normal chemical operating regime in water treatment plants, thermal power units and district heating networks, in order to avoid the formation of deposits and the occurrence of corrosion phenomena;
d. determination of the composition – quantitative and qualitative – of the wastewater at discharge.
Supervision and control of the chemical regime in the thermal circuit of the plant and in the water treatment plants are carried out based on periodic analyses carried out in the chemical laboratory

Conclusion:
The treatment of wastewater from thermal power plants employs a combination of technologies to minimize environmental impact. Each approach has its own benefits and limitations, with the selection depending on factors such as contaminant type and concentration, cost-effectiveness, and regulatory compliance. To enhance efficiency and safeguard the environment, thermal power plants typically implement integrated treatment systems that combine multiple technologies. Water treatment represents the totality of processes aimed at obtaining water with appropriate physico-chemical indices, in order to

ensure safe and long-term operation of thermal power units. The equipment of power and thermal power plants with water treatment installations, consisting of make-up water preparation installations, turbine base condensate treatment installations, industrial condensate treatment installations returned by consumers and feed water conditioning installations, must be carried out in such a way as to ensure the maintenance of physico-chemical indices in the water-steam-condensate circuits, within the limits permitted by this regulation.

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