University of Applied Sciences in Nowy Sącz

Monograph

ENVIRONMENTAL PROTECTION TRANSPORT AND LOGISTICS PRODUCTION ENGINEERING

editors

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Contents

Introduction

We present the monograph comprising selected articles for the papers delivered at the International Scientific Conference "TRANSPORT AND LOGISTICS | MECHATRONICS AND PRODUCTION ENGINEERING | ENVIRONMENTAL PROTECTION | INFORMATION TECHNOLOGY". The conference was held on 26-27 May 2022 in the Koszarka Venue & SPA hotel in Gródek nad Dunajcem, Poland.

The articles submitted to the conference were evaluated through non-public review and acceptance by the Scientific Council of the conference. Out of the works submitted, twenty were chosen and included in this monograph.

As contemporary technology is orientated towards improvement, innovation and environmental protection, a decision was made to compile publications delivered at the conference and prepare the monograph which comprises the latest scientific achievements in the major fields of technology important to the human kind. Dynamic development in recent years has certainly changed an outlook on the present world. The issues presented in this monograph fit in the research trend orientated towards both improvements and a fresh look at contemporary technologies.

The monograph is divided into three thematic sections. In the first section, titled "Anthropogenic pollution – research directions and new technologies in environmental engineering and energy", published are the articles discussing a wide range of issued related to environmental protection and power engineering. The editors trust that reading that section will add to the improvement and promotion of environmental awareness in contemporary world.

The second section, titled "Intelligent IT and mechatronic solutions as a guarantee of reliability and safety of systems of means of transport and Logistics", comprises works on topics related to motor and rail transport. Works in which the authors present the latest logistic tools are also included. The guarantee of reliability and safety of transport systems and logistics has always been a priority, and has become even more important in view of noticeable technical progress.

The third section, titled "New challenges, technologies and solutions innovations in production engineering" comprises articles in which the latest scientific and technological achievements in production engineering, which inevitably strives after process perfection, are presented.

The editors of the monograph hope that the conclusions of various research issues will enable the readers to become more familiar with the ideas relevant to them, and will be a source of knowledge and inspiration in acquiring competences in research.

The Conference Organisation and Scientific Committee would like to thank heartily all the Authors for the preparation of their articles, and recognise the reviewers for their effort in the drafting their opinions.

Section I

Anthropogenic pollution – research directions and new technologies in environmental engineering and energy

Selected threats and methods of protection of critical infrastructure objects in the context of the effects of disrupting their functioning and ecological safety

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Abstract: The sense of security and the functioning of the economy depend mainly on proper operation of such areas as: power engineering, communications, transport, health care and education. Yet, it requires continuous and uninterrupted access to utilities, such as: water, gas, sewage, energy. Disruption of the functioning of one of these areas may adversely affect another element, causing undesirable social and economic effects. The work presents an analysis of the elements and methods of critical infrastructure protection, along with the assessment of the emerging threats at the local and global level. At this level, it is crucial to minimize the possibility of crisis situations in each of the categories of possible hazards, i.e.: natural, technical hazards, economic and social or terrorist threats, and to act appropriately to combat them. The actions taken to protect critical infrastructure facilities must be constantly improved in order to effectively combat the constantly evolving threats arising in the modern world. The objective of the article was to analyze potential threats to the functioning of critical infrastructure objects from thesocio-economic perspective, including also the period of COVID-19 pandemic.

Key words: critical infrastructure; epidemics; natural disasters; protection of critical infrastructure; threats to critical infrastructure.

1. Introduction

Critical infrastructure comprises the facilities, devices and service providers indispensable for the proper functioning of the society and manufacturing sectors of the economy (Krupa, Wiśniewski, 2015). In Poland, there are different definitions and divisions of infrastructure, which is defined as: facilities particularly important for country's security and defense, areas, facilities, equipment and transport means subject to mandatory protection, critical infrastructure. Critical infrastructure plays a huge role in the functioning of the country and the life of its citizens, and its protection is one of the most important objectives the country has to face (Dz.U.03.116.1090, 2003; Dz.U. 1997, Nr 114, poz. 740, 2003). This is confirmed by the Act of April 26, 2007 on crisis management. Pursuant to this Act, critical infrastructure is viewed as systems and interconnected functional facilities (including building structures, machinery, installations and services), indispensable and important to ensure security of the country with its citizens and to ensure efficient functioning of public administration bodies, institutions and entrepreneurs (Kouzmin, 2008). Critical infrastructure includes the following systems: supply of power, energy raw materials and fuels, communications, ICT networks, financial, food supply, water supply, health protection, transport, rescue services, public administration ensuring continuity of operations and production, storage, safekeeping and use of chemical or radioactive substances, including pipelines for hazardous substances. The act also specifies the European critical infrastructure, which comprises the above-mentioned systems located on the territory of the Member States of the European Union, the disruption or destruction whereof would significantly affect at least two Member States (Dz.U. z 2007 r., Nr 89, poz.

590). Threats that are very often lead to crisis situations have an impact on the security and proper functioning of the above-mentioned critical infrastructure, they can be divided into the following categories: natural hazards, technical threats, terrorism, social and economic. Natural hazards include such phenomena as flooding, strong winds, prolonged droughts, tectonic movements, icing and heavy snowfall, as well as epidemics (Brown et al., 2006). Technical threats usually involve citizens, or rather the environment in which they operate, and critical infrastructure facilities, which may result from breakdowns in industrial, municipal, construction or transport facilities (Svendsen, Wolthusen, 2017; Gronba-Chyła et al., 2022; Młyński et al., 2012). Attention should also be paid to the ever-developing terrorist threats, or rather cybercriminals, who use their skills to paralyze the operating systems of e.g. banks, transport, communication facilities, but also factories, enterprises and power plants. As pointed out by Radziejewski, attacks of this type happen quite frequently, mainly in order to gain access to important strategic information or R&Ddata from competing countries (2011). With respect to economic threats to the objects of critical infrastructure related to facilities and installations of sanitary sewage systems, operational problems may arise including damage or destruction, which consequently translate into large economic losses. Such a situation may take place as a result of natural disasters, but also in the event of a terrorist attack on a selected object (Kuśnierz, Świerczek, 2014). An important element of the functioning of critical infrastructure is the social aspect, which, in the face of a threat of the destruction of CI systems, may lead to an outbreak of panic, which may result in an outbreak of social discontent due to interruptions in the supply of basic carriers (water, energy) necessary for the daily functioning of every society (Dygnatowski, 2020). In the concept of social functioning of critical infrastructure, a new phenomenon has emerged in recent years regarding the impact of people's emigration, including the mass movement of people. This phenomenon generates challenges for local communities receiving refugees by providing them with infrastructure services. This applies to additional supply of water, energy, sewage collection and logistics, for which the existing critical infrastructure has not been designed (Araya, Faust, Kaminsky, 2019).

2. Analysis of elements of critical infrastructure

Based on the literature review, the analysis of the elements of critical infrastructure in terms of its function and structure was performed. The development of civilization is attributed principally to continuous improvement and better sense of security of each of us, it applies not only to the protection of individuals, but also to measures undertaken to ensure safe functioning of the industrial, transport entities or other units needed in everyday life. Critical infrastructure facilities comprise primarily: power engineering, communications, transport, health care and education. We can treat the energy sector as the main pillar of the functioning of other areas of critical infrastructure. Each of the functioning units today needs more and more energy, both to heat apartments, houses or to ensure proper functioning of e.g., computers, mobile phones and other devices that have become an indispensable part of our everyday life (Hryb, Matyasik, 2018; Przydatek, Kochanek, Basta, 2017). Regrettably, such needs create dangerous threats, including the negative impact of conventional energy on the environment, increasing electricity prices, or depleting reserves of fuel. The continually decreasing fossil fuel resources necessitate the diversification of current sources of energy production, including solid fuels based on biomass or recovered from waste containing a biodegradable fraction (Ciuła et al., 2019;

Gawlik et al., 2007, Kowalski et al., 2015). An alternative solution which addresses this problem is the development of renewable energy sources such as wind, biomass, water, solar energy, geothermal energy of high or low enthalpy. Scattered energy based on renewable sources improves energy security of the country as well as increases the accessibility of these sources in the event of hazards effected by natural disasters or other threats (Ekins, 2004; Ciuła et al., 2022; Dyjakon et al., 2019). A natural threat to power generation industry, over which we have no direct influence, is climate change, including frequent and long--lasting heat waves, which lead to increased power consumption from power plants, straining their operations, and when it is combined with low groundwater levels, it may bring about a serious problem with electricity supply to consumers. In order to reduce the negative effects of such threats, it is necessary to focus primarily on innovative technical solutions, starting from transmission and production of energy to its reception and storage. Solutions based on manufacturers' experience, creation of improved wind turbines generating energy from wind, construction of underwater turbines, improvement of photovoltaic panels and many other concepts translate not only into safer energy transmission and distribution, but also into the reduction of the emission of harmful substances to the atmosphere during its production when traditional methods or fuels are used (Zakrzewska, Gil-Świderska, 2018; Kowalski, 2020). Although we do have partial influence on technical or even terrorist threats, yet in the energy sector we are mainly confronted with inadequate safety of data protection systems, as well as with possible failures of other facilities: industrial (release of toxic substances), municipal (shortages of electric power, water, heat, gas supplies), construction (construction disasters), transportation means, especially vehicles transporting hazardous substances (Ciuła, 2021; Gaska et al., 2019; Wysowska, Wiewiórska, Kicińska, 2021). Communications are another important component of critical infrastructure. It is of crucial importance in the economy, facilitating negotiation processes, relations between administration – citizen, citizen – administration, as well as between the citizens themselves, and it helps in storing data and in maintenance of backup power systems. Communications cover all areas of sending information and receiving information, as well as the management method of the distribution of energy, water, gas and other elements necessary for the functioning of these elements (Brown et al., 2006). The greatest threat in this area is posed by cyberterrorism, and the protection against this threat must be provided on many levels, i.a.to ensure the functionality, stability and integrity of the critical infrastructure (Jankowski, 2018). Transport is another element of critical infrastructure exposed to natural and technological hazards. Natural hazards may include naturally occurring rainfall, heat, icing, which can significantly affect the speed and quality of transport of raw materials and food. With respect to technological hazards, transport can be exposed to various types of equipment failure. It is a key element ensuring the reliability of transport facilities in extreme conditions for which they are also designed. This mainly applies to damage to mechanical drive systems and their connections for road and rail transport. Transport is an important component of other areas of critical infrastructure. In the energy sector, its disturbance may result in the lack of raw materials needed to heat homes, produce electricity, and thus it may disturb the functioning of society and paralyze many industrial branches, communications, access to education and health care (Kowalski, 2018; Kowalski, 2021). Dangerous effects of a disrupted functioning of critical infrastructure can also be seen in the health care sector on the example of such facilities as hospitals. They are dynamic units, exposed both to natural, technological and terrorist

threats. To start with, any natural hazard n. in the form of flood, earthquakes, or disruption of energy supply paralyzes the way the healthcare system performs its functions. It is important that each institution of this type should be prepared to implement a crisis situation strategy, emergency plan, and to ensure the safety of patients (Brown et al., 2006). It is also important to mention the possibility of an epidemic that would paralyze the efficient functioning of the healthcare system, diagnosing, treatment and prevention of further diseases. Civilization threats also include terrorism. In terms of healthcare, patient registration systems and life-saving devices, which are also subject to technological threats, are particularly vulnerable to cyber-terrorist attacks. Climate changes observed in recent years have a significant negative impact on the natural environment, on the economy as well as on critical infrastructure. They also have a significant impact on natural disasters, their frequency, including the number of death casualties and enormous material damage (Kucharska, 2020). Table 1 shows the occurrence of natural disasters and their frequency on a global scale.

Table 1
Average annual losses effected by natural disasters in the world in 1990-2019 and in 2020

Name	Unit	1990-1999	2000-2009	2010-2019	2020
Frequency of disasters	times	258	386	331	313
Number of deaths	persons	43367	78137	45075	15082
Population affected	ten thousand	20098	22775	16849	9897
Direct economic loss	USD 0.1	1109	1153	1758	1731

Source: own study.

The losses in economy in the years 1990-2019 presented in Table 2 refer to prices in 2019, while the data for 2020 refer to the level of prices in a given year. When comparing the data for 2020 with the average for 1990-2019, we can observe that the frequency of major natural disasters was by 4% lower, and the number of fatalities was by 73% lower. In terms of the number of people affected by a natural disaster, this figure was by 50% lower, and the direct economic losses were by 29% higher than those in 2020 (Global Natural Disaster Assessment Report, 2020, accessed: 02.02.2022).

3. Analysis of protection methods of critical infrastructure

In order to analyze the contemporary critical infrastructure, it is not enough to focus only on its elements and threats, but first and foremost to think about ways to protect it, in order to be able to effectively prevent emergency situations and quickly remove losses. Protection of critical infrastructure consists, among other things, in ensuring the functionality, continuity of operations and integrity of the entire critical infrastructure, so that the risk of the occurrence of undesirable incidents is minimized, and also in enabling fast reconstruction of the infrastructure in the event of failures, attacks or unforeseen events destroying its structural organization. The problem involving the interdependence and the dynamics of interaction of CI resources has been addressed by Ostrowska (2021), who analyzed important factors involving the structure of the resource model that could be useful in the processes of managing the operation of critical infrastructure in the event of emergencies. All measures undertaken within the scope of critical infrastructure, including

protective ones, should primarily focus on: collecting and exchanging information about threats to critical infrastructure, developing and implementing procedures in the event of threats, restoring critical infrastructure and cooperation between public administration and the owners or operators of critical infrastructure. Such steps are necessary, because nowadays the elements of critical infrastructure are more and more interdependent, not only in terms of one country, but also on a regional, European and even global scale. In the modern world, the resistance of critical infrastructure to external threats has become a key issue in crisis management, as well as the protection of individual CI components. Depending on the type of threat, this can result in certain disruptions and problems in the resistance of CI, which may inevitably lead to negative consequences for the population and the economy of individual countries. In this regard, a detailed identification and understanding of the threats and their consequences is of key importance for improving a country's preparedness in the event of unexpected incidents, such as the COVID-19 pandemic. The solution proposed by the authors (Osei-Kyeiet et al., 2021) consists in generating a checklist dedicated to a given threat, which will be redistributed among the countries and governments at risk. The main stakeholders will be exchanging information and experience in order to create a barrier and to strengthen the resistance of a given CI system. In fact, such a solution aims to create a knowledge base at the international level that will help in effective counteracting a prospective threat. Unlike the protection of individual CI systems, individual facilities require mainly physical protection, which is generally acknowledged and widespread in the modern world. It consists in performing activities aimed at ensuring the safety of life, health and personal integrity as well as the protection of property. In other words, these are measures which prevent crimes and offenses against property, and they control unauthorized access of persons to the protected area. The ICT protection focuses more on minimizing disruptions in the functioning of critical infrastructure, and more specifically, in the functioning of systems of a given infrastructure and ICT networks. It is a protection against hacker attacks and cyber terrorism, and it provides an effective counteraction against such incidents. This issue, correlated with the current technological progress, should be aimed at reducing the burden on the ICT system, so that it is not a weak link vulnerable to hacking attacks. It is of key importance that each sector of the critical infrastructure should take on the responsibility of cyber security and should determine the required method of returning to stabilization (Dawson et al., 2021). In the case of cooperation with other economic entities, legal protection is necessary. Such entities may not comply with the legal tools in force – laws aimed at controlling infrastructure management, e.g. by blocking unwanted decisions of management boards, so that there are no disruptions in the functioning of critical infrastructure (Quitana, Molinos-Senante, Chamorro, 2020). It should be noted that a significant role in the protection of critical infrastructure is played by the Internal Security Agency. Its tasks include, first of all, counteracting, preventing and removing the effects of incidents ofterrorist character. All these activities are carried out in cooperation with government administration bodies. However, we must not forget about the obligation imposed on the public administration body and the owners of critical infrastructure to immediately provide information on any terrorist threats to critical infrastructure systems (Steele, Legacy, 2017). In Poland today we can talk about additional security for critical infrastructures. Alert levels are not only implementing protective measures against various attacks, but they also counteract terrorist or sabotage

threats. Alert levels are introduced by a regulation issued by the Prime Minister and heads of central offices at the central level, and at the voivodship level by the voivode. We can talk about four alert levels: ALFA, BRAVO, CHARLIE and DELTA. Each of them performs a number of tasks, by means of executive organs, for the protection of infrastructure and the population (Nowikowska, 2022). Let us take a closer look at it by analyzing each of them. Alfa is the first alert level covering the protection of the endangered infrastructure in the following areas: transfer of information, accessibility of personnel, control of vehicles and people on the premises, checking the state of facilities or rooms as well as means of communication and alarm system, as well as reviewing procedures and tasks for the protection of the population in terms of: monitoring places where people and public utility buildings are concentrated, and informing services about noticed unusual signs of behavior or activity. In the case of the second level of alert (BRAVO), it covers all the first-level undertaken measures, and those for the protection of the endangered infrastructure, comprising warning workforce, moving vehicles away from building facilities and control of parking procedures, strengthening the security of building facilities, control of people, luggage and mail sent to offices, protection of office transport, checking the inventory and equipment, as well as, for the protection of the population, monitoring vehicles, people and objects in the endangered areas, information and instruction campaigns for the public. Theprovisions of the first and second degrees are complemented by the third alert level (CHARLIE), which additionally includes tasks to protect the infrastructure at risk, by: on-call duty shifts for decision-making staff, strict control of people and vehicles, limiting common access, strengthening security services, arming the authorized security personnel, introducing additional security and counterintelligence protection procedures and protection in diplomatic missions, as well as, for the protection of the population: strengthening the protection of mass events (cancellation of events), inspecting medical database and resources, updating data on water supply and places of temporary stay of the population. In order to protect the critical infrastructure most effectively, the fourth level of alert (DELTA) should be introduced, which comprises all measures listed in the first, second and third level and those aimed to protect the endangered infrastructure. To this end, it is necessary to introduce traffic restrictions in endangered areas, prohibit the organization of mass events, prepare the logistics backup of medical or sanitary facilities, ensuring also work continuity of the headquarters of emergency services (Ostrowska, 2021; Kosowski, 2014). All these alert levels protect critical infrastructure, but their combination can create an effective protective wall against possible threats to information and infrastructures, and can help in gathering information and find out the ways of obtaining information by external entities. Their main task is to analyze the effects of natural disasters in a particular country. The effects of threats are mainly attributed to industrial facilities and critical infrastructure, and these projects also help to improve the operation of emergency services (Kraussmann, Girgin, Necci, 2019). Some projects are also useful for farmers to analyze the occurrence of droughts or floods. The project which is most noticeable by the citizens is the RCB alert, which provides information in the event of a regional threat in the form of SMS messages (Łukasik et al., 2014).

4. Results and discussion

The threats existing in the facilities of critical infrastructure, locally in the territory of a given country, may also have a global dimension and affect the world economy. These threats also apply to facilities used for the treatment of hazardous waste and its transboundary shipment (Sobiecka, 2016). In their work Rehak et al. analyzed the assessment of the consequences of critical infrastructure failure in terms of the quantitative aspect, presenting the theory of synergistic connections, the effects of joint action and their impact on critical infrastructure and society. The used SYNEFIA methodology demonstrated an increased accuracy and mapping fidelity of the consequences of CI failures, the ability to react and the resilience of critical infrastructure (2016). The most severe disaster in financial terms was in Japan. In 2011 there was an earthquake there, and as a result of this event, automotive companies were forced to close their factories, exposing themselves to losses of millions. Also in 2011, there was a flood in Thailand, which resulted in the closure of the second largest hard drive company. At the turn of 2010 and 2011, a flood occurred in Queensland (Australia), blocking the export of coal from those regions to other countries of the world (Alcazar, Zeadally, 2015; Lewis, 2020). The Global Natural Disaster Assessment Report, published in 2021, contains data on natural disasters (ND8) in the world, which in 2020 occurred in the amount of 313 events and affected 123 countries and regions. Figure 1 shows the percentage of each type of natural disaster that potentially threatens the critical infrastructure (Global Natural Disaster Assessment Report, 2020, accessed: 02.02.2022).

Based on the literature data on losses caused by natural disasters in the world in 2020, as presented in Figure 1, four aspects (A4) were subjected to analysis, i.e. the frequency of disasters, the number of deaths, the number of people affected and direct economic losses (provided in Table 1). For this purpose, the program Statistica, v 13.3 TIBCOI Software Inc. was applied (Statistica, version 13.3, 2017), which calculated the mean and the standard deviation, and the results are presented in Figure 2.

The objective of the analysis was to determine which of the natural disasters (ND8) occurring in 2020 had the greatest impact on the amount of losses in relation to the four aspects (A4). The highest average, at the level of 41.74, was recorded for floods which were the most frequent in 2020, affecting 34% of the population subjected to all disasters, and they were responsible for 30% of economic losses. The average of 33.5 involved storms (typhoons, hurricanes), which were the cause of the largest economic losses, constituting 54% of all losses, and they involved the largest number of people, i.e. 46%. The third highest average of 10.7 concerned extreme temperatures that resulted in the highest number of deaths, i.e. 42% of all recorded deaths as a result of natural disasters in 2020.

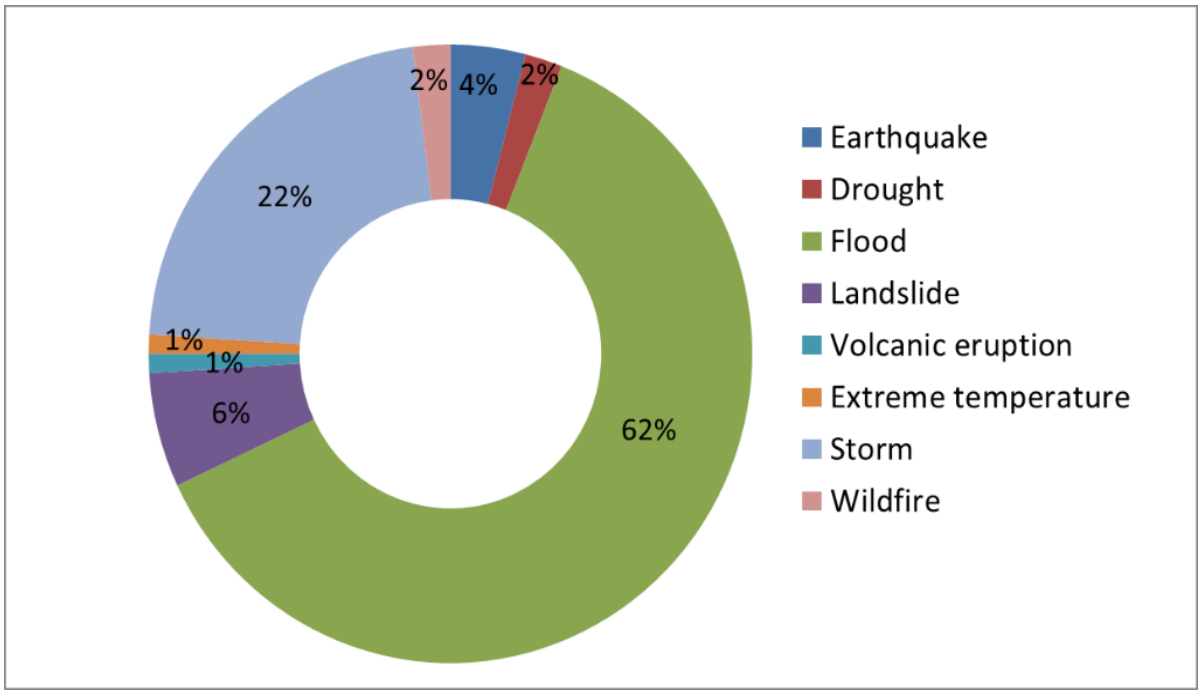

Figure 1. Natural disasters in the world in 2020.
Source: own study.

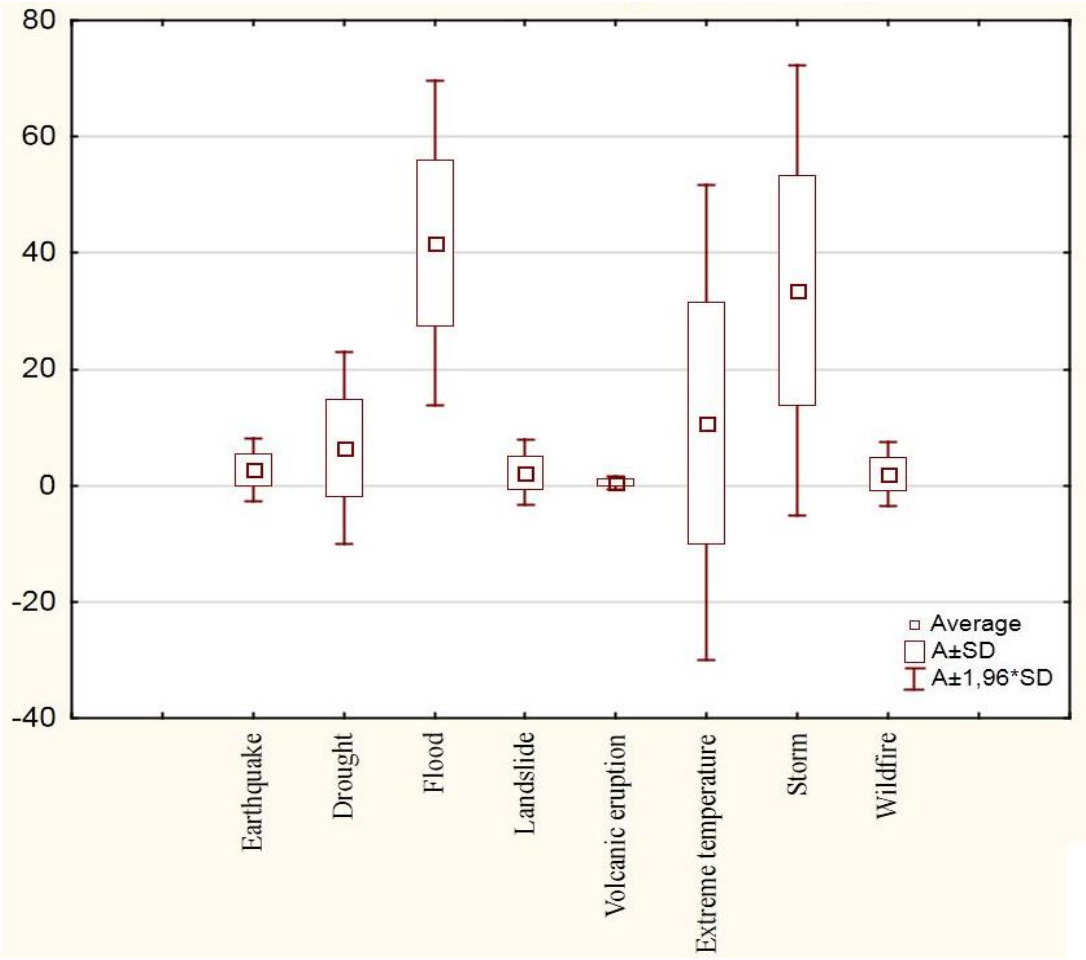

Figure 2. The impact of individual natural disasters on the socio-economic losses in 2020.
Source: own study.

The next three natural disasters generated averages at the following level: droughts 6.5, earthquakes 2.75, and landslides 2.25. The smallest impact on the four analyzed aspects (A4) had volcanic eruptions: 0.5 and fires: 2.0, which generated the smallest economic and personal losses. The resilience of local communities to the failures of critical infrastructure related to flood hazards was presented in the work of de Bruijn et al. The presented approach was aimed at supplementing the prevailing flood risk analyses and creating a common platform for actions to be undertaken by local authorities, crisis response services, as well as owners and operators of critical infrastructure. The use of resilience index "person disruption days" was proposed, based on the views of experts and stakeholders who participated in the workshops, on the literature and interviews, using the example of the flooded and hurricane-hit area of Fort Lauderdale, Broward County, Florida. The results showed that the index can be used to increase the resilience of CI to flood hazards, but it can also be applied as an element of raising the resilience of a local community in mitigating the effects of floods (Maranet, 2019). The analysis of the resilience of the urban network of critical infrastructure including water, sewage, gas, transport, energy and communication networks was presented in their work by Liu and Song, who reviewed the literature on the impact of the above-mentioned networks on proper functioning of modern cities. The results of the analysis showed that urban networks are vulnerable to various threats, both natural and man-made, due to the characteristics of large-scale networks. Such a situation is caused by high concentration of many CI facilities in the city, which in turn increases the scale of potential consequences in effect of a threat (Liu, Song, 2022). Another threat to the world economy as well as to the Polish economy is referred to as the so-called BLACKOUT incident. It has been thoroughly analyzed by Alhelouet al. (2019), who indicated that research is still being carried out on the improvement of electricity supply security systems in order to avoid cascading and continuous blackouts. The world economy needs more and more energy, which has to be transported over more and more distances. The natural threat in this respect is also posed by the changing climate, since high air temperature increases the losses in the transmission of electricity in the grids responsible for its distribution. At the same time, the frequency and intensity of extreme phenomena that pose threat to the transmission infrastructure is growing (Fang, Sansavini, 2019). The system of critical infrastructure responsible for energy supply will undergo major changes in the coming years due to the decarburization of the global energy sector. Climate changes, are more and more perceptible, and when they are identified with the emission of carbon dioxide into the atmosphere, they enforce the use of the so-called clean sources, neutral for the environment. According to Kucharska (2020), the main goal for the energy sector is to shift its production to the sector of renewable energy sources. The energy sector is currently often overloaded and susceptible to failures, especially in summer. The overloading is mainly due to the peak demand for energy, e.g. during the construction or renovation season, or during hot weather. Table 2 presents the possible consequences for the energy sector.

The energy sector, which is a system of supplying energy, energy raw materials and fuels, is very sensitive to potential disruptions resulting from internal causes, e.g. power block failures, or external ones, e.g. due to fuel shortage. The development of conventional energy is correlated with its negative impact during the operation as well as with its impact in the case of natural disasters, which may result in environmental contamination. The observed increase in demand for energy is caused by higher purchasing

power of citizens, which in turn may contribute to interruptions in energy supply and, consequently, to economic problems also for entrepreneurs. The key element in terms of energy management is the efficiency of its production, transmission and the use in technological processes, as well as heating purposes of building facilities.

Table 2
Possible consequences for the energy sector

Incident	Consequences
Development of food processing industry	Many companies operate with a minimum level of stored produce, or they cannot stop production processes without huge costs or risks, e.g. environmental contamination
Increase in consumer income	Increased purchasing power (e.g. for electricity-powered appliances)
High energy demand in summer	Possible power cuts due to overloaded power grid

Source: own study.

The awareness of energy consumers, including also the individual ones, and the use of risk management procedures, can significantly reduce the risk of breakdowns, power losses and following them incidences of blackout (Lewis, 2020). Incidences of blackout in Poland appear in summer and winter periods, e.g. on April 8, 2008, a failure occurred in Szczecin and in the neighboring poviats, which was caused by intense wet snowfall that damaged high and low voltage lines. The estimated final cost of this failure was PLN 54.1 million. It comprised the costs incurred by enterprises, local governments, residents and the costs of rescue operations threats to the critical power infrastructure sector and their impact on the other correlated dependent sectors were described in (Rehaket et al., 2020). The emerging energy failures have a far-reaching impact, not only on the society itself, but also on dependent sectors and elements of critical infrastructure. These sectors involve in particular: water supply and sewage systems, healthcare, ICT and communication of financial systems, financial markets and public administration. Therefore, in crisis situations, it is crucial to quickly resume all systems that have failed or have been attacked, based on the developed procedures and technical measures (Quitana et al., 2020). As a result of the outbreak of the COVID-19 pandemic, critical infrastructure facilities were forced to reorganise their work system, including moving to remote working. The results of a survey conducted in 2020 on a group of respondents representing business entities operating in Poland, showed that until the outbreak of the COVID-19 pandemic, about half of the companies worked remotely to a limited extent. Now, as many as 67% of companies that had not previously used remote working have decided to do so following the outbreak of the pandemic. The industries that have implemented remote working the most since the outbreak of the pandemic are: real estate, IT, business services and business outsourcing and shared service centers. To a much lesser extent, remote working has been used in trade, public administration, transport, shipping and logistics, automotive and aviation (Dziwisz, 2020). Figure 3 shows selected industries that are dominant in the field of remote work and those that with problems are starting to implement new work organization.

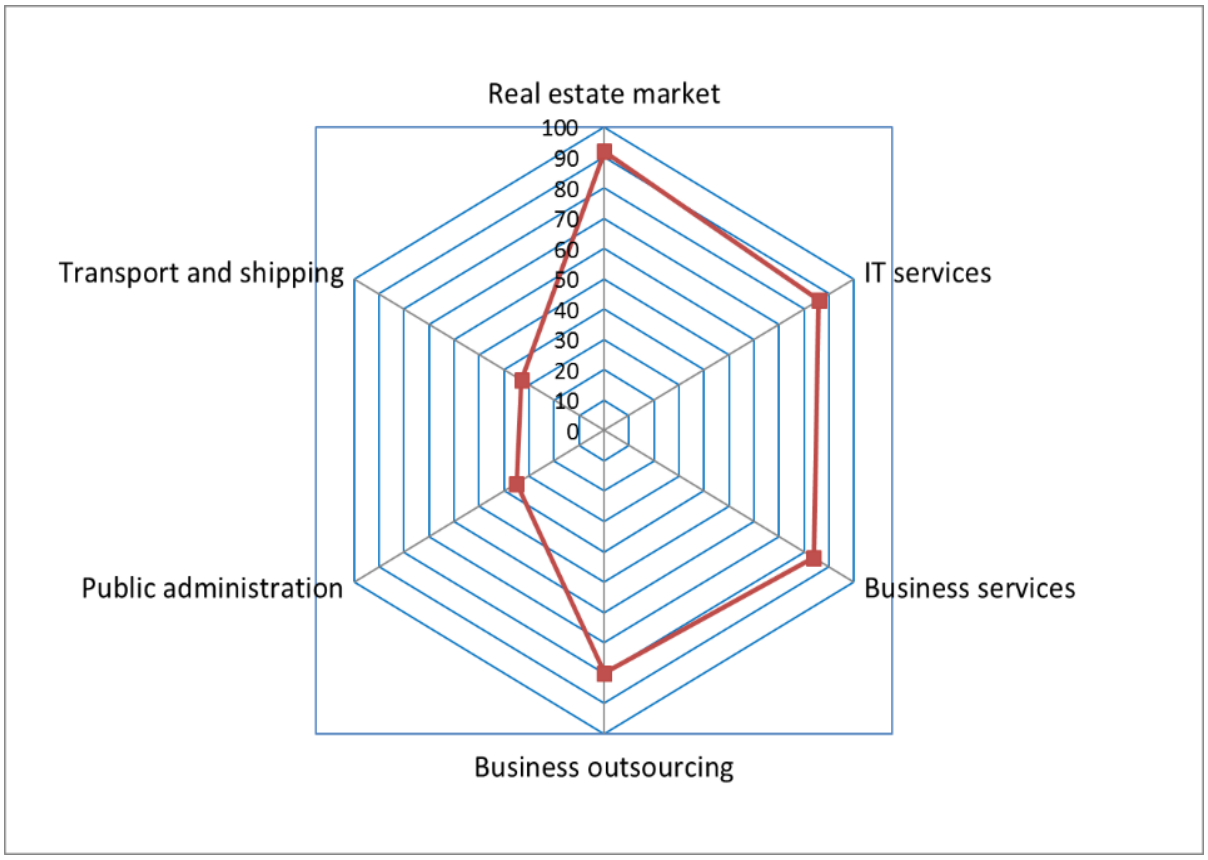

Figure 3. Percentage of remote working in selected industries.
Source: own study.

During the pandemic, the sectors of business and IT services implemented the remote work system to the largest extent, while other industries, including public administration, have been implementing it on a systematic basis due to the specific nature of provided services. This state of affairs is indirectly related with the provision of appropriate equipment for IT specialists as well as with the availability of security measures against hacker attacks. In view of the above, it can be concluded that this period favours the development of IT services, which poses a certain risk to critical infrastructure. Cybercriminals see the virus crisis as an opportunity to launch attacks, as the number of potential "victims" has increased dramatically. Research in Italy, UK and the US has shown that in March 2020 alone, the intensity of cyber threats increased by 25-30%, with increasingly sophisticated methods. In Poland in 2019, cybercrime affected the majority of companies surveyed accounting for 68%, while far less than half have developed procedures to respond in the event of a cyber-attack (Dziwisz, 2020; Lallieet et al., 2021). The reality of COVID-19 has revealed the insufficient nature of regulations and procedures involving above-standard behavior of the employers towards the staff employed in facilities being part of the country's critical infrastructure. The present situation has been defined in terms of the global epidemic crisis which is still ongoing, and we must be aware that the acquisition of experience by the operators of critical infrastructure related to working in COVID-19 conditions is not merely a fact of the past, but is still most relevant (Wróbel, Wróbel, 2021).

5. Conclusions

Critical infrastructure plays a key role in the functioning of the country and in the lives of its citizens, and the protection of the infrastructure is one of the most important goals facing any country. The methods of its protection and security should be constantly improved, although there is no straightforward way to ensure its reliability. New technical threats emerge all the time, but also threats resulting from natural causes. Critical infrastructure facilities are key elements of the security system at the local level, but also on a global scale, including power engineering, communications, transport, health protection. In this hierarchy, an important role is played by the critical infrastructure in the field of power engineering, which is the main component of many systems constituting the foundation for the functioning of a given country. Also, the healthcare system in the last two years, as a result of the spread of the coronavirus (SARS-CoV-2), has been subjected to a serious test on a global scale, posing a new challenge for the protection and proper operation of the healthcare system. The reality of COVID-19 has revealed the insufficient nature of regulations and procedures involving above-standard behavior of the employers towards the staff employed in facilities being part of the country's critical infrastructure, especially with regard to cybercrime. Critical infrastructure sectors were a particular target for hacker attacks during the pandemic. The analysis of the elements of critical infrastructure performed in the work demonstrated, on a global scale, that there is a continuous increase in the number of critical incidents to which CI is subjected. The nature of these incidents involve mainly terrorist attacks, natural disasters related to climate change, and failures caused mainly by the technical condition of devices but also by human error, while the analysis of the ways to protect critical infrastructure does not give a clear answer as to the method of its protection. Each of the CI systems must be treated individually according to its specificity and sensitivity, both social and technical. The use of procedures in the event of an incident is crucial in order to take appropriate measures adequate to the situation. The analysis of the consequential threats to the critical infrastructure demonstrated their great diversity as well as a large extent of damage. The threats and disasters that have arisen over the last 10 years were effected by natural forces, which, as a result of climate change, are becoming a serious threat. This primarily applies to typhoons, hurricanes, tsunami, earthquakes, heat or cold zones. The key issue in this respect is to reduce the emission of pollutants into the air, mainly from power engineering sectors. Therefore, the challenge for the coming years in this regard will involve a partial departure from fossil fuels in favor of renewable energy sources, which, by being applied locally, improve energy security of a given country, and thus limit the possibility of a blackout. The main objective for the protection of critical infrastructure is to ensure the safety of the functioning of the country and its citizens, including an efficient communication process in order to transmit information to the population about possible threats (SMS, email). This communication process in the event of an incident can shorten evacuation times and reduce potential material losses or causalities. Taking into consideration the fact that critical infrastructure covers virtually every area of social life due to strong interdependencies, a failure of one of such elements causes a domino effect, increasing the risk of hazard and the following it consequences. The critical element is the energy sector, whereof challenge for the coming years is to carry out decarbonization through the diversification of energy sources, efficiency of its generation, transmission and use. The research undertaken in the study has demonstrated that the emerging new threats to proper functioning of critical

infrastructure generate a direct response in the form of new tools and methods of operation that can counteract these threats. Such a state bespeaks of high competence of people managing the critical infrastructure, which is indirectly attributed to the ability of drawing conclusions from the events that have already occurred.

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Analysis of atmospheric air pollution with PM 10 and PM 2.5 in selected cities of the Małopolskie Voivodeship in 2015-2020

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Abstract: Atmospheric air quality, and in particular the level of its pollution resulting from anthropological processes, is a potential threat to human health and life. One of the substances emitted to the air from combustion of fuels is particulate matter and its fractions PM 10 and PM 2.5. Due to its structure particulate matter below 2.5 μm, PM 10, and especially PM 2.5, penetrating deep into the respiratory system is a serious health hazard for humans. The aim of the study is to analyze the air quality in the Małopolskie Voivodeship in terms of the content of particulate matter in 2015-2020, along with the identification of those regions with the highest particulate matter concentration and identification of the sources of its emission.

Key words: dust pollution, particulate matter, ambient air pollution.

1. Introduction

Atmospheric air pollution by PM 10 and PM 2.5 are among the most dangerous environmental pollutants for the human body. The world health organisation already indicated in 2012 that about 7 million people died worldwide due to inadequate air quality (Filak, Hoffman, 2020). In cities, the problem often assumes global significance. High levels of pollution are explainable for highly industrialised cities, where the pollution generated often exceeds standards by several times (https://polskialarmsmogowy.pl/files/artykuly/1346.pdf, accessed: 31.03.2022). The situation is a little different for urban agglomerations, where dust of both natural and technological origin is raised into the air (Azarov et al., 2017), so it is important to constantly monitor them. The determination of PM 10 and PM 2.5 is an essential component in the assessment of their hazardous effects on human health. PM 10 contains suspended particles smaller than 10 μm, similarly PM 2.5 contains particles smaller than 2.5 μm, and each is capable of absorbing hazardous substances on its surface, including dioxins and furans, heavy metals and polycyclic aromatic hydrocarbons. These dusts can easily enter the lungs, causing poisoning, inflammation of the upper respiratory tract, lung cancer, allergic diseases and asthma. PM 2.5 is particularly dangerous, as it has the ability to penetrate deep into the alveoli, causing permanent damage to them as it enters the bloodstream (https://polskialarmsmogowy.pl/files/artykuly/1346.pdf, accessed: 31.03.2022). In recent decades, the effects of PM 10 and PM 2.5 on the human body have particularly begun to be looked at (Azarov et al., 2017). Indeed, these dusts are responsible for pulmonary circulatory diseases and can lead to death (Lioy, Georgopoulos, 2011; Barraza-Villarreal et al., 2008; Self et al., 2017). In Europe, an estimated 307,000 premature deaths in 2019 alone were caused by chronic exposure to fine particulate matter 10 micrometres or less in diameter (PM 10) and coarse particulate matter 2.5 micrometres or less in diameter (PM 2.5) (https://www.eea.europa.eu/publications/health-risks-of-air-pollution, accessed: 01.04.2022), and around

40,000 premature deaths have been attributed to chronic exposure to nitrogen dioxide (NO2) (https://www.eea.europa.eu/publications/health-risks-of-air-pollution, accessed: 01.04.2022). Moreover, in Poland the largest number of cities belong to urban areas with the highest estimated PM mortality burden (Khomenko et al., 2021), and despite the estimated decreases in the content of particulate matter in ambient air, these cities still often do not meet the guidelines provided by the World Health Organization – WHO (Nazar, Plata-Nazar, 2021; Traczyk, Gruszecka-Kosowska, 2020).

In Poland, atmospheric air pollution reaches high values, and one of the most polluted voivodships is Małopolska, with its capital in Krakow. The city has for many years been regarded as an example of an agglomeration with poor air quality. High concentrations of particulate matter and gaseous pollutants have been recorded here since the 1950s. In the1990s, the main reason for such quotations was the buoyant development of industry and the operation of thermal power plants and steelworks (Nowicki, Ribbe, 2001).The limit values set for ambient concentrations of pollutants in the directives on air quality and cleaner air for Europe (CAFE) are often exceeded (https://www.miteco.gob.es/es/calidad-y-evaluacion-ambiental/temas/atmosfera-y-calidad-del-aire/air-quality-in-europe_2019_tcm30-187944.pdf, accessed: 13.04.2022; https://ec.europa.eu/environment/archives/enlarg/handbook/air.pdf, accessed: 13.04.2022; https://www.gios.gov.pl/pl/, accessed: 13.04.2022). According to the European Environment Agency (EEA) report on air quality in Poland (2010-2015), it is in large cities and agglomerations that the largest percentage of the population, as much as 80-88%, is exposed to concentrations exceeding EU standards for both PM10 and PM 2.5. The average PM 2.5 concentration in Poland is 22.8 $\mu g/m^3$, such high levels may be due to the burning of solid fuels (mainly coal) in households (Choi, Melly, Spengler, 2015). The shares of households, services, energy, or road transport in PM 2.5 (particles with a diameter below 2.5 μm) emissions in Poland in 2017 were 38%, 5%, and 9%, respectively (Bebkiewicz, 2019). These sectors also had similar shares for PM 10 emissions (particles less than 10 μm in diameter). At present, almost 80% of carcinogenic benzo(a)pyrene is emitted from the household and service sectors. Statistics from the World Health Organisation (WHO) show that mortality due to poor air quality in Poland in 2018 was 36.3 deaths per 100,000 inhabitants (https://www.who.int/docs/default-source/gho-documents/world-health-statistic-reports/6-june-18108-world-health-statistics-2018.pdf, accessed: 11.04.2022). However, when classifying particulate and gaseous pollutants in urban areas, it should be estimated that these concentrations consist mainly of emissions from transport and industry (Bokowa, 2008). Considering research results covering a wider territory, within the European Union, transport generates as much as 12% of PM 10 and for PM 2.5 15%, where industry generates 28% of PM 10 and 24% of PM 2.5 respectively (Badyda, 2009; Gliniak, Zuśka, Miczyński, 2015; https://www.eea.europa.eu/publications/air-quality-in-europe-2015, accessed: 09.04.2022; https://www.eea.europa.eu/publications/air-quality-in-europe-2016/download, accessed: 09.04.2022). For Poland alone, in 2015, air pollution costs consumed about €16 billion, or about 3% of Polish GDP; it is possible that by 2050 external costs will decrease by €2.4 billion (Zyśk, 2020).

2. Research problem and research method

This article uses materials showing PM 10 and PM 2.5 dust contents obtained from the website of the Polish institution dealing with air pollution level monitoring, the Chief Inspectorate for Environmental Protection (https://powietrze.gios.gov.pl/pjp/, accessed: 31.03.2022; https://www.gios.gov.pl/en/, accessed: 28.02.2022). They were analysed in detail for PM 10 and PM 2.5 concentrations from 2015-2020, for measurement stations located in the Małopolska voivodeship, and then compiled into calculations and comparison charts in Microsoft Excel.

One of the most frequently examined cities in terms of air pollution in the Małopolskie Voivodeship is Krakow. Several research projects have already been conducted there (Samek, 2009; Wilczyńska-Michalik, Michalik, 2015; Wilczyńska-Michalik, 2015; Samek et al., 2016; Samek, 2016; Bogacki, Bździuch, 2019; Rzeszutek et al., 2019), whose results unfortunately showed excessive concentrations of harmful dust. The results for concentrations of PM 10 and PM 2.5 particulate matter for selected cities in the Lesser Poland Voivodship have been analysed below, including one of the stations of the Chief Inspectorate for Environmental Protection in Krakow, from among several for which results have been published since 2007 (http://krakow.pios.gov.pl/, accessed: 20.02.2022).

Table 1 presents in detail the surveyed measuring stations in the Małopolskie Voivodeship and their addresses.

Table 1
Description of air monitoring stations for the Małopolskie Voivodship

Measuring station	Address
MpBochKonfed	Bochnia, ul. Konfederatów Barskich
MpKrakBujaka	Krakow, ul. Bujaka
MpNoSaczNadb	Nowy Sącz, ul. Nadbrzeżna
MpTarBitStud	Tarnów, ul. Bitwy pod Studziankami
MpTrzebOsZWM	Trzebinia, os. Związku Walki Młodych
MpZakopaSien	Zakopane, ul. Sienkiewicza

Source: https://powietrze.gios.gov.pl/pjp/ (accessed: 31.03.2022).

Measurements of PM 2.5 and PM 10 pollution were recorded for the above monitoring stations, as a result of which it is possible to compare measurements of the two pollutants. The measuring stations are located in the vicinity of streets with increased traffic in residential areas. The cities in which measurement stations for PM 10 and PM 2.5 particulate matter were located were selected on the basis of availability of measurement data and are located in characteristic cities of the Lesser Poland Voivodship with some of the highest concentrations of pollutants.

Table 2 presents the average annual pollution of PM 10 from 2015 to 2022, representing the results of measurements from stations located in selected cities in the Małopolskie Voivodeship.

Measurement stations are located in Krakow, Tarnów, Nowy Sącz, Trzebinia, Bochnia and Zakopane. In the city of Krakow in 2015 the value of pollution was PM 10 at the level of 43.66 $\mu g/m^3$, in 2016 the value was 38.87 $\mu g/m^3$, in 2017 40.24 $\mu g/m^3$, in 2018 the value of pollution was 42.02 $\mu g/m^3$, successively in 2019 it was at the level of

35.01 μg/m^3, finally in 2020 the value of pollution was 30.53 μg/m^3.In the city of Tarnów in 2015 the pollution value of I was PM 10 was recorded at 30.64μg/m^3, in 2016 the value was 29.48μg/m^3, in 2017 31.45μg/m^3, in 2018 the pollution value was 31.87μg/m^3, successively in 2019 it was at 26.37μg/m^3, finally in 2020 the pollution value was 23.29μg/m^3. In the city of Nowy Sącz in 2015 the pollution value I was PM 10 was recorded at 45.74μg/m^3, in 2016 the value was 40.64μg/m^3, in 2017 42.58μg/m^3, in 2018 the pollution value was 37.55μg/m^3, successively in 2019 it was at 34.92μg/m^3, finally in 2020 the pollution value was 33.62μg/m^3. In the city of Trzebinia in 2015 the pollution value of I was PM 10 was recorded at 33.18μg/m^3, in 2016 the value was 34.14μg/m^3, in 2017 36.03μg/m3, in 2018 the pollution value was 32.89μg/m^3, successively in 2019 it was at 29.38μg/m^3, finally in 2020 the pollution value was 25.63μg/m^3. In the city of Bochnia, in 2015 I was recorded a pollution value of PM 10 at 35.94μg/m^3, in 2016 the value was 34.77μg/m3, in 2017 37.50μg/m^3, in 2018 the pollution value was 35.92μg/m^3, successively in 2019 it was at 29.11μg/m^3, finally in 2020 the pollution value was 27.29μg/m^3. In the city of Zakopane in 2015 the value of pollution I was PM 10 was recorded at 32.89μg/m^3, in 2016 the value was 29.79μg/m^3, in 2017 29.60μg/m^3, in 2018 the value of pollution was 29.66μg/m^3, successively in 2019 it was at 38.37μg/m^3, finally in 2020 the value of pollution was 24.92μg/m^3. The values of pollution for the above cities between 2015 and 2020 have decreased.

Table 2

Pollution values of PM 10 in μg/m^3 in the years 2015-2020 for selected measuring stations in the Małopolskie Voivodeship

Year	Location of measuring station					
	Krakow	Tarnów	Nowy Sącz	Trzebinia	Bochnia	Zakopane
2015	43.66	30.64	45.74	33.18	35.94	32.89
2016	38.87	29.48	40.64	34.14	34.77	29.79
2017	40.24	31.45	42.58	36.03	37.50	29.60
2018	42.02	31.87	37.55	32.89	35.92	29.66
2019	35.01	26.37	34.92	29.38	29.11	38.37
2020	30.53	23.29	33.62	25.63	27.29	24.92

Source: https://powietrze.gios.gov.pl/pjp/ (accessed: 31.03.2022).

Table 3

Pollution values of PM 2.5 in μg/m^3 in the years 2015-2020 for selected measuring stations in the Małopolskie Voivodeship

Year	Location of measuring station					
	Krakow	Tarnów	Nowy Sącz	Trzebinia	Bochnia	Zakopane
2015	33.72	25.16	36.01	25.84	29.21	28.22
2016	30.20	24.36	31.49	27.18	29.01	25.61
2017	31.85	25.79	34.1	27.55	30.62	24.68
2018	30.84	24.78	32.54	23.97	28.83	24.37
2019	24.7	20.08	27.31	20.4	23.08	19.75
2020	20.79	17.5	26.83	17.95	21.13	20.53

Source: https://powietrze.gios.gov.pl/pjp/ (accessed: 31.03.2022).

Table 3 presents the annual average PM 2.5 pollution from 2015 to 2022, representing the results of measurements from stations located in selected cities in the Małopolskie Voivodeship.

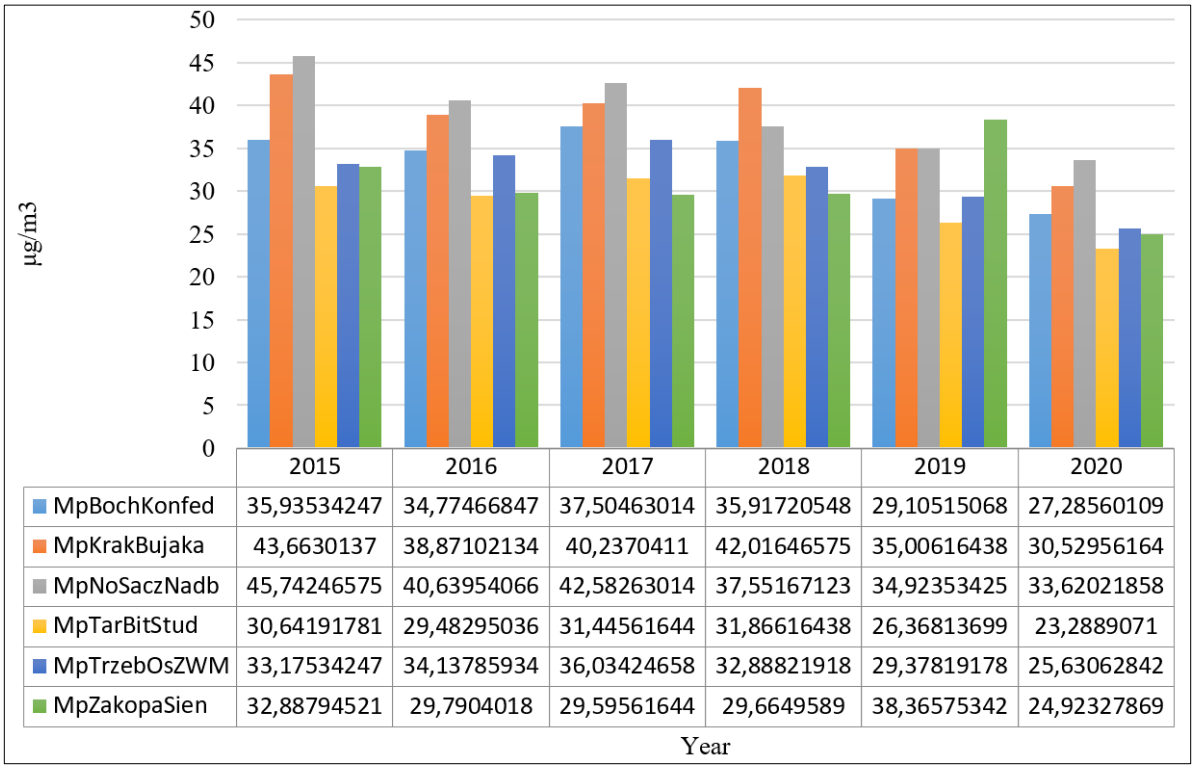
Measurement stations are located in Krakow, Tarnów, Nowy Sącz, Trzebinia, Bochnia and Zakopane. In the city of Krakow in 2015 the value of pollution was PM 2.5 at the level of 33.72 μg/m^3, in 2016 the value was 30.20 μg/m^3, in 2017 31.85 μg/m^3, in 2018 the value of pollution was 30.84 μg/m^3, then in 2019 it was at the level of 24.7 μg/m^3, finally in 2020 the value of pollution was 20.79 μg/m^3. In the city of Tarnów in 2015 the pollution value of I was PM 2.5 was recorded at 25.16 μg/m^3, in 2016 the value was 24.36 μg/m3, in 2017 25.79 μg/m3, in 2018 the pollution value was 24.78 μg/m^3, successively in 2019 it was at 20.08 μg/m3, finally in 2020 the pollution value was 17.5 μg/m3. In the city of Nowy Sącz in 2015 the value of pollution I was PM 2.5 was recorded at 36.01 μg/m^3, in 2016 the value was 31.49 μg/m^3, in 2017 34.1μg/m^3, in 2018 the pollution value was 32.54 μg/m^3, consecutively in 2019 it was at 27.31μg/m^3, finally in 2020 the pollution value was 26.83μg/m^3. In the city of Trzebinia in 2015 the pollution value of I was PM 2.5 was recorded at 25.84 μg/m^3, in 2016 the value was 27.18 μg/m^3, in 2017 27.55 μg/m^3, in 2018 the pollution value was 23.97 μg/m^3, successively in 2019 it was at 20.4 μg/m3, finally in the city of Bochnia in 2015 the pollution value of I was PM 2.5 was recorded at 29.21 μg/m^3, in 2016 the value was 29.01 μg/m^3, in 2017 30.62μg/m^3, in 2018 the pollution value was 28.83μg/m^3, successively in 2019 it was at 23.08 μg/m^3, finally in 2020 the pollution value was 21.13 μg/m3. In the city of Zakopane in 2015 the value of pollution I was PM 2.5 was recorded at the level of 28.22 μg/m^3, in 2016 the value was 25.61 μg/m^3, in 2017 24.68 μg/m^3, in 2018 the value of pollution was 24.37 μg/m^3, successively in 2019 it was at the level of 19.75 μg/m^3, finally in 2020 the value of pollution was 20.53 μg/m^3.The values of pollution for the above measuring stations in 2015-2020 decreased.

3. Results and discussion

When analysing the obtained results of annual PM10 and PM 2.5 concentrations in selected cities of Lesser Poland Voivodeship, it should be noted that air pollution with the above-mentioned particulate matter decreased between 2015 and 2020. When comparing the obtained data with the Regulation of the Minister of Environment of 24 August 2012 on the levels of certain substances in the air (Journal of Laws 2012, item 1031; https://isap.sejm.gov.pl/isap.nsf/download.xsp/WDU20120001031/O/D20121031.pdf, accessed: 18.04.2022), it can be seen that the values of PM 10 and PM 2.5 concentrations were, however, frequently exceeded during the analysed five-year period. According to the regulation, these values should not exceed 20 μg/m^3 for PM 2.5 and 40 μg/m^3 for PM 10 during the calendar year under review (https://isap.sejm.gov.pl/isap.nsf/download.xsp/WDU20120001031/O/D20121031.pdf, accessed: 18.04.2022).

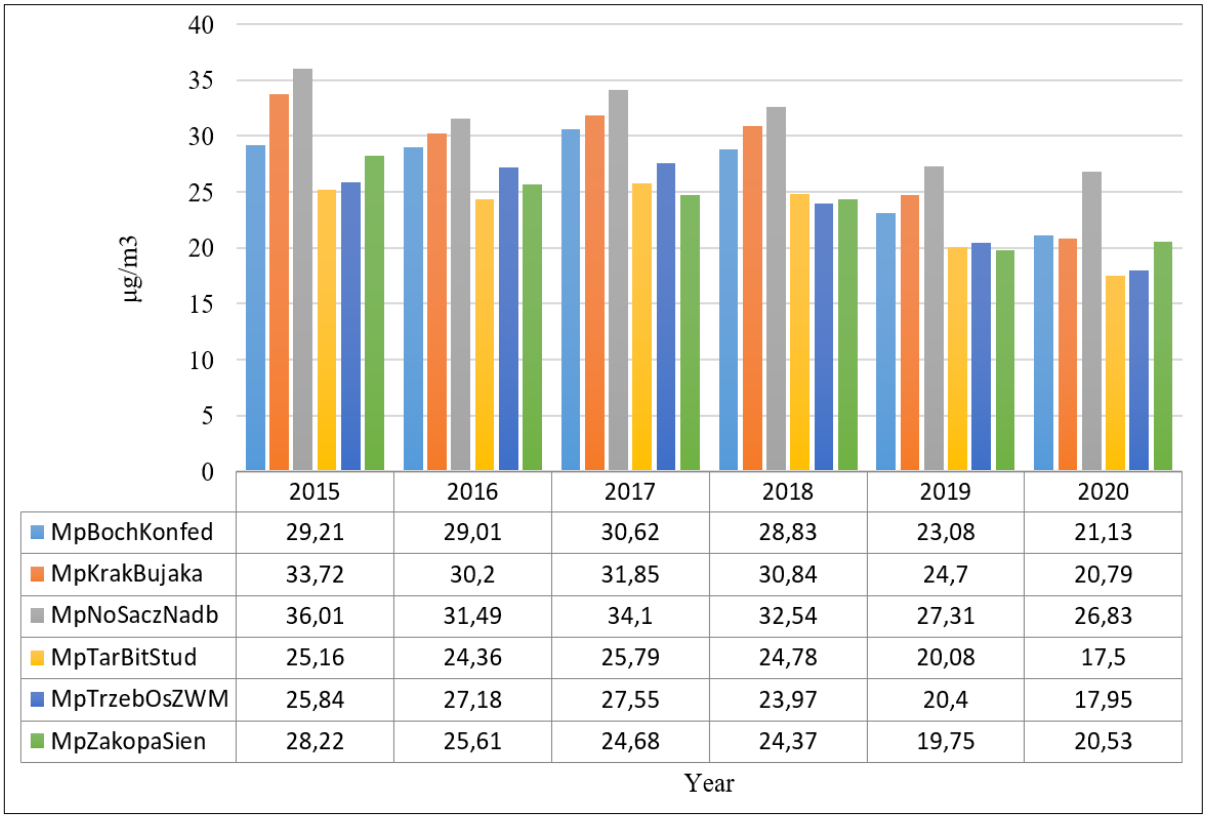
Figures 1 and 2 present changes in the average annual pollution of particulate matter PM 10 and PM 2.5 for the measurement stations described above in selected cities of Lesser Poland Voivodship.

The concentrations of PM 10 and PM 2.5 particles in the analysed cities over the last few years have had a downward trend, but reached values of up to approx. 37 μg/m^3 and 46 μg/m^3, which proves that the standard for PM 2.5 is exceeded twice as much as the standard for PM 10 (https://isap.sejm.gov.pl, accessed: 18.04.2022).



	2015	2016	2017	2018	2019	2020
MpBochKonfed	35,93534247	34,77466847	37,50463014	35,91720548	29,10515068	27,28560109
MpKrakBujaka	43,6630137	38,87102134	40,2370411	42,01646575	35,00616438	30,52956164
MpNoSaczNadb	45,74246575	40,63954066	42,58263014	37,55167123	34,92353425	33,62021858
MpTarBitStud	30,64191781	29,48295036	31,44561644	31,86616438	26,36813699	23,2889071
MpTrzebOsZWM	33,17534247	34,13785934	36,03424658	32,88821918	29,37819178	25,63062842
MpZakopaSien	32,88794521	29,7904018	29,59561644	29,6649589	38,36575342	24,92327869

Figure 1. Changes in average annual PM 10 pollution for measurement stations for the Małopolskie Voivodeship in 2015-2020.
Source: own study.



	2015	2016	2017	2018	2019	2020
MpBochKonfed	29,21	29,01	30,62	28,83	23,08	21,13
MpKrakBujaka	33,72	30,2	31,85	30,84	24,7	20,79
MpNoSaczNadb	36,01	31,49	34,1	32,54	27,31	26,83
MpTarBitStud	25,16	24,36	25,79	24,78	20,08	17,5
MpTrzebOsZWM	25,84	27,18	27,55	23,97	20,4	17,95
MpZakopaSien	28,22	25,61	24,68	24,37	19,75	20,53

Figure 2. Changes in average annual PM 2.5 pollution for measurement stations for the Małopolskie Voivodeship in 2015-2020.
Source: own study.

This issue was taken up in his work by Rataj, who mentioned the location of the area as the reason for such a state, and attributed the large number of replacements of solid fuel boilers for household heating, especially in the Krakow agglomeration, to the decrease in average concentrations of PM 10 and PM 2.5 (Rataj, Holewa-Rataj, 2020). Currently, there are two anti-smog resolutions in force in the Małopolskie Voivodeship. One of them is adopted separately for the city of Krakow (Resolution No. XVIII/243/16), the other for the rest of Lesser Poland (Resolution No. XXXII/452/17). Under the Resolution No. XVIII/243/16, as of September 1, 2019, only gaseous fuels or light fuel oil are required to be used in fuel combustion installations, in particular boilers, fireplaces and cookers, in the area of Krakow if they supply heat to the central heating system or emit heat. The provisions of this resolution also apply to the production of heat for non-heating purposes and are not limited to private buildings, as they also cover the occasional use of fireplaces, the heating of commercial buildings, public institutions, greenhouses and tunnels, drying rooms and catering facilities. In addition, as of 1 July 2017, it is not permitted to operate a newly installed coal or wood boiler or fireplace with emission parameters worse than those set out in the EU regulations in the whole of Małopolska. According to the guidelines of the Marshal's Office of the Małopolska Region, the replacement of installed boilers that do not meet ecodesign requirements is to be carried out in stages, so that

- by the end of 2022, it is necessary to replace coal- or wood-fired boilers that do not meet any emission standards;
- by the end of 2026, boilers which meet the basic emission requirements, i.e. are class 3 or class 4 according to the PN-EN 303-5:2012 standard, must be replaced;
- boilers meeting the requirements of class 5 according to the PN-EN 303-5:2012 standard may be used until the end of their service life (Rataj, 2020).

Analysing further, more detailed results of concentrations of particulate matter, in individual cities of Lesser Poland Voivodeship, presented in diagrams in Figure 1 and 2, one may speak of a decrease from 2016 in average PM 10 pollution by 1.17 $\mu g/m^3$ for the measurement station located in Bochnia, in relation to 2015, successively in 2017 there was an increase of 2.73 $\mu g/m^3$ in relation to 2016, and between 2018 and 2020 there was a decrease in PM 10 pollution for the station. The total decrease in PM 10 pollution between 2015 and 2020 was 8.65 $\mu g/m^3$. Similarly, for PM 2.5 pollution, there was a decrease of 0.20 $\mu g/m^3$ in 2016 compared to 2015, an increase of 1.61 $\mu g/m^3$ in 2017 compared to 2016, and a decrease in PM 2.5 pollution between 2018 and 2020 for the cities concerned. The total decrease in PM 2.5 pollution between 2015 and 2020 was 7.91 $\mu g/m^3$. A similar downward trend, but with concentrations still exceeding standards and the formation of the so-called smog, was noted by Bogacz in his work. Its results showed that heating buildings with solid fuels still emits the largest part of the pollution generated into the environment. This trend can also be seen for the measurement station located in Krakow, where in 2016 there was a decrease of 4.79 $\mu g/m^3$ in average PM 10 pollution compared to 2015, but in 2017 and 2018 there was an increase of 1.37 $\mu g/m^3$ and 1.78$\mu g/m^3$ compared to previous years. There was a decrease in PM 10 pollution for the station between 2019 and 2020, and the total decrease in PM 10 pollution between 2015 and 2020 was 13.13 $\mu g/m^3$. Similarly, for PM 2.5 concentrations, 2016 saw a decrease in average pollution of 3.52 $\mu g/m^3$ compared to 2015, 2017 saw an increase of 1.65 $\mu g/m^3$ compared to 2016. In 2018 to 2020 there was a renewed decrease of approximately 1.05$\mu g/m^3$ from previous

years. The total decrease in PM 2.5 pollution between 2015 and 2020 was 12.92 μg/m^3. The increases in PM 10 and PM 2.5 concentrations in Krakow Bogacki, justified by the location of the measurement stations and cited heavy traffic in the vicinity of the control points as their main cause (Bogacki, Rzeszutek, Heba, 2016), Modeling studies conducted by Bogacki showed that emissions from engines and abrasion of tyres, linings and road surface in shaping the average concentrations of air pollutants in the street canyon for PM 10 and PM 2.5 are 27 and 24% respectively (Bogacki, 2016). A large influence in Krakow, as shown in Godłowska's study, is the limitation of wind speed, which is greatly influenced by the urban infrastructure, under certain conditions making it extremely difficult to remove pollutants emitted in street canyons, and when increasing the proportion of built-up area the airflow changes its character from isolated, in the presence of sparsely distributed buildings, to roughly disturbed, in which the wind penetrates into the interiors of street canyons often causing a swirling movement in them (2019). For the measurement station located in Nowy Sacz, a decrease of 5.1 μg/m^3 in average PM 10 pollution was recorded in 2016 compared to 2015. In 2017, there was an increase of 1.94 μg/m^3 compared to 2016, similar to other measuring stations. There was a decrease in PM 10 pollution for the station between 2018 and 2020, and the total decrease in PM 10 pollution between 2015 and 2020 was 12.12 μg/m^3. Similarly, for PM 2.5, 2016 saw a decrease in average PM 2.5 pollution of 4.52 μg/m^3 compared to 2015, 2017 saw an increase of 2.61 μg/m^3 compared to 2016, and 2018-2020 saw a decrease in PM 2.5 pollution for the city. The total decrease in PM 2.5 pollution between 2015 and 2020 was 9.21 μg/m^3. For the measuring station located in Tarnow, in 2016 there was a decrease of 1.16 μg/m^3 in average PM 10 pollution compared to 2015, in 2017 and 2018 there was an increase of 1.97 μg/m^3 and 0.42 μg/m^3 compared to 2016 and 2017. In contrast, there was a decrease in PM 10 pollution for the station between 2019 and 2020. The total decrease in PM 10 pollution between 2015 and 2020 was 7.35 μg/m^3. For the city of Tarnów, 2016 noted a decrease of 0.8 μg/m^3 in average PM 2.5 pollution compared to 2015. There was an increase of 1.43 μg/m^3 in 2017 compared to 2016, and a decrease of approximately 0.99 μg/m^3 on average between 2018 and 2020 compared to 2017. The total decrease in PM 2.5 pollution between 2015 and 2020 was 7.66 μg/m^3. For the measuring station located in the city of Trzebinia, in 2016 and 2017 there was an increase of 0.96 μg/m^3 and 1.89 μg/m^3 in the average PM 10 pollution compared to previous years, and in 2018-2020 there was a decrease in PM 10 pollution for the station. The total decrease in PM 10 pollution between 2015 and 2020 was 7.55 μg/m3. For the city of Trzebinia, 2016 and 2017 also saw an increase in average PM 2.5 pollution of 1.34 μg/m^3 and 1.89 μg/m^3 compared to previous years. There was a decrease in PM 2.5 pollution for the city between 2018 and 2020, with a total decrease in PM 2.5 pollution of 7.84 μg/m^3 between 2015 and 2020. For the measuring station located in Zakopane, a decrease in average PM 10 pollution was recorded between 2015 and 2017. There was an increase of 0.06 μg/m^3 in 2018 and 2019 and an increase of 8.71 μg/m^3 from previous years. In 2020 there was a renewed decrease in PM 10 pollution for the station. The total decrease in PM 10 pollution between 2015 and 2020 was 7.97 μg/m^3. For the city of Zakopane, there was a decrease in average PM 2.5 pollution between 2015 and 2019, but an increase of 0.75μg/m^3 in 2020 compared to 2019. The total decrease in PM 2.5 pollution between 2015 and 2020 was 8.47 μg/m^3. The jumps from a decreasing to an increasing trend in pollutant concentrations of PM 10 and PM 2.5, as shown in studies by (Godłowska, 2019; Bogacki, 2016; Bogacz, 2018),

from one year to the next, may be rooted in a number of factors, both in increased traffic (exhaust emissions), greater consumption of fuels for heating buildings, and may also be influenced by the specifics of the area itself, the amount and type of urban development and the location of the region. In urban, mountainous areas, exceedances are read much more frequently than in open areas where the air mass flow is freer.

Considering the overall results, exceedances of the permissible concentration standards for PM 10 are seen mainly in 2015, 2016, 2017 and 2018, occur most frequently in Kraków and Nowy Sącz, with average exceedance values ranging from as little as 1 μg/m^3 to about 17 μg/m^3. For PM 2.5 annual exceedances occur much more frequently, and the predominant cities where these standards are exceeded are Krakow, Nowy Sącz and Bochnia. Exceedances of over 20 μg/m^3 reach up to about 16 μg/m^3 above the norm and are particularly noticeable in Krakow and Nowy Sącz. As noted by (Bokwa, 2016) in her work and by (Godłowska, 2019) in her modelling studies, exceedances of acceptable concentration standards can result from the specification of cities, and air pollution in a given location depends primarily on factors such as:

- emissions, i.e. how many and which pollutants are released into the atmosphere and in what way;
- physico-chemical changes of pollutants in the atmosphere, e.g. a weak, long--lasting rain effectively washes away many pollutants from the atmosphere, while fog combined with sulphur dioxide forms sulphuric acid;
- the emmission of pollutants, i.e. how much pollution reaches a given point and where it comes from;
- dispersion conditions, that is, whether weather conditions are conducive to the rapid transport and efficient dispersion of air pollutants (Bokwa, 2016).

In addition, the main air pollution with PM 10 and PM 2.5 (PM10, PM2.5) in cities comes, especially during the heating period, mainly from the combustion of fossil fuels – especially in individual furnaces at low combustion temperatures. Abrasion from asphalt, car tyres and metals is also a source of pollution (http://www.euro.who.int/data/assets/pdf.file/0006/189051/Health-effects-of-, accessed: 18.04.2022). Pollutants may also originate from areas not covered by vegetation – hence their high concentration also in the warm season. Particulate matter PM10 (particle size <10 μm in diameter) is particularly harmful, especially particles 3-5 mm in size and smaller (http://www.euro.who.int/data/assets/pdf_file/0006/189051/Health-effects-of-, accessed: 18.04.2022), for PM 2.5 emitted as primary pollutant, there is a risk of secondary pollutants due to transformation of SO2, NO2, NH3 and volatile organic compounds (https://www.ciop.pl, accessed: 18.04.2022). The most frequent exceedances of permissible levels of particulate matter occur in towns and agglomerations of southern and central Poland that is in: the Upper Silesian agglomeration, the Cracow agglomeration, the Rybnik-Jastrzębska agglomeration and the Łódź agglomeration. The main reason for these exceedances is population density and terrain (www.gios.gov.pl, accessed: 18.04.2022). In the Lesser Poland Voivodeship, using the example of Krakow and Bokwa's research, it can be said that pollutants emitted in cities in the area often tend to accumulate over agglomerations, and additionally urban development and relief prevent air purification in a quick and easy way (2017). Urban buildings create a kind of obstacle to the free flow of air and also contribute to the weakening of the wind speed, creating the so-called curtain effect, where the lower limit of the wind

speed is assumed to be 3-5 m/s (Szymanowski, 2004). All pollutants emitted into the atmosphere accumulate in layers because the increase in air temperature combined with altitude causes the portion of air rising upwards (e.g. exhaust from cars or heating cookers), i.e. the portion of air with a higher temperature than the surrounding air (and therefore lighter), to finally reach the level where the surrounding air has the same or higher temperature and further upwards movement ceases. Under such conditions, even small emissions of pollutants quickly lead to high pollutant concentrations, as shown in a study by (Hajto, Rozwoda, 2010).

In Poland, the least polluted provinces can include Podlaskie, Warmińsko-Mazurskie and Zachodniopomorskie provinces (Zagórska et al., 2018). Studies on the content of PM 10 and PM 2.5 were carried out by Zagórska and others who focused on the causes of emissions of this pollutant in urban and industrialised environments. The results of the study by Zagórska and others showed that the conscious choices of the inhabitants of a given area concerning the method of heating households, not burning rubbish, not overheating dwellings, the conscious choice of greener forms of transport and energy-saving devices, such as energy-saving light bulbs, but also the terrain and lower density of urban agglomerations may contribute to low concentrations of particulate matter (2018).

4. Conclusions

Lesser Poland Voivodeship is one of the most polluted areas in Poland. High concentrations of PM 10 and PM 2.5 particulate matter adversely affect the health of the province's residents. The analysis of concentrations, of the above-mentioned particulates, in the years 2015-2020 allowed to determine their annual concentrations in particular periods. The data obtained from the Environmental Protection Inspectorate made it possible to select six measuring stations, located in towns: Bochnia, Kraków, Nowy Sącz, Tarnów, Trzebinia, Zakopane and come to the following conclusions:

- Concentrations of both PM 10 and PM 2.5 are decreasing from 2015 to 2020.
- The highest pollution values each year are achieved at stations in Krakow and Nowy Sącz.
- The highest recorded value for PM 10 was above 45 $\mu g/m^3$ and for PM 2.5 was above 35 $\mu g/m^3$ for the measurement station in Nowy Sącz in 2015.
- The lowest values can be seen in 2020 for the measurement station in Tarnów, where PM 10 was about 24 $\mu g/m^3$ and PM 2.5 about 18 $\mu g/m^3$.

The location of measuring stations should also be taken into account, those located near busy roads, such as in Nowy Sącz at ul. Nadbrzezna, give results indicating the main origin of pollution generated by transport. The analysis of the results of PM 10 and PM 2.5 concentrations has taken into account data from those stations which measure both PM 10 and PM 2.5 concentrations, some of the most dangerous particulates for human health. A similar factor, air pollution, especially for the city of Krakow, is the terrain. The city is located in a valley, built up with urban agglomeration, does not allow free flow of air masses, cleansing the air from harmful particles, in addition, in cities, household heating with solid fuels and heavy traffic do not help to reduce harmful concentrations of suspended particles PM 10 and PM 2.5.

A positive result of the analysis is that there has been a downward trend in ambientair pollution since 2015; however, exceedances of the limit standards, which allow limits of 20 μg/m^3 for PM 2.5 in a calendar year and 40 μg/m^3 for PM 10, are still recorded. In 2020, only the stations in Tarnów and Trzebinia maintained the lowest values of PM 10 and PM 2.5 concentrations not exceeding the set standards. Other stations could record exceedances of up to around 15 μg/m^3 for PM 2.5 between 2015 and 2020.

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Ecological awareness of the inhabitants of Nowy Sącz County

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Abstract: The environmental awareness of a community is crucial to implement the principles of sustainable development in all areas of human activity. Its current level is crucial in the development of the young generation. The aim of this paper is to carry out a study of environmental awareness of the residents of Nowy Sącz County. The aim of the study is to check how the individual environmental projects or social campaigns implemented in Nowy Sącz County function and adapt. The research problem will be formulated in the form of a main question, while survey research will be used as a research method. The research will be carried out through an online survey and a stationary survey. The survey will consist of 3 stages, which will include the areas of air protection, waste management and water protection. The result of the research will allow to provide the answer about the level of ecological knowledge of the residents of Nowy Sącz County in three key areas. Currently, the residents in the study area are increasingly aware that they have a real impact on the environment through responsible purchasing, types of energy sources used in households, and means of communication and transport they choose. Nowosądecki County has the highest air pollution index. Through this, a number of different projects and social campaigns have been introduced to reduce air pollution. The results of the study have shown to what extent these activities are put into practice, and when made available to the local government, they can be used to develop effective methods of environmental protection activities.

Key words: environmental awareness, environmental protection, Nowy Sącz County.

1. Introduction

According to (Baltromiuk, 2009), environmental awareness is a necessary element in the development of the economy and in the development of the society. Striving for sustainability is one of the most important issues in environmental awareness. We are increasingly aware that our actions have an impact on the environment. As a result, a person can build and support the environment, but also can cause its degradation and destruction. It is often the case that human actions can have unintended consequences and be dangerous to the environment in which we live. We recognize that our planet has finite limits, which makes the steps we take in technological science should be prudent and in harmony with what is natural. We must not interfere with the biological rhythm of the environment (Sobczyk, 2000).

For a long time now, we have noticed an increase in activities that promote eco--friendly lifestyle. According to (Johnson, 2016), the first noticeable element was the actions of large companies, which began to encourage the performance of actions that would reduce pollution, such as reducing the use of disposable plastic bags. Currently, carrying out activities that reduce pollution, no longer only concern the companies themselves, who also cared about their image, but also individuals who decide to do so by using renewable energy sources, reducing CO_2 emissions, segregating garbage, etc.

By making a preliminary analysis, we are able to conclude that everything is going in the right direction. However, we still need to pose a question: is it because of the increasing ecological awareness in the society? Or is it just a financial element, because many people use public transport or electric cars. This is because the use of these means of transport is cheaper, considering the prices of fossil fuels. A similar aspect is the use of photovoltaic panels or solar collectors, which reduce air pollution by lowering the consumption of fossil fuels such as brown or hard coal. However, it is estimated that this situation is also related to the possibility of savings for photovoltaic panels users due to rising prices of coal, gas and electricity (ekologiczni.com.pl, accessed: 12.04.2022).

On many websites of companies which are dealing with installing and designing renewable energy sources systems, we notice charts which show the possibility of saving money compared to the old technology. For this purpose, a survey has been carried out which aim is to investigate the ecological awareness of the residents of Nowy Sącz County, which is located in the Lesser Poland Voivodeship and is characterized by high air pollution, which is confirmed by the research done by the Regional Inspectorate for Environmental Protection in Kraków – Branch Office in Nowy Sącz. The research was also carried out in the scope of:

- surface water;
- trash segregation (Gondek, 2018).

2. Purpose and scope

The aim of this paper is to carry out a study of environmental awareness of the residents of Nowy Sącz County. Conducting such a study is to check how the individual ecological projects or social campaigns implemented in Nowy Sącz County function and adapt. Survey research was used for the research method. The research was conducted by means of a survey carried out online and stationary. The survey consists of 3 stages, which includes the area of air protection, waste management and water protection. The result of the research will allow to answer what is the level of ecological knowledge of the residents of Nowy Sącz County in three key areas.

3. Survey analysis

The survey is anonymous and consist of 3 stages, which include air protection, waste management and water protection. In the survey there are single-choice, multiple-choice and open-ended questions. The survey was conducted online and in a stationary form in Nowy Sącz County. This county is located in the southern part of Małopolska Voivodeship. Nowy Sącz County consists of 16 municipalities. According to the Central Statistical Office (GUS, 12.04.2022), the county has a population of 216,994 people. A total of 498 people who live in Nowy Sącz County took part in the survey.

3.1. General Data

At the beginning of the survey, the research was conducted to check the basic data. The total number of 498 people took part in the survey, among which 37% of them were men and 63% were women. The respondents were in the following age range:

- under 25 years old – 30% of respondents;
- 26 to 40 years old – 42% of respondents;
- 41 to 60 years old – 21% of respondents;
- over 60 years old – 7% of respondents.

The people who took part in the survey were both city residents (69%) and people living in the countryside (31%). In the next question the respondents answered that 52% of them live in an apartment and 48% in a single-family or multi-family house. A bar picture in Figure 1 below is showing the respondents' answers to the questions described above.

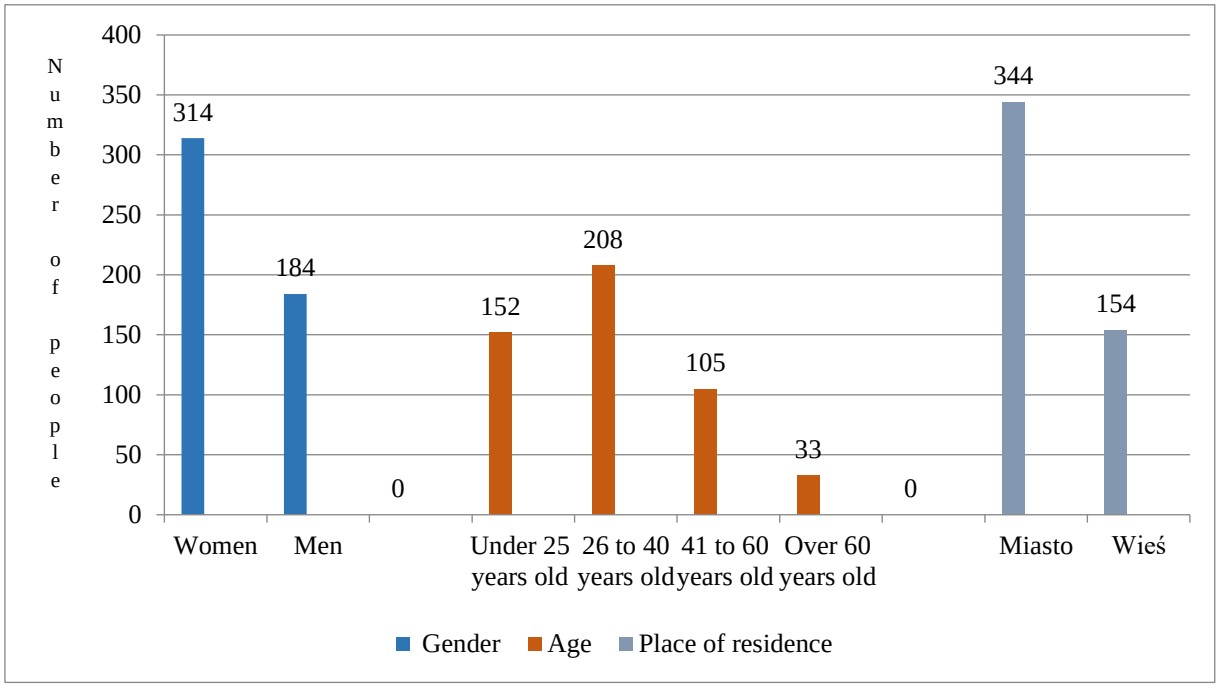

Figure 1. Picture showing responses to gender, age, and residence.
Source: own study.

3.2. Stage I – Air protection

Air protection is not only an important part of the European policy, but also of Nowy Sącz County, because the air pollution index in the area of Nowy Sącz is notably high, and compared to other cities in Poland, Nowy Sącz takes the leading place in air pollution. Based on the CAFE Directive, the authorities of Nowy Sącz County are obliged to develop a project of air protection, where particular indicators of pollution exceed the basic values. The problem of air pollution is not only a regional problem, but also this aspect is addressed between international institutions (Supreme Chamber of Control, 2014).

The first stage of the survey concerned air protection. Due to the high air quality problem in Nowy Sącz County, the questionnaire examined how the inhabitants find information about the air quality and what actions they take to improve the air quality.

Question one, was a multiple-choice question and asked about the sources respondents use to check air pollution levels. The respondents answered as follows:

- 27% of people – use social networking sites to get information about air quality;
- 18% of people – use phone applications;
- 28% of people – use local websites;
- 19% of people – use local radio;
- 1% of people – answered "other", giving the following media: GIOS, Chief Inspectorate of Environmental Protection, infosmog, from friends/family, from "powietrze.gov" website.

The second question concerned smog, to what extent it threatens the health of the respondents. To this question 73% answered that it is a real threat to our health, 22% that smog is a threat to our health, but this threat is not so serious. The smallest number of people – 3% – answered that smog does not threaten our life and it is a matter of publicity in the media, and 2% of people answered that they do not have an opinion.

Question number three covered sensibility of smog effect. For this question 87% of the respondents said that they feel the effects of smog and the most frequent symptoms were: allergy, asthma, sore throat, runny nose, headache, shortness of breath, cough, weakness and fatigue, worse complexion, bitter taste in throat, cough after coming back from walking/jogging, and itchy eyes. Only 13% of the respondents answered that they do not feel any effects of smog. According to the Supreme Audit Office (2018), long-lasting air pollution over cities or towns causes various types of chronic respiratory diseases as well as cancer. The diseases mentioned, which the respondents acquired as a result of the existing air pollution, are confirmed by scientists. Looking at the results of the questions above, one can see that in spite of undertaking various social campaigns aiming at making the society aware of the real threat of the smog, still 5% of the society of Nowy Sącz County believes that smog is not a threat to their health.

The fourth question concerned measures that enable to fight against smog. As many as 77% of the respondents answered that they do not use any measures that would help to fight smog. On the other hand, only 23% of the respondents answered that they use the following measures: humidifiers, air purifiers, replacing the stove, using a car that meets Euro 6 norm, using an electric bike, having a chimney filter, having a photovoltaic system, using public transport, paying attention to the quality of the fuel in the stove, using a hybrid/electric car.

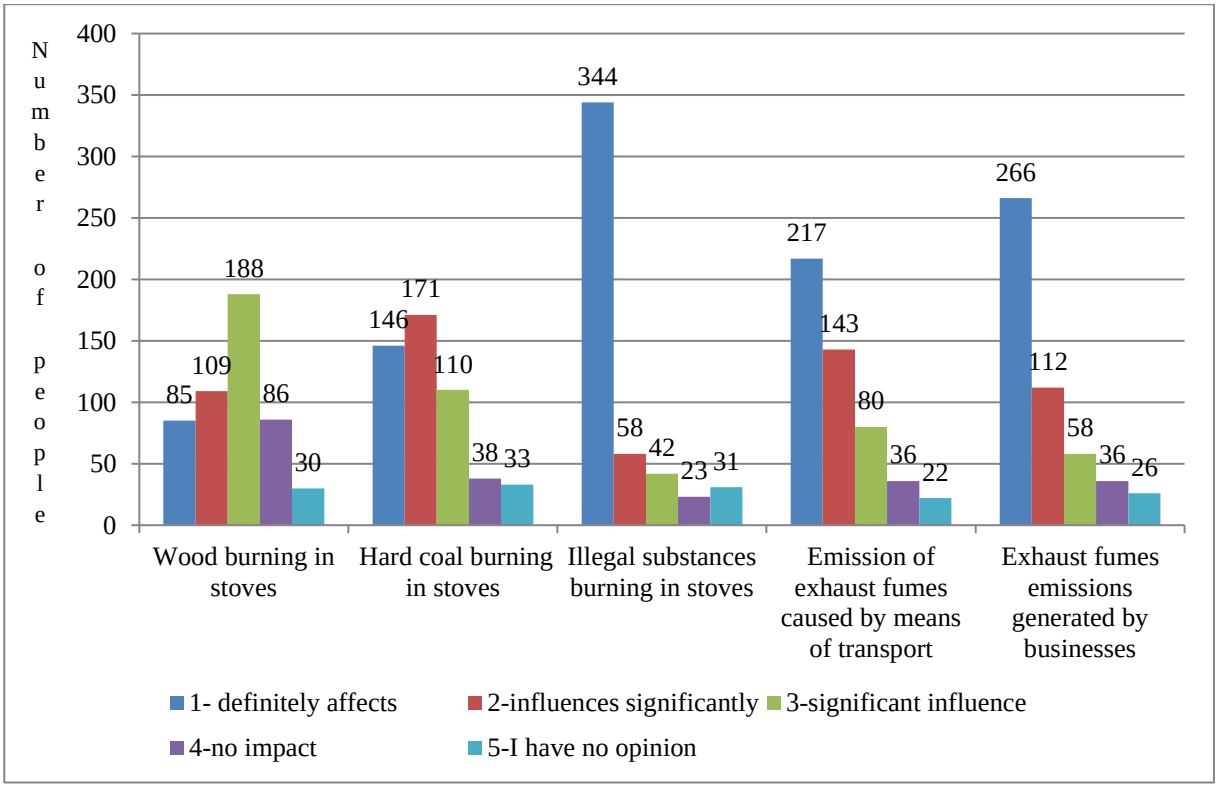

Figure 2. Responses to the question "Influence of a given factor on smog formation". Source: own study.

The fifth question covered the causes of smog formation. The respondents had to mark on a scale from 1-doubtful to 5-don't know how smog formation is caused by a particular factor. 38% of the respondents consider that wood burning in stoves has little influence on smog formation. On the other hand, 34% of respondents think that burning hard coal in stoves has a significant impact on smog formation. Respondents also stated that burning illegal substances in the stove significantly influences the smog formation in 69%, while the emission of exhaust fumes caused by means of transport influences it only in 44%. On the other hand, exhaust emissions generated by businesses strongly influence smog formation in 53%. Figure 2 of the picture below shows the individual responses of the respondents.

According to Turek (2018), when hazardous substances are burned in stoves, several substances dangerous to the human body are released into the atmosphere. Such substances are arsenic, dioxins, carbon, sulfur and nitrogen oxides, PM10 and PM2.5. Each of the substances mentioned are poisons. Thanks to numerous campaigns carried out by the authorities of Nowy Sącz County, the majority of citizens are beginning to pay attention to what they burn in their stoves.

The next question was: “Has the building in which you live undergone thermomodernization?”. The answer “YES” was given by 39% of the respondents. The answer “NO” was given by 23% of the respondents, where 33% of the respondents did not know if their house was thermo-modernized, and 5% of the respondents did not have thermo-modernization but it is planned. Those who answered “YES” reported that the modernization usually consisted of: insulating the building and sealing windows, insulating the elevation, installing an additional layer of Styrofoam, and using a new generation of furnaces and replacing pipe systems in the building.

The next question relates to the heating source used by respondents to heat their homes. Respondents gave the most votes for district heating, as many as 35%. Then natural gas came second at 27%. Next, the respondents answered that the heating sources they use are as follows: coal – 15%, wood – 14%, LPG – 2%, fuel oil – 2%. In Figure 3 below there is a picture showing the individual responses to the question regarding the heating source used.

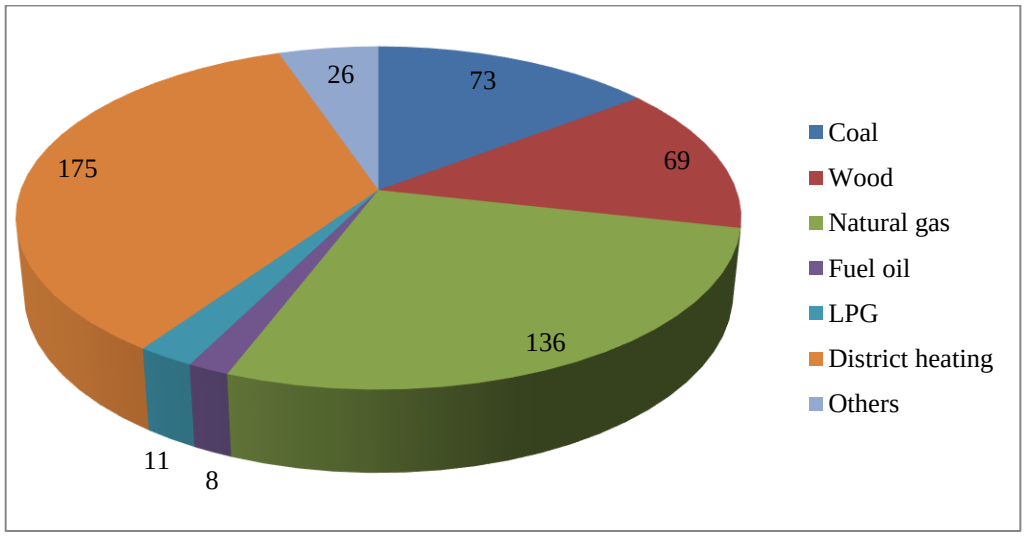

Figure 3. Responses to the question “What type of heating source do you use?”.
Source: own study.

The last question relates to the amount of renewable energy used by the respondents. The largest number of people, 72%, do not use any renewable energy sources, 10% of respondents use photovoltaic panels, 6% of people use a heat pump, 3% use a biomass stove, 1% use wind turbines, and only 2% of respondents use hydroelectric power. In Figure 4 below, a picture is showing the individual responses to the question.

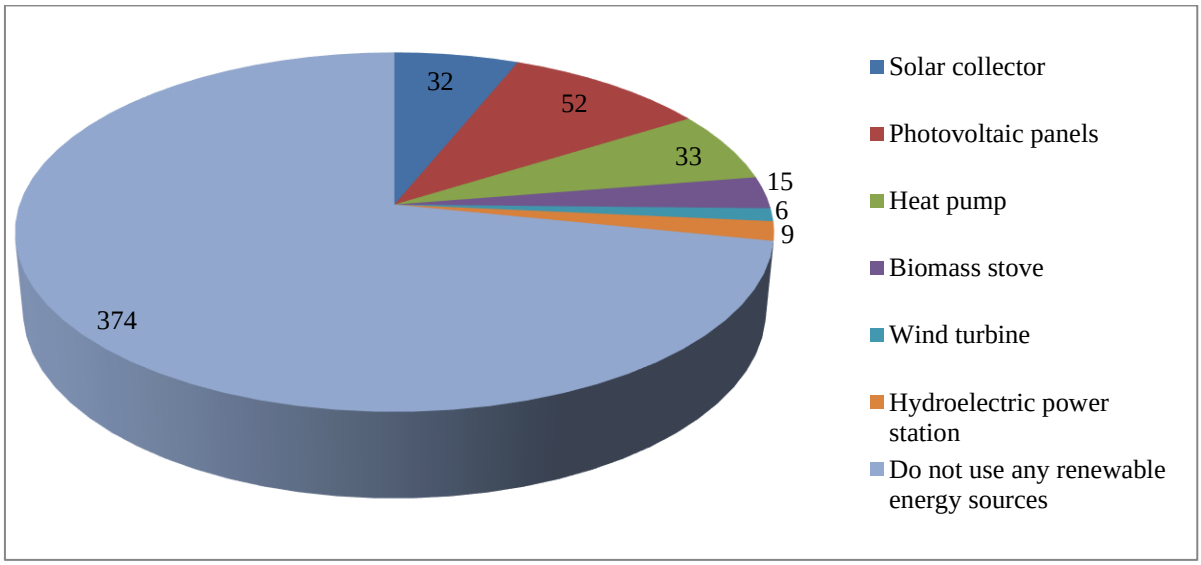

Figure 4. Responses to the question "What types of renewable energy do you use?". Source: own study.

The basic requirement of life is clean air, which is an indicator of a healthy human body. Many harmful substances are still being emitted because of human beings. Understanding how dangerous these substances are is essential to avoid and reduce their impact on human health (Choi, 2009). In Nowy Sącz County and all over the country, various projects and resolutions are being introduced that prohibit the continued use of stoves and boilers with outdated technology. These regulations are enforced by the municipal police, who, using drones equipped with special sensors, control the smoke rising from the houses' chimneys. Thanks to the extension of the municipal guard's duties, it is possible to check whether the residents smoke in their stoves and, in case of abuse, to enforce fines for burning prohibited substances in their stoves. In Nowy Sącz County there are also nationwide and local subsidizing programs for energy modernization. Such subsidies are targeted at families who want to replace the furnace or want to invest in photovoltaics. The implementation of these projects shows that air quality is an important element of the environment, to which more and more people are beginning to pay attention to (Śliwowski, 2020).

3.3. Stage II – Waste management

In urban agglomerations, processes and facilities are closely interrelated. Their inseparable element is the generation of municipal waste, which creates not only an economic problem, but above all an environmental problem. Therefore, municipalities and cities are obliged to ensure cleanliness and tidiness within the designated area. Each municipality and town have their own waste management system. This system includes collection of municipal waste, its transportation and its processing. Waste management consists of planning and implementation of projects as well as their control (Wąsowicz, 2018).

The second stage of the conducted survey consists of 9 questions that concern the aspect of waste management in Nowy Sącz County. The number of 498 people took part in that stage. All respondents answered every question. These questions were single choice ones, whereas one of the questions was an open one.

The first question was about the use of bags while shopping. The largest number of respondents, 69% answered that they always take a bag when shopping. Next, 18% said they take bags if they remember, 10% take their own bag only for larger purchases. The least number of people answered that they do not take their own bag for shopping but prefer to buy one at the checkout. This answer was chosen by only 3% of respondents.

The second question was a the one related to product packaging. This question was designed to find out how many people pay attention to the quality of the packaging they buy while shopping. 50% of the respondents occasionally pay attention to the packaging they buy. On the other hand, only 35% pay attention to whether the packaging is recyclable, and 15% of the people surveyed do not pay attention at all to the packaging they purchase. According to Adom (2012), waste is a by-product of human activity. Development and economic growth produce more and more packaging. One way to manage waste in a better way is to produce recyclable packaging. Such packaging is beneficial to the environment and can be used several times and from such packaging, we can produce more packaging.

The third question was about the possibility of waste segregation. All respondents answered positively to this question. This way 100% of respondents answered that it is possible to segregate waste in their place of residence. After the amendment of the Act on maintaining cleanness and order in municipalities, every property owner is obliged to segregate waste. Thus, the answer to the question about possibility of waste segregation is affirmative in each case.

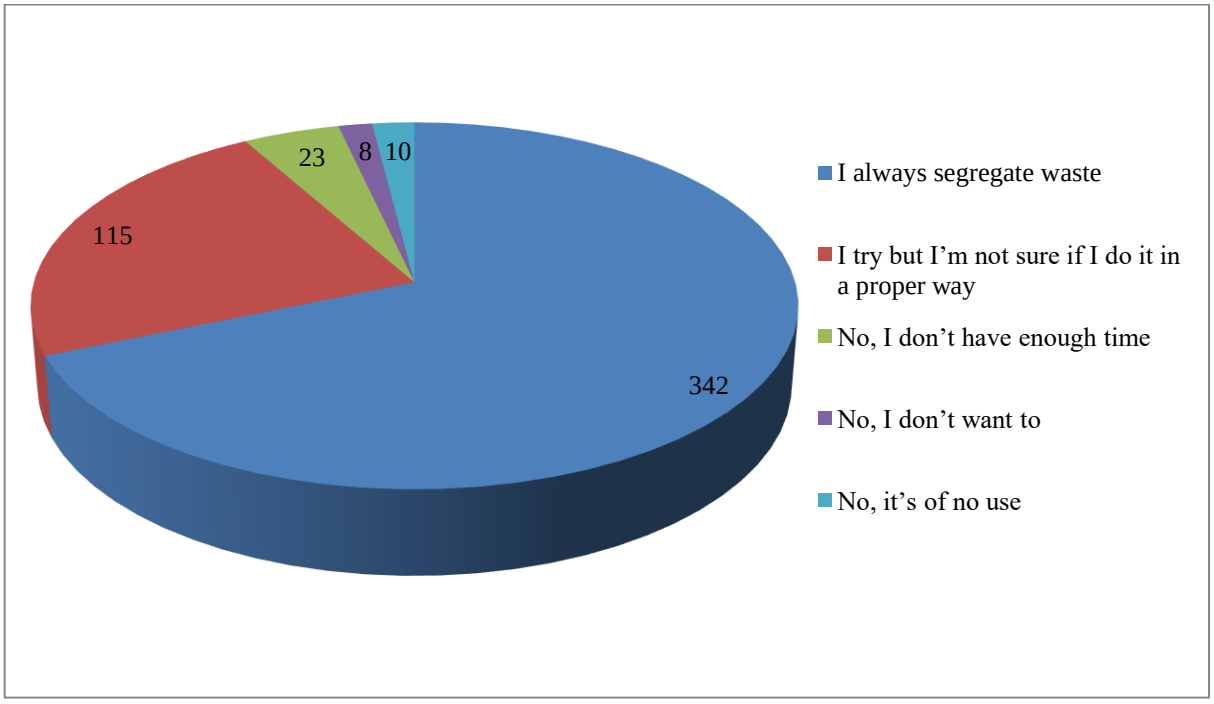

Figure 5. Individual responses to the question "Do you regularly separate waste?".
Source: own study.

The next question relates to regular waste segregation. As many as 69% of people answered that they always segregate waste, while 23% of people try to segregate waste, but they are not sure if they do it in a proper way. The remaining people responded that they do not have time to segregate waste, they do not want to, and they do not see the point in segregating waste. Figure 5 presents showing the responses to the question about regular waste segregation.

The fifth question was an open-ended question and asked about the problems faced by the respondents in segregating garbage. About 33% answered that they have no problem with segregating waste. The remaining part of the surveyed people answered that the biggest problem they have is making a room for waste baskets for each category, segregation of bio-waste, the lack of precise information on what kind of waste can be put into specific container, the lack of containers in the yard for segregated waste, regular emptying of containers by companies, the lack of bags for segregated waste, with juice or milk cartons, electrical appliances or batteries, specification of what material the packaging comes from. A lot of respondents noticed that companies which collect segregated waste, do not collect it in separate vehicles but mix it together with mixed waste and take everything to a landfill.

The next question was about waste treatment facilities operating in Nowy Sącz County. The respondents answered that 75% of them do not live near any waste processing installations. On the other hand, 25% of respondents said that the following waste processing facilities were located near their homes: a landfill, a PSZOK company which segregates waste, a composting facility, or the MPEC biomass incineration plant in the Gorzków housing estate. The biomass incinerator is not as well-known as thermal waste treatment, but it is also applied in Nowy Sącz, which is a big plus. According to Kreith (2002) different fractions of biomass can be used as fuels. The energetic use of biomass can be done by two technologies. The first technology is the incineration of raw mixed waste. The second technology is the incineration of properly prepared residual fractions, which are the most energetic.

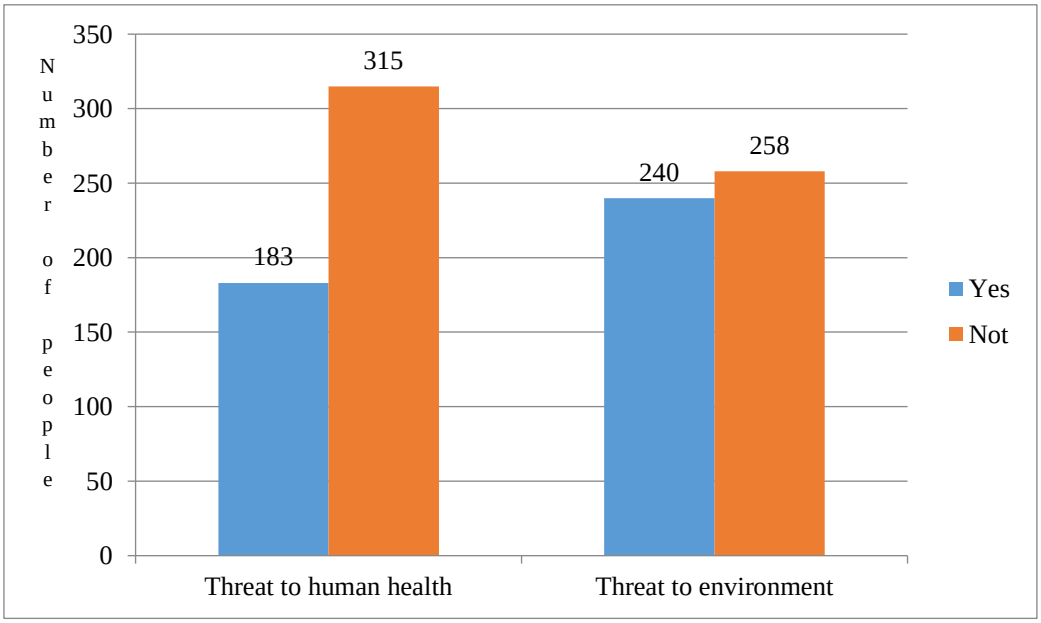

Figure 6. Individual responses to the question "Do you think these installations pose a threat to human health or the environment?".
Source: own study.

The seventh and eighth questions asked about the impact of waste treatment facilities on human health and the environment. 183 respondents answered that waste treatment facilities have a significant impact on human health. In contrast, 240 respondents answered that waste treatment facilities have a significant impact on the environment. Figure 6 shows the individual responses to the questions about the impact of waste treatment facilities on human health and the environment.

Most often, thermal waste processing plants raise a lot of doubts among the residents of Nowy Sącz County, especially the thermal waste processing plant. Due to this reason, many institutions have a big problem with localization of such plants, because most of the people do not agree to locate such plants near their homes. Most often, the community hides behind such arguments as noise or higher pollution emissions. Thermal fuel processing plants, on the other hand, are modern, so their environmental impact is constantly controlled. Moreover, these plants are covered by regulations that are rigorously checked (Golek--Schild, 2018).

The last question concerned the knowledge of the principles of waste treatment facilities operations. The majority of respondents know the principles of waste processing facilities operations. Most of them know how a waste sorting plant and a composting plant function. The fewest know how a thermal waste disposal plant operates. Figure 7 presents of individual responses to the question about knowledge of the principles of waste processing facilities operation.

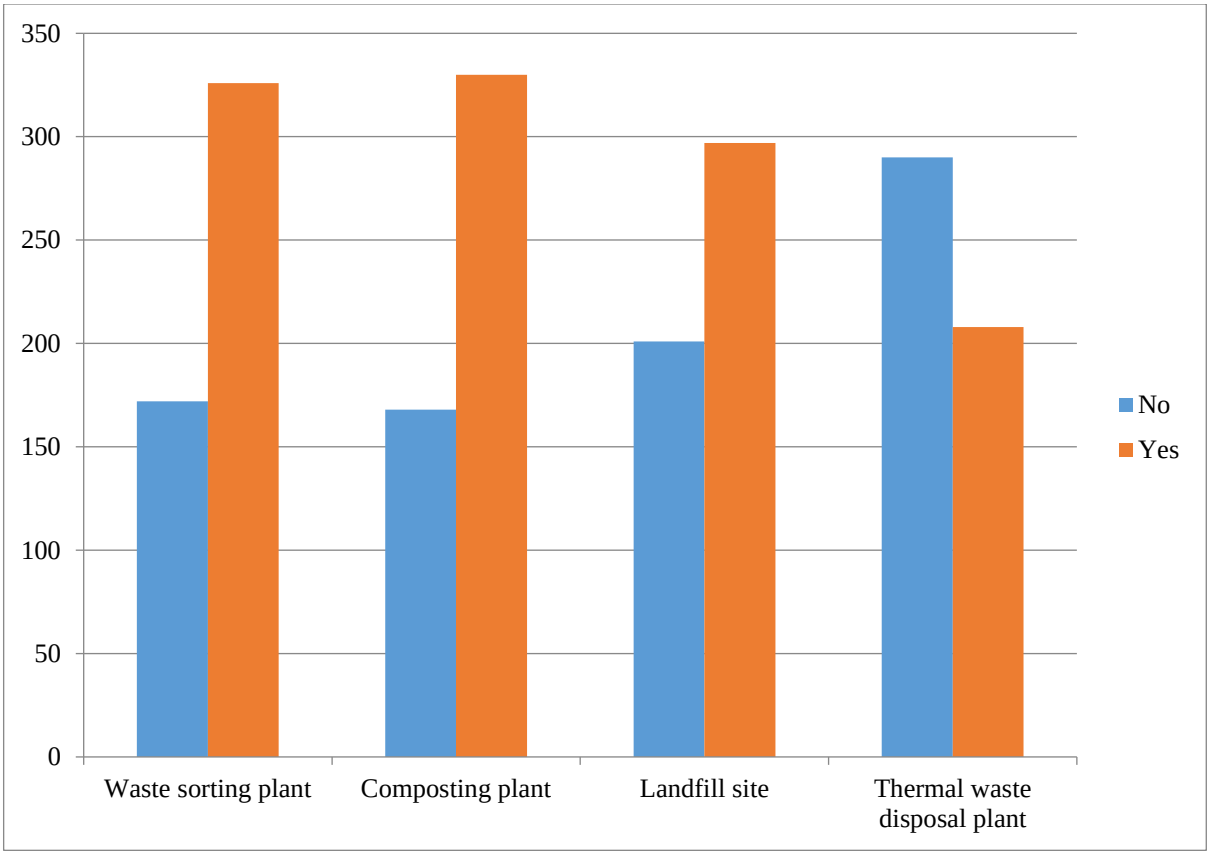

Figure 7. Individual responses to the question "Are you familiar with the principles of facilities?". Source: own study.

Residents of Nowy Sącz County are more and more aware of how to deal with waste. The most problematic for the society is waste segregation. Many factors such as inability to store many waste containers at home, or the problem of segregation of individual packages contribute to the growing awareness of waste management. This is because people who report such problems want to segregate waste in an appropriate way and are counting on finding the solution of their problems. Thanks to that, we can observe a significant increase of interest in the subject of waste segregation and its processing. This behavior is strongly influenced by numerous campaigns and projects carried out in Nowy Sącz County (Zalewska, 2019).

3.4. Stage III – Water conservation

Inhabitants of Nowy Sącz County are supplied with water by Sadeckie Wodociagi. Water must meet certain requirements regulated by legal acts to be accepted for public use. The quality of water is primarily determined by the amount and type of contaminants that occur in it. This makes water protection particularly important. This is not only caused by human activity, which creates pollution, but also by droughts, which are occurring more and more often (Supreme Chamber of Control, 2011).

Stage three of the analysis consisted of an analysis of aspects related to water conservation. It consisted of 10 questions from A to J. Nine questions were single choice. While one question was multiple choice.

The first question was about how to save water while doing daily activities and was multiple choice one. It read as follows: "How do you save water while performing your daily activities?". Responses were given by 498 respondents where 252 respondents said that they do not pour away water that can be used for something, 266 respondents take care of the plumbing so that it does not leak, 264 respondents do not let water run while washing, 334 respondents use shower instead of bathtub, 241 respondents use water saving programs. On the other hand, 5 respondents, in addition to the above answers, answered that they additionally collect rainwater, do not wash dishes under running water, and insert full laundry and dishwashing. Figure 8 presents showing the responses to the question on how to save water.

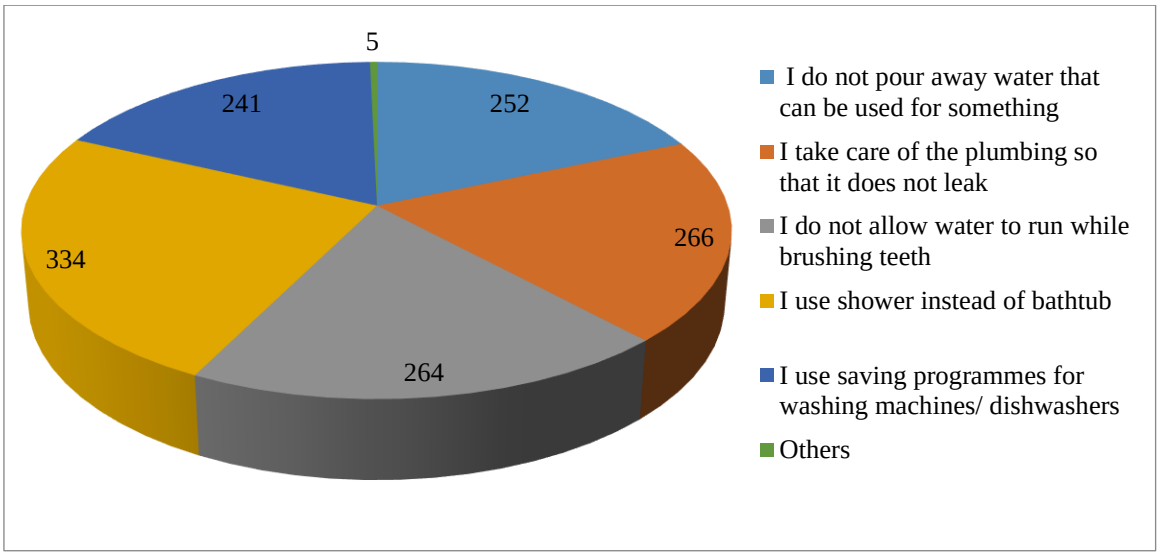

Figure 8. Individual responses to the question "How do you save water during your daily activities?". Source: own study.

The next question concerned having your own well or using a water supply network. The question was a one-choice question and was answered by all respondents. Respondents most often use the water supply network, at 81%. In contrast, 11% of respondents use their own dug well and 8% of respondents use their own drilled well. Regardless of the source of the water being drawn, people who use water supply network or their own well need to be aware of sustainable water intake. In modern times, in summer as well as in winter time, we have to deal with droughts. By consciously managing our water intake, we are able to save a larger amount of water, which year after year becomes a valuable component of nature (Chelmicki, 2001).

The third question presented to what extent the respondents describe the quality of tap water in their place of residence. The question was a one-choice question and was answered by all respondents. As many as 38% of the respondents described the quality of their tap water as good, 32% as average, 20% as very good, 7% as bad and 3% as very bad. A significant number of the residents of Nowy Sącz and surrounding areas use water supplied by Sadecki Wodociągi, which, according to company representatives, contains a total of about 70-110 [mg/l] mineral components, so it falls within the range for low-mineralized waters. On average, it has 6-9 [mg/l] sodium, 50-90 [mg/l] calcium and about 18 mg/l magnesium. The parameters presented confirm that the quality of the Nowy Sącz water is very good, although most of the respondents answered that the quality of the water is good. This may be due to the fact that some people have their own dug or drilled wells (swns.pl, 13.04.2022). Figure 9 presents showing the number of individual responses to the question on tap water quality.

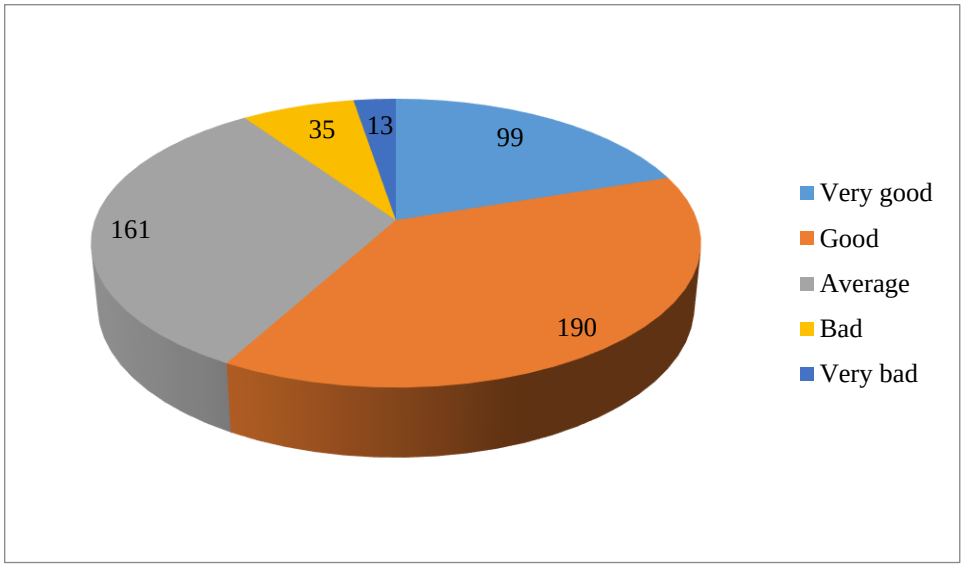

Figure 9. Individual responses to the question "How would you rate the quality of tap water where you live?".
Source: own study.

Another question asked in the survey was about inspecting sanitation facilities such as taps or toilet in terms of tightness. The question was a one-choice question and was answered by all respondents. To this question, 24% responded that they do not inspect sanitation tightness. On the other hand, 76% of the respondents answered that they check the sanitation facilities tightness:

- once every six months;
- once every three months;
- once a month;
- once or twice a year;
- until failure;
- all the time;
- every few months;
- weekly or daily.

The control of sanitary facilities is a key element for the proper functioning of a residential building. Technical literature indicates that the inspection intervals of sanitary facilities should be 1 year since the failure of a sanitary facility can lead to flooding of the apartment. Also, minor defects may result in much higher water consumption and thus a higher water bill. The sanitation defects that happen most often are for example: a leaky tap valve or a toilet valve that does not close (Guzik, 2014).

The fifth question was about the time of watering the plants. Most people, 53%, water their plants at any time of the day. Whereas 45% of the respondents water their plants in the early morning or evening and 2% at noon.

The next question was about how to wash the car. An automatic car wash is used by 46% of the surveyed people. On the other hand, 39% of respondents use a manual car wash and 15% of them wash their car manually on their own property. The fact is that the regulations prohibit washing cars on one's own property because water contaminated with operating fluids from the vehicle may get into the groundwater. This causes its pollution. This infraction results in a fine of 500 zloty, depending on the regulations of the municipality (The Act of 13 September 1996, 13.04.2022).

The seventh question concerned the method of washing dishes. The respondents indicated that they most often rinse washed dishes under running water. Less frequently they use the method of using two sink compartments, where they wash dishes in one compartment and rinse them in the other. The least frequently respondents wash and rinse dishes under running water. Washing dishes under running water is the least efficient way and results in the highest water consumption. Research has shown that washing dishes using running water requires 80 litre of water, with washing dishes using two compartments, reducing water consumption to 13 litre (businessinsider.com, accessed: 13.04.2022). Figure 11 presents a picture showing the number of individual responses to the question on how to wash dishes.

The next question was about owning a dishwasher. The question was one-choice question and was answered by all respondents. As many as 54% of the respondents declared that they owned a dishwasher. On the other hand, 46% of the respondents answered that they do not have a dishwasher. Using a dishwasher is much more cost effective and thus has a positive impact on reducing water consumption. An average dishwasher consumes 13 litre of water where manual washing consumes even 80 litre of water, i.e., it is 6 times more. Calculations show that a purchase of a dishwasher can pay for itself already after 4 years of continuous use (bogatyzwyboru.pl, accessed: 13.04.2022).

The ninth question was about municipal sewage disposal. The question was answered by all respondents. The question was a one-choice question. 76% of the respondents indicated that they use the sanitary sewage system. On the other hand, 13% have their own sewage treatment plant and 11% use a septic tank. Every household produces sewage, which needs to be disposed of. For this purpose, a sewage system is installed. It is a type of sanitary system responsible for the disposal of wastewater and drainage. Sanitary sewers carry wastewater to the main lines where it then goes to the municipal treatment plant located in Nowy Sącz, at 1 Wiklinowa St. This is the fastest and easiest way to dispose wastewater as it does not require direct intervention of the residents unlike the septic tanks which need to be emptied (Guzik, 2014). Figure 11 presents a picture showing the number of individual responses to the question regarding sewage disposal.

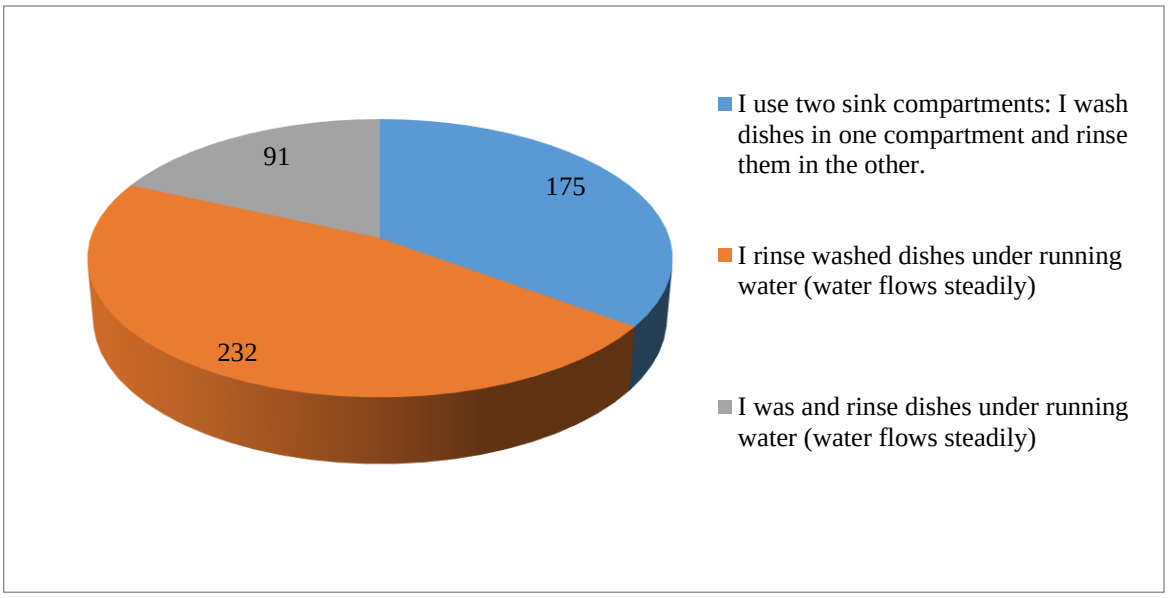

Figure 10. Individual responses to the question "How do you wash dishes in the sink?".
Source: own study.

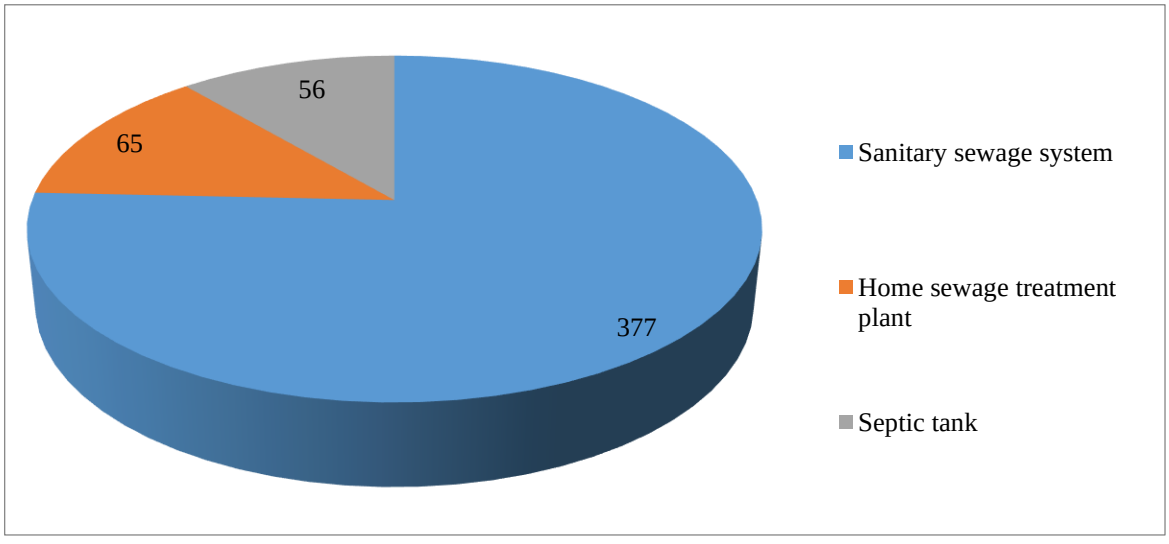

Figure 11. Individual responses to the question "Municipal wastewater from your property/ apartment is disposed to?".
Source: own study.

The last question was about rainwater harvesting. The respondents answered that 38% cannot harvest rainwater and 31% do not harvest rainwater. On the other hand, 31% of the respondents collect rainwater. Rainwater harvesting systems, based on the location of the storage tank, are divided into aboveground and underground systems. Above ground systems are most often used to collect water for domestic purposes such as watering flowers etc. However, the use of underground tanks makes it possible to collect rainwater for domestic purposes. On the other hand, the use of underground tanks allows for the collection of large amounts of water that is stored. These tanks can hold from 1100 litre to 65000 litre, depending on the type of tank. Water from the tank is then transported through PVC pipes to the building circulation. A properly calculated, selected and installed rainwater collection and utilization system can thus save a large amount of water (Królikowska, 2019).

Inhabitants of Nowy Sącz County are more and more aware of the fact that water in natural environment is limited, and its proper management is an essential element of existence of the society and economy. The reason is the overexploitation of water resources and pollution of underground or surface waters.

In most cases, wastewater, which is generated by the consumption of abstracted water by industry, households, or agriculture, can cause pollution. The most important element for Nowy Sącz County will be the development of the sewerage system, which will reduce illegal disposal of sanitary waste. It will also increase sanitary control in apartments and single-family houses, which were built on the rights of old architecture, when ecology was not so important in the life of society. In addition, over the years, residents of Nowy Sącz County have reduced washing of vehicles on the property, which has a positive impact on the quality of soils in the county, thus increasing the quality of groundwater (Guzik, 2014).

4. Conclusions

The questionnaire was prepared in order to determine the ecological awareness in Nowy Sącz County, which is located in the southern part of Małopolska. The survey consisted of 3 stages, which include air protection, waste management and water protection. In the survey there are 30 close-ended single choice questions, multiple choice and open questions.

Based on the results of the survey, it can be concluded that the residents of Nowy Sącz County have a high environmental awareness in the areas of water protection and waste management. Residents are not only aware of how to save and manage waste consciously, but they also practice pro-ecological activities. These activities include activities such as segregating garbage, saving water by using a dishwasher, using an automatic car wash etc.

Unfortunately, the biggest drawback of the residents of Nowy Sącz County is the lack of appropriate actions for air protection. The first stage of the survey shows that the inhabitants are aware of the dangers of polluted air, but they still do not take appropriate actions to reduce air pollution. As much as 77% of the respondents do not use any methods to reduce air pollution. In such a case, as many campaigns as possible should be carried out to promote technologies limiting the effects of smog by e.g., using chimney filters, using electric cars or vehicles with Euro 6 emission standard. The inhabitants should be aware that each of “us” has an influence on the atmosphere surrounding “us”, not only big companies, but each of the inhabitants of Nowy Sącz County.

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Subjective assessment of thermal comfort in an educational building

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Abstract: Nowadays, there is a growing tendency and interest in intelligent buildings. This is related to their main idea of energy self-sufficiency, ensuring the highest quality internal air parameters (air temperature, relative humidity, carbon dioxide, etc.), management of lighting, energy production and consumption. Therefore, it was decided to conduct research in such an educational building on a group of students. For this purpose, a device for measuring microclimate parameters was used for the measurements. Additionally, questionnaires were used which the students completed during the measurement. 15 students aged 20 to 22 participated in the study. The obtained parameters for the selected room were 21.8oC for the air temperature, 29.35% relative humidity and 1157 ppm carbon dioxide content. The main assumption of the work was to focus on students' thermal impressions related to the perception and assessment of the current air temperature and relative humidity in an intelligent building.

Key words: thermal comfort, assessment of thermal sensations, relative humidity, air temperature.

1. Introduction

Currently, there is a significant interest and trend in intelligent buildings. This is mainly due to the fact that intelligent buildings are self-sufficient in terms of energy, as well as providing building users with the best possible thermal conditions. In short, thermal comfort is the state of a person who does not pay attention to the ambient temperature at any given time. He is neither cold nor warm. This means that the thermal conditions in which he finds himself suit him. Ideal thermal conditions are difficult to achieve, taking into account the individual tolerance to heat and cold of each person. We have no influence on the formation of thermal comfort outside. We can only adapt to it. However, much more can be done with the thermal comfort conditions inside the buildings. It is difficult, but modern technologies and devices combined with knowledge make it possible to achieve optimal conditions. The most difficult to achieve thermal comfort in large buildings, where there are many people.

Thermal comfort is affected by many factors, including air temperature and velocity, relative humidity, carbon dioxide concentration, and clothing. Research on thermal comfort in smart buildings has been done by Krawczyk and Krakowiak (2021) and Dębska, Krakowiak and Kapjor (2020). In the study Krawczyk and Krakowiak (2021) two buildings were compared, an intelligent building (having BMS – Building Manager System) and a traditional building. The study showed that the respondents preferred significantly higher humidity. On the other hand, paper of Dębska et al. (2020) showed two methods to compare thermal comfort, indirect and direct. The results showed that 80% of the students did not like the prevailing microclimate conditions.

In Poland, research on thermal comfort is also done by Majewski, Telejko and Orman (2017). Kaushik, Arif, Tumula, Ebohon (2020) discussed factors affecting thermal comfort, including air temperature, carbon dioxide, relative humidity and volatile organic compounds. And Ma, Zhao, Wang, Yang (2022) dealt with the insulation performance of clothing and its effect on the comfort of users. The researchers showed that fabrics also affect the comfort of building occupants. Other authors, such as Vilcekova, Meciarova, Burdova, Katunska, Kosicanova, Doroudiani (2017) dealt with the study of thermal comfort in school buildings. This paper discussed the comparison of actual results with subjective results, which showed the differences between PMV and TSV (Thermal Sensations Vote). Munonye (2020) performed a study in an elementary school with 180 students. The results showed that the respondents preferred a lower temperature of 28.1°C during the rainy season. Buonocore, Vecchi, Scalco, Lamberts (2020) performed a study in Brazil in which students preferred air temperatures ranging from 23 to 24°C.

The currently available literature focuses mainly on traditional buildings, and not on intelligent buildings, which are still scarce. It is important to study the internal environment in such buildings so that in the future all parameters responsible for the feeling of thermal comfort will make people feel thermal satisfaction while staying in the rooms of an intelligent building. Therefore, the objective of this paper is to evaluate subjective thermal comfort using two methods, with 15 respondents aged between 20 and 22 years.

2. Research problem and research method

The study was conducted in the Energis educational building (Figure 1), which consisted of measuring air parameters with a Testo microclimate meter and conducting anonymous surveys. The questionnaires allowed the room users to evaluate the thermal comfort and their preferences. Fifteen students between the ages of 20 and 22 participated in the study.

The study was conducted at the beginning of March in 2022 in the afternoon hours, i.e. still during the heating season. The test room has underfloor heating and mechanical ventilation is responsible for air exchange. The area of the room was 63.91 m2. It should also be mentioned that on the day the test was carried out, the indoor temperature was 2°C and the sky was completely cloudy. The environmental measurement lasted more than 15 minutes (the time in which the parameters stabilized), and then the results were saved. The device was placed in the central part of the room during the measurement. The accuracy of the Testo meter is ±0.3°C for temperature, ±3% for humidity and ±50 ppm for carbon dioxide. First, the entire measuring station should be unfolded, all probes should be turned on and connected to the meter. After switching it on and pressing the "start" function, data are downloaded that the meter reads and saves from the probes. The meter does not require calibration. During the study, students completed anonymous surveys, as shown in Figure 2.

Figure 1. Educational Building of the Kielce University of Technology.
Source: own study.

Figure 2. Students at the time the study was performed.
Source: own study.

The survey contains 14 questions about the currently felt temperature, acceptability and its preferences, assessment and preferences of humidity. In addition, the survey includes such questions relating to productivity, light intensity, clothing and mood of respondents. In this way, the respondents' answers to the questions included in the survey made it possible to complete the study and analyse it in the next chapter.

3. Results

The parameters inside the room obtained with the use of the environmental meter were for air temperature 21.8ºC, relative humidity 29.35% and carbon dioxide equal to 1157 ppm. Therefore, taking into account the above parameters and the students' responses, the Thermal Sensation Vote (TSV) chart was obtained. Moreover, in order to get to know TSV, students describe their current feelings in the studied room, assessing the temperature as too hot, too warm, pleasantly warm, comfortable, pleasantly cool, too cool or too cold. Figure 3 below shows the obtained Thermal Sensation Vote results.

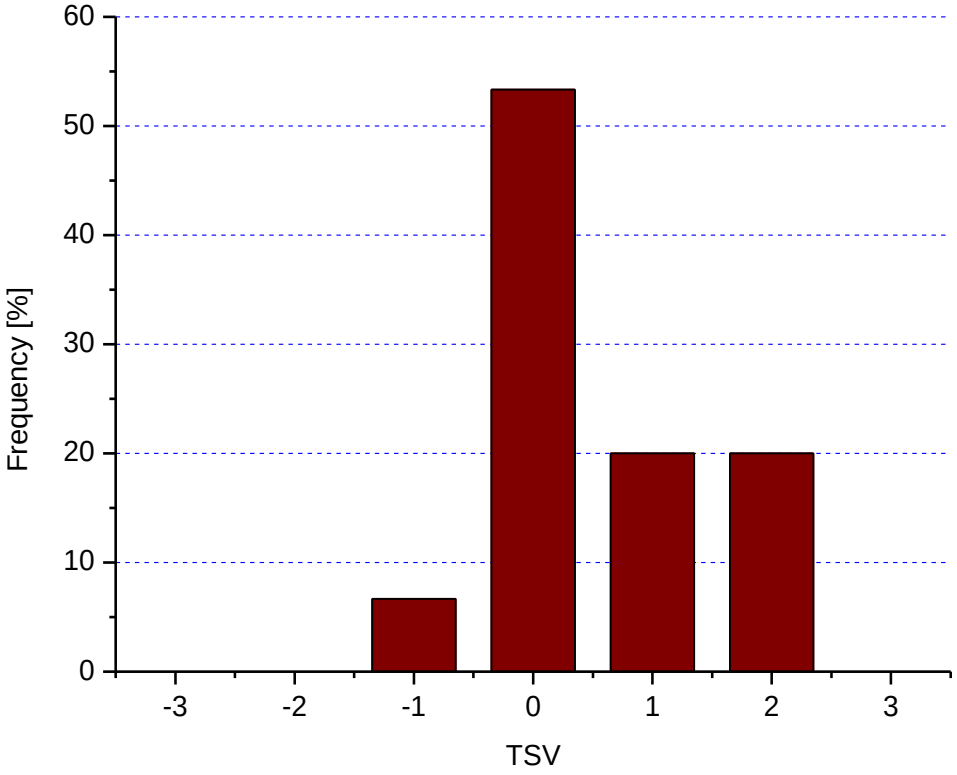

Figure 3. Air temperature sensations based on students' answers: -3 – too cold; -2 – too cool; -1 – pleasantly cool; 0 – comfortable; 1 – pleasantly warm; 2 – too warm; 3 – too hot.
Source: own study.

On the basis of Figure 3, it appears that as much as 80% of the group is in thermal comfort. These persons marked answers "-1", "0" and "1". On the other hand, 3 people described the prevailing air temperature in the examined room as already too warm. In this case, the temperature assessment could have been influenced by clothing, well-being and individual preferences. After analyzing the students' thermal impressions, the temperature was assessed (Temperature Assessment Vote – TAV), whether it was comfortable, acceptable, unpleasant or definitely unpleasant in the classroom. Figure 4 shows the respondents' assessment of temperature.

It can be noticed that for 86.67% of people the temperature was comfortable and acceptable, which is reflected in the data obtained in Figure 3. Only 13.33% of people indicated that the temperature was already unpleasant. The picture x3 shows the Thermal preferences vote (TPV). The respondents stated whether they would like to change the temperature to a cooler or warmer than the current one.

According to the data from Figure x3, 80% of people would not want any change to a higher or lower temperature. On the other hand, 20% of people would like a change to be cooler in the room. This is analogous to the responses of people from Figures 3 and 4, who indicated that the room is too warm and that the temperature is already unpleasant. No less important parameter that will be discussed later is the relative humidity in the assessment of students (Humidity Assessment Vote – AHV). In this question, the students assessed whether the air was too dry, adequate or too humid. The obtained results are presented in Figure 6.

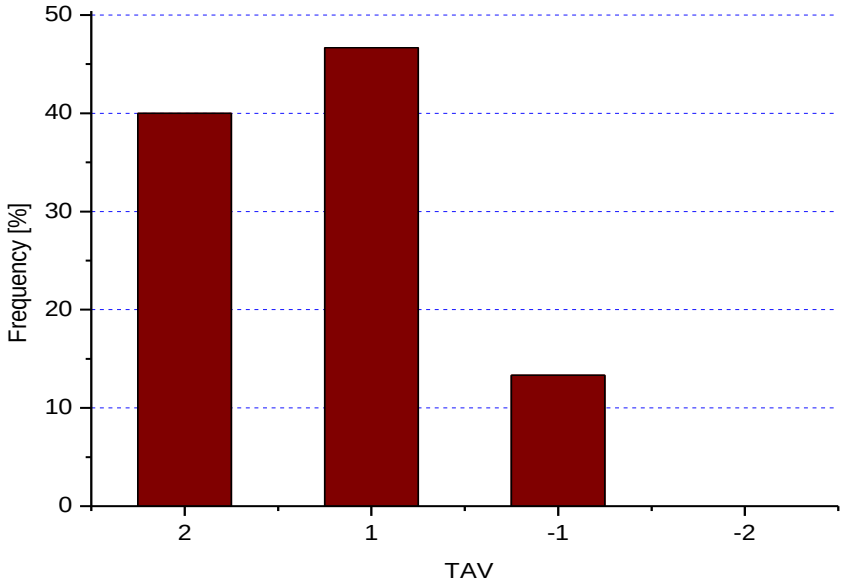

Figure 4. Assessment of temperature according to students in the room: -2 – definitely unpleasant, -1 – unpleasant, 1 – acceptable, 2 – comfortable.
Source: own study.

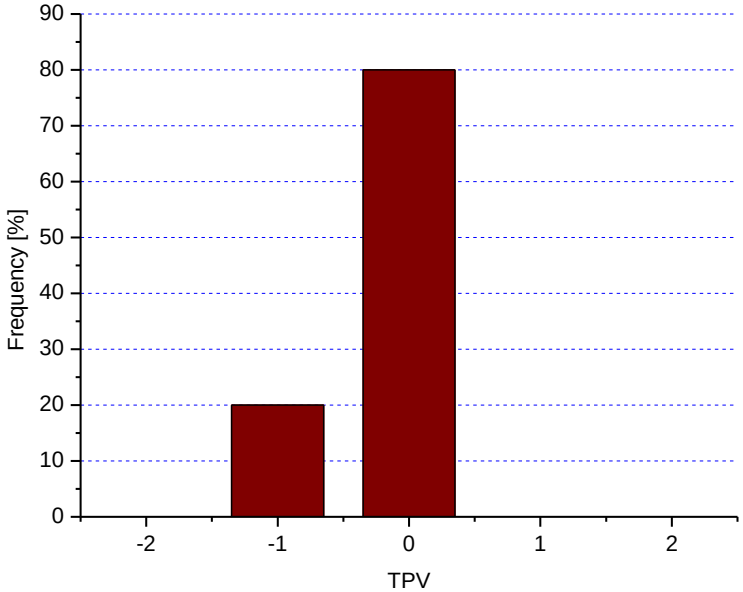

Figure 5. Thermal preferences (TPV) of people in the examined room: -2 – definitely cooler; -1 – cooler; 0 – no change; 1 – warmer; 2 – definitely warmer.
Source: own study.

About 67% of people rated the relative humidity pleasant. On the other hand, for about 7% of respondents, it turned out that it was quite humid, on the other hand, there were as many as 27% of people who thought that the room was quite dry. The next Figure 7 will provide information on whether students would like to change the moisture value to a higher or lower, or leave it unchanged (Humidity Preferences Vote – HPV).

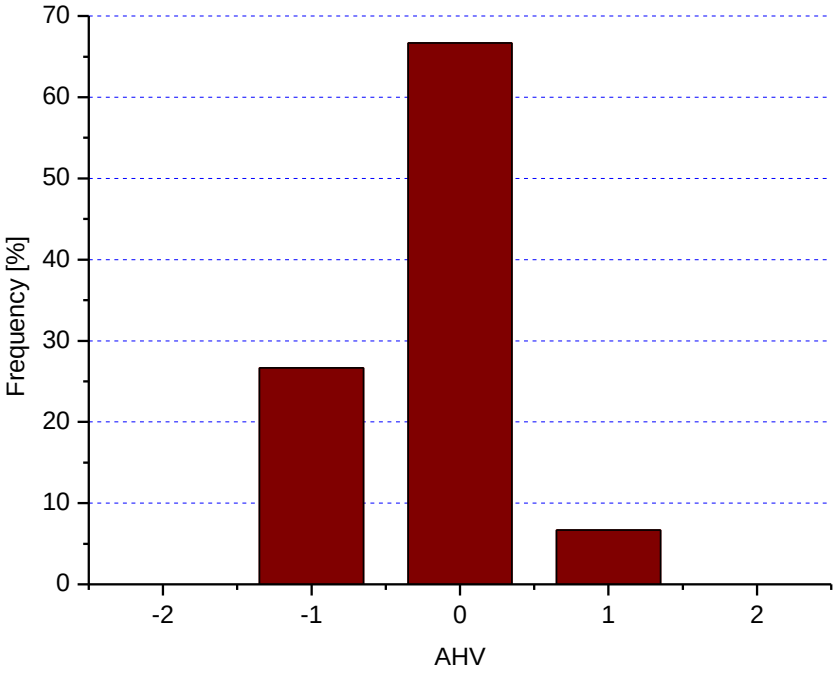

Figure 6. Assessment of relative humidity by the studied group of students: -2 too dry; -1 – quite dry; 0 – pleasantly; 1 – quite humid; 2 – too humid.
Source: own study.

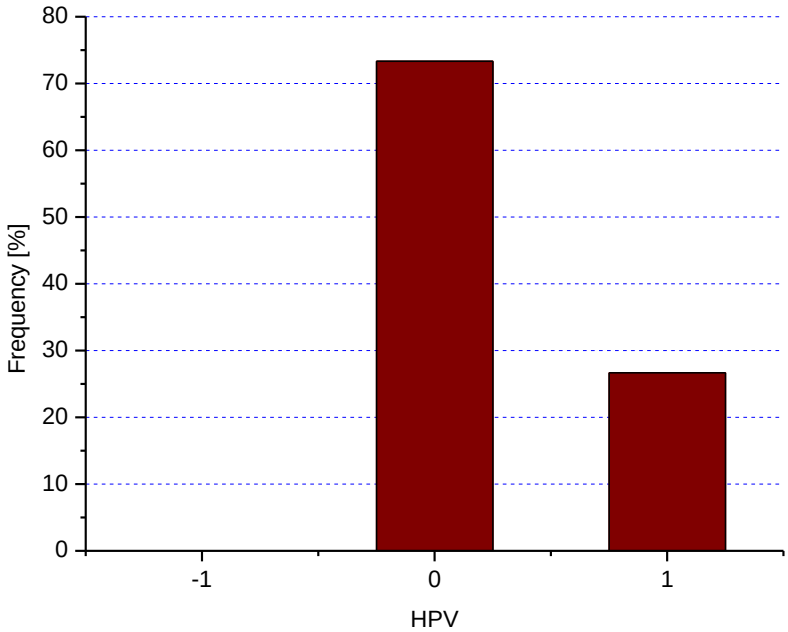

Figure 7. Humidity Preferences Vote based on data from survey sheets: -1 – more dry; 0 – no change; 1 – more humid.
Source: own study.

For about 73% of students, the humidity may remain unchanged. However, 27% of people would choose to change the current humidity to a more humid one. Similarly, these are the same 4 people who indicated in Figure 6 that according to their opinion, the room is quite dry.

4. Conclusions

The analysis showed that 80% of people consider their current feelings as comfortable. Only 13% of people were dissatisfied with the prevailing temperature, while about 27% of people would like more humid in the room. Summing up, the Energis building is conducive to the feeling of thermal comfort for learners and working people, which is undoubtedly a necessary condition to function well in closed spaces. It should also be noted that the examined fat woman would not like to change the temperature to a different one, only 20% were in favour of a cooler one. To sum up, the Energies building fosters a sense of thermal comfort for students and employees, which is undoubtedly a prerequisite for good functioning in confined spaces. In addition, the study confirmed the validity of designing and building intelligent buildings in the future, because they will be able to create such a microclimate that will be most felt by people.

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Changes in electrokinetic potential of yeast cells of the candida genus under the influence of submicron polystyrene particles

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Abstract: This study evaluated the effects of polystyrene submicron particles with an unfunctionalized surface on electrokinetic (zeta, ζ) potential of Candida albicans and Candida krusei cells. The electrophoretic light scaterring (ELS) method was used to determine the zeta potential. Our results showed that analyzed parameter altered as a function of size (100 and 200 nm) of polystyrene particles used as well as the pH of electrolyte solution. The changes in the cell surface characteristics may contribute to a better understanding of the behavior and functions of microbial cells under various factors as well as environmental conditions. The zeta potential (surface charge) is an important parameter in order to examine adaptation mechanism(s) in yeasts to an acidic environment, being crucial to measure the charge at the cell surface.

Key words: zeta potential, polystyrene, *Candida albicans*, *Candida krusei*.

1. Introduction

Civilizational development is associated with the use of plastic; from 1950 to 2018, about 6.3 billion tonnes of plastics have been produced worldwide. Plastics are made up of synthetic organic polymers and are widely used in different applications like water bottles, construction materials, etc. (Alabi et al., 2019). Large plastic fragments can be gradually degraded into microplastics (defined as plastic fragments smaller than 5 mm) in marine environment through physical, chemical and biological processes (Yi et al., 2021). The fragmentation of microplastics into smaller particles and the increasing production of nanoplastics suggest a plausible yet unclear hazard in the natural environment. Plastic particles in microscale or nanoscale are used in drug delivery, personal care products, and bioimaging (Lai, Liu, Qu, 2022).

One of the most commonly used plastics is polystyrene (PS) – a product of polymerization of styrene monomers (Figure 1). It is used for the production of styrofoam and other products like toys and cup covers. Once in the environment, polystyrene can undergo weathering through UV radiation, mechanical abrasion, biological degradation, and disintegration that result in the occurrence of microplastics which could eventually reduce to nanoplastics (Awet et al., 2018).

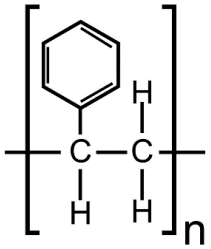

Figure 1. Stucture of polystyrene.
Source: own study.

Polystyrene particles can undergo transformation in i.e. their size or charge, thereby affecting their mobility and bioavailability. Because of its small size, large specific surface area and strong hydrophobicity, PS can be easily absorbed onto heavy metals, organic pollutants and microorganisms (Zhang et al., 2020). The small size and high surface area of polystyrene particles make it possible to pass through the biological barriers and potentially enhance their bioactivity (Awet et al., 2018). The results of both in vivo and in vitro studies have suggested that PS particles might penetrate organisms through several routes such as skin, respiratory and digestive systems. While the negative impacts of polystyrene are widely reported, particularly on marine vertebrates, impacts on microbial life remain poorly understood. Since polystyrene can be easily synthesized in a wide range of sizes, it is perfectly suited as a model to study the effects of the particle surface characteristics on physicochemical parameters of microorganisms (Kik, Bukowska, Sicińska, 2020).

The Candida genus comprises opportunistic fungi which can become pathogenic when the immune system of the host fails. Candida species are a major cause of morbidity and mortality worldwide and thus represents a serious threat to public health (Santos et al., 2018). *Candida albicans* (Figure 2) is the most frequent etiological agent of candidiasis. However, other *Candida species* like *Candida krusei*, despite not being isolated as commonly as the others, caused the infections of special relevance in the clinical setting due to its intrinsic resistance to fluconazole (Gómez-Gaviria, Mora-Montes, 2020). The pathogenesis of Candida species is barely understood, and the rate of infections is increasing rapidly. Furthermore, a steady increment in resistance to traditional antifungal medicaments has resulted in the necessity to control Candida infections through early diagnosis and prevention of candidiasis (Santos et al., 2018).

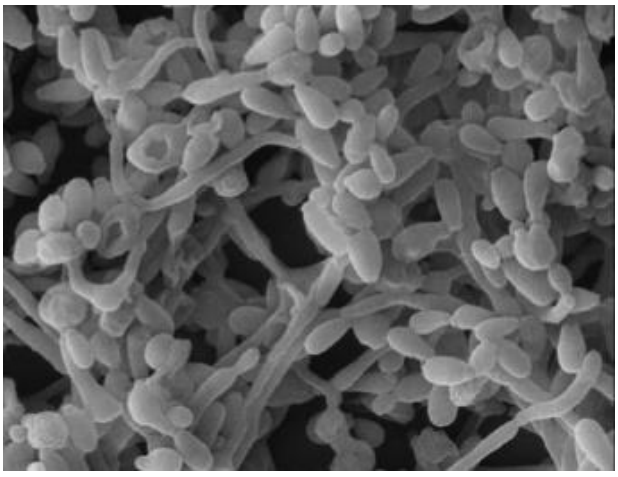

Figure 2. Scanning electron microscopy of a Candida albicans biofilm.
Source: "Candida species: current epidemiology, pathogenicity, biofilm formation, natural antifungal products and new therapeutic options" J.C.O. Sardi, L. Scorzoni, T. Bernardi, A.M. Fusco-Almeida, M.J.S. Mendes Giannini (2013), *Journal of Medical Microbiology, 62*(1), pp. 10-24.

The adherence properties of Candida are of special interest and its ability of Candida to attach to plastics may be exploited in studying its interaction with surfaces. Since Candida is a constituent of the normal flora, its relation to the host is at times benign and at times pathogenic; this situation may be the result of the ability of the organism to regulate virulence properties under varying environmental conditions (Cooling et al., 2005).

Yeasts' surfaces are characterized by their electric charge, which allows the measurement of electrokinetic potential through electrophoretic mobility of the cells. ζ-potential is noted as the electrical potential at the edge of electric double layer versus the bulk electric potential (Figure 3). In colloidal systems, electrokinetic potential is widely used as an indicator to reflect the stability. Large ζ-potential values are associated with strong electrostatic repulsions between colloidal particles, which simultaneously prevent particles from aggregation. Most viable cells have fixed negative charges on the cell membrane surface, primarily due to cell wall components such as phosphates, proteins, and carboxylate groups (Chang et al., 2002). Nevertheless, regardless of taxonomic classification, all microbial cells contain carboxyl, phosphoric, and amino groups in their outer membranes. These groups can easily be ionized as a function of environmental pH and contribute to the net charge of the cell surface. At physiological pH, most microbial cells possess a net negative surface charge, due to the cell membrane phospholipid bilayer (Harkes et al., 1992). Microbes are also negatively charged due to the presence of polysaccharides. The degree of this charge can be determined based on electrostatic mobility of cells in an electric field (Jafari, 2020).

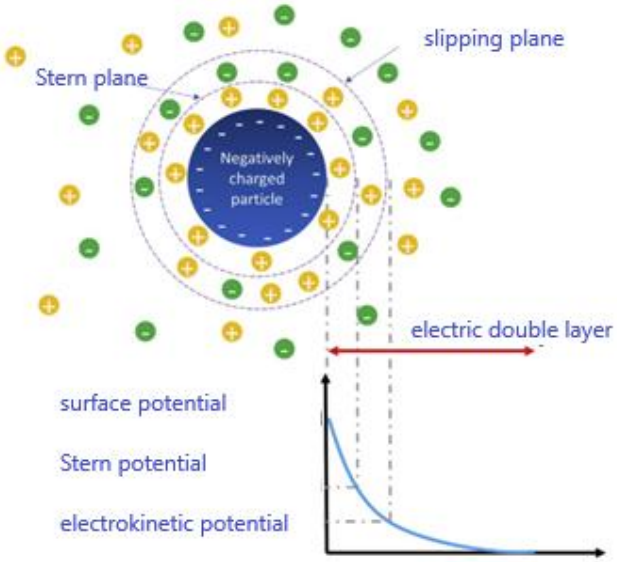

Figure 3. Diagram of electrical double layer.
Source: *Characterization of nanoencapsulated food ingredients*, S.M. Jafari, 2020, Academic Press: Elsevier.

2. Research problem and research method

The electrophoretic behavior of polystyrene submicron particles with an unfunctionalized surface with a diameter of 100 and 200 nm (PS-100 and PS-200) towards the yeasts: Candida albicans and Candida krusei was examined. Submicron size range is defined as 100-1000 nm (Zhang et al., 2018).

PS particles were provided by Polysciences, Inc. and were used unaltered. The microorganisms were grown on specially designed dishes at 30°C in Mueller Hinton broth. The microorganisms were then vortexed together with the sterilized sodium chloride at 200 rpm. In order to make sure that the obtained suspension contained the right amount of microorganisms, its optical density (which had to be in the range of 0.10-0.13) was determined, by means of spectrophotometric measurements. The next step was to prepare a solution containing Candida albicans or Candida krusei and polystyrene.

The physicochemical characterization was performed through the analysis of electrokinetic potential using the Zetasizer Nano ZS equipment (Malvern Instruments Ltd., Worcestershire, United Kingdom). The samples were transferred into disposable cuvettes (DTS 1070). Electrophoretic light scattering was used to define changes in electrokinetic potential of the yeast cells in a function of pH (pH changing every unit in the range of 3-11). The zeta potential reported herein was obtained as the average of three independent measurements performed on each sample. All measurements were carried out at a temperature of 25°C. The value of the zeta potential was calculated using the Henry correction of Smoluchowski's equation:

$$\zeta = \frac{3\mu\eta}{2\varepsilon\varepsilon_0 f(\kappa a)}$$

where μ stands for is the electrophoretic mobility, η is the viscosity of the aqueous solution, a is the particle radius, κ^{-1} is the Debye length, ε0 and ε are the permittivity of free space and the relative permittivity of the medium, respectively.

3. Results and discussion

The effect of two-sized polystyrene submicron particles (100 and 200 nm) on zeta potential of *Candida albicans* and *Candida krusei cells* was evaluated. is an indicator of the cell wall components' electric changes and was estimated by measuring the electrophoretic mobility. The velocity of particles or cells moving in an electric field can be directly measured by determining the frequency change of the scattered laser light and is dependent on various factors such as temperature, ionic strength, pH of the medium, electric field strength, and the net surface charge of the particle (Wilson et al., 2001). Direction of the movement is affected by the charge of the particle. Since zeta potential is influenced by environmental factors such as pH, temperature or ionic strength, we performed the experiment in a function of pH, in a constant temperature and a constant ionic strength. It should be emphasized that the environmental pH can permanently alter cell wall composition and microbial virulence (Montville, 1997).

Figure 4 and 5 show the electrokinetic potential values of *Candida albicans* (Figure 4) and *Candida krusei* (Figure 5) cells untreated and treated with 100 nm and 200 nm polystyrene particles plotted against the pH of electrolyte solution. The data were collected in the Table 1 and Table 2 respectively.

As can be observed, all *Candida albicans* and *Candida krusei cells* (both untreated and treated with PS particles) are characterized by the negative zeta potential values in pH > 6), for example from -26,48 ± 1,25 mV for control Candida krusei cells to -40,23 ± 1,04 mV for the cells after exposure to PS-200 at pH = 10 (Table 2). With increasing diameter of PS particles, zeta potential values dropped down; 200 nm PS particles caused the increase of the negative values of the electrokinetic potential compared to 100 nm ones in such pH range. Similar trends were observed for both *Candida albicans* and *Candida krusei* cells. In acidic solution (pH < 6), the zeta potential values were less negative for all *Candida cells* compared to values obtained in pH > 6. Depending on the analyzed system, in pH range between 3 and 6, the isoelectric point was observed.

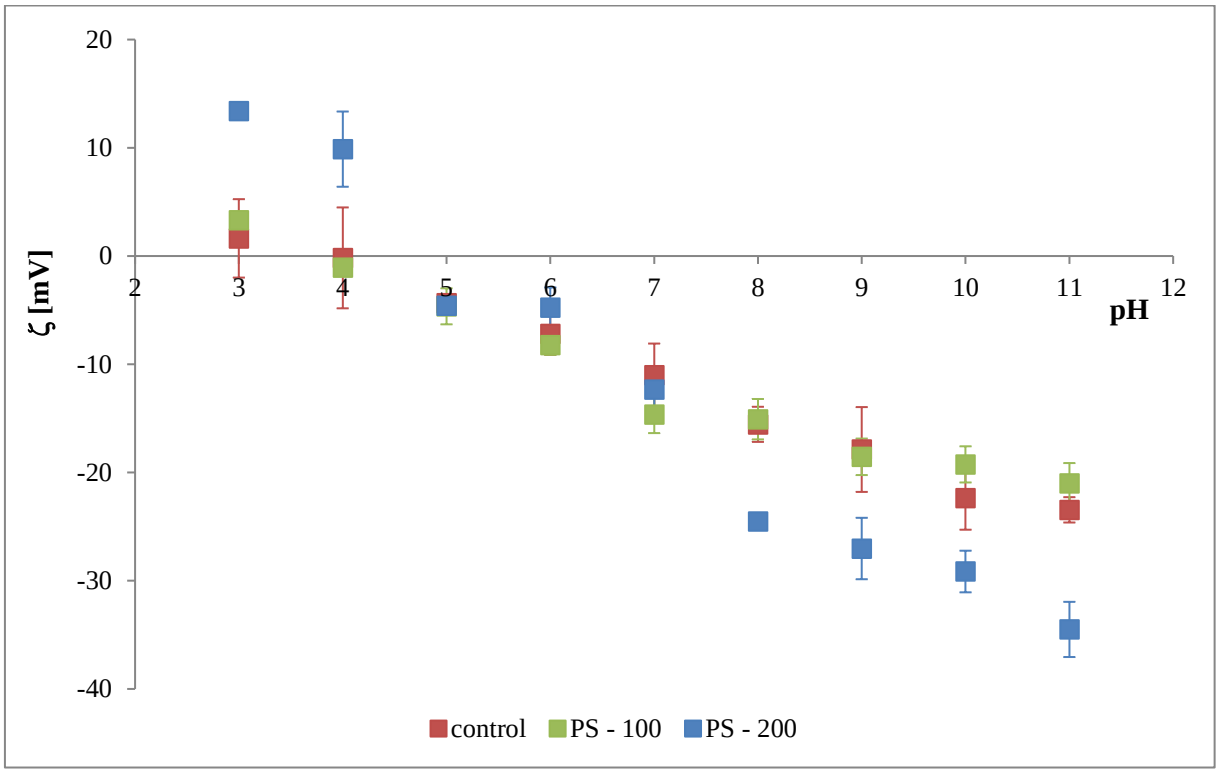

Figure 4. The zeta potential of *Candida albicans* cell membrane as a function of the pH of the electrolyte solution. Membranes untreated (■) or treated with 100 nm (■) and 200 nm (■) of polystyrene polymer.
Source: own study.

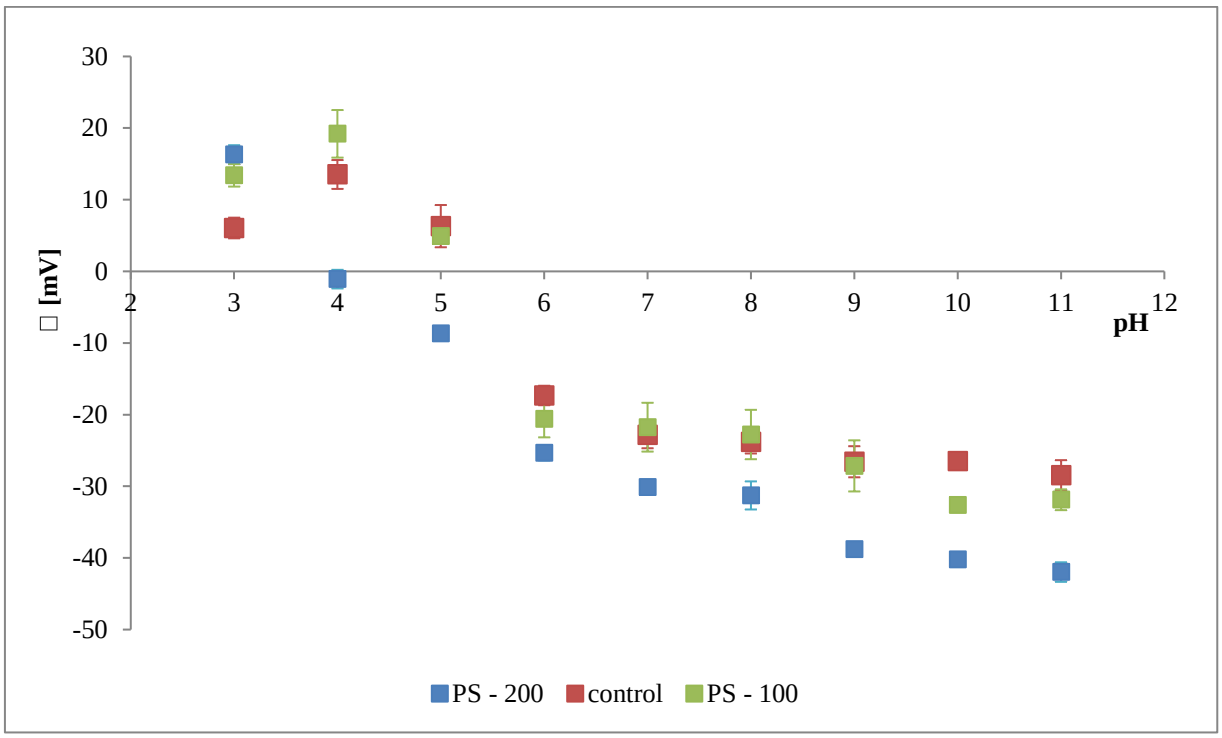

Figure 5. The zeta potential of *Candida krusei* cell membrane as a function of the pH of the electrolyte solution. Membranes untreated (■) or treated with 100 nm (■) and 200 nm (■) of polystyrene polymer.
Source: own study.

Table 1
The zeta potential of the Candida albicans after exposure to PS-100 and PS-200

pH	Zeta potential [mV]		
	control	PS-100	PS-200
3	1.63 ± 3.62	3.30 ± 0.58	13.40 ± 0.71
4	-0.17 ± 4.66	-1.06 ± 0.42	9.88 ± 3.47
5	-4.32 ± 0.70	-4.65 ± 1.63	-4.60 ± 0.76
6	-7.19 ± 1.94	-8.22 ± 0.91	-4.78 ± 1.87
7	-11.02 ± 2.93	-14.65 ± 1.71	-12.35 ± 1.77
8	-15.55 ± 1.62	-15.08 ± 1.87	-24.53 ± 0.50
9	-17.88 ± 3.92	-18.55 ± 1.69	-27.03 ± 2.84
10	-22.35 ± 2.94	-19.25 ± 1.67	-29.15 ± 1.92
11	-23.45 ± 1.17	-21.28 ± 1.87	-34.50 ± 2.55

Source: own study.

Table 2
The zeta potential of the Candida krusei after exposure to PS-100 and PS-200

pH	Zeta potential [mV]		
	control	PS-100	PS-200
3	6.06 ± 1.44	13.40 ± 1.56	16.30 ± 1.31
4	13.53 ± 2.02	19.20 ± 3.32	-1.09 ± 1.30
5	6.32 ± 2.95	4.91 ± 0.63	-8.68 ± 0.45
6	-17.33 ± 1.36	-20.60 ± 2.57	-25.33 ± 1.06
7	-22.85 ± 1.84	-21.75 ± 3.40	-30.10 ± 0.91
8	-23.83 ± 1.59	-22.78 ± 3.45	-31.28 ± 1.96
9	-26.58 ± 2.17	-27.15 ± 3.57	-38.78 ± 0.71
10	-26.48 ± 1.25	-32.60 ± 1.02	-40.23 ± 1.04
11	-28.48 ± 2.12	-31.88 ± 3.47	-41.98 ± 1.36

Source: own study.

A large positive or negative value of the electrokinetic potential (higher than +30 mV and lower than -30 mV) indicates physical stability due to the electrostatic repulsion of individual particles. On the other hand, a small value of the electrokinetic potential may cause aggregation or flocculation of particles due to the van der Waals forces (Joseph, Singhvi, 2019). Based on the data collected in Table 1 and Table 2, generally it can be concluded that all analyzed systems are characterized by moderate stability. In the case of Candida albicans cells only at pH 11 while treating by PS-200, the zeta potential value is lower than -30 mV. In case of Candida krusei cells, PS-100 has a stabilizing effect at pH = 10-11 while PS-200 – even for pH > 7.

Reassuming, the presented data show that both PS-100 and PS-200 influence the values of electrokinetic potential of Candida krusei and Candida albicans cells. More significant changes were noted while treating the yeasts' membranes using PS-200. Since the zeta potential is changing under the influence of polystyrene submicron particles, it can be predicted that the particles adsorb on both candida cell surfaces.

4. Conclusions

This study investigated the impact of different sizes (100 and 200 nm) of polystyrene submicron particles with an unfunctionalized surface on the electrokinetic potential of Candida albicans and Candida krusei cells. Both PS-100 and PS-200 caused changes of the investigated physicochemical parameter at the whole pH range. Based on the obtained data, it might be presumed that analyzed submicron polystyrene particles are attached to the yeasts' membranes of the Candida genus.

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Water level dynamics in lakes within the range of the cone of depression an opencast mine: Physicochemical effects of extreme precipitation

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Abstract: Climate change leads to an increase of the frequency of extreme rainfall causing among others intensification of the runoff from catchment area into lakes. This paper presents changes in water quality and trophic state of four large mining lakes (near Konin, western Poland) following changes in water level after an extreme rain event. The amount of water retained in studied lakes decreased between 1965-2008 as a consequence of low annual precipitation and water drainage into the depression cone of open-cast mine. Starting from 2010 higher inflows were accompanied by an increase in the lakes volume and effects on water transparency, oxygenation and trophic state during summer stagnation. The renovation of surface outflow resulted in the reduction of nutrient concentrations (over 40% of TN, about 30% of TP, respectively to the period of lake isolation) was noted in one lake. Evidently, extreme short-term changes in the lake water level can result in deterioration of water quality, especially in lakes without outflow.

Key words: lake water balance, extreme rainfall, opencast mine, water quality.

1. Introduction

The recent changes to the global climate bring about a higher frequency of extreme weather events such as heat waves, droughts and torrential rainfalls. Climate models evidence that an increase in heavy precipitation is probable in Europe in the 21st century (Cioffi et al., 2015; Rajczak, Pall, Schár, 2013). One of the most pronounced effects of climate change is an increased variability of rainfall patterns resulting in prolonged drought interrupted by torrential rainfalls and flooding, which was observed in Central Europe in the last decade (Bissolli et al., 2011; Mosley, 2015).

Floods, as well as droughts, are caused by accelerated water runoff, which foreclose replenishment of soil moisture (Trenberth et al., 2014). Meanwhile, the lack of water is a common problem in Central and Western Europe. Changes in the surface water table and a strong tendency to its decrease have been noted in Poland already in the 1930s (Choiński et al., 2011; Sobczyński, Joniak, 2013; Wrzesiński, Ptak, 2016). The decreasing water table has been observed over entire lake districts as well as in small water bodies in forested and agricultural areas (Joniak, Kuczyńska-Kippen, 2010; Przybyłek, 2011). This problem has become troublesome mainly in economic aspects since led to drying up of many lakes or caused changes in the water balance. Those changes have been caused by a shift from throughflow to without-outflow, which increase the eutrophication process and undesirable changes of water quality (Joniak et al., 2013; Klimaszyk et al., 2015; Messyasz et al., 2015).

The influence of catchment area on lakes is realized mainly through the dispersed surface runoff and through the supply of matter via a network of natural and artificial watercourses. On the one hand, the main hydrological reasons of water level changes are

seasonal fluctuations of meteorological conditions and changes in centers of atmospheric pressure (the North and South Atlantic Oscillations) on the other (Hofmann, Lorke, Peeters, 2008).

Moreover, an excessive human activity such as exploitation of water and fossil fuel resources (Hangen-Brodersen, Strempel, Grűnewald 2005; Molina et al., 2009; Policht--Latawiec, Kapica, 2013), drainage and urbanization of the catchment area (Blann et al., 2009) lead to regional disturbances in the catchment surface flow, changes in the ground water levels as well as modifications in drought–flooding hydrological patterns (Trenberth et al., 2014; Mosley, 2015). Regional disturbances in precipitation can lead to modifications in drought–flooding hydrological patterns (Trenberth et al., 2014; Mosley, 2015). The reason for local changes in hydrological systems is an excessive human activity, in particular exploitation of water resources and fossil fuel resources (Hangen-Brodersen et al., 2005; Molina et al., 2009; Policht-Latawiec, Kapica, 2013) as well as drainage and urbanization of the catchment area (Blann et al., 2009).

The Gnieźnieńskie Lakeland is situated in the western part of Poland. This region is characterized by former open-cast mines, which have adverse impact on the local water balance. The depression pit created by the open-cast brown coal mine functioning is the most influential factor (Figure 1). The effects of changes in the local hydrological and hydrogeological conditions and the effects of atmospheric systems are clearly visible on this area. The outflow takes even up to 20% of the total annual precipitation, during the vegetation season, the evaporation from arable lands is by 10% higher than the total annual precipitation, while the evaporation from forested areas by 40% (Stachowski, Oliskiewicz--Krzywicka, Kozaczyk, 2013).

Until recently the direction and character of the water quality changes in these lakes were assumed to be determined mainly by the excessive escape of water into the depression cone (Orłowski, Ilnicki, 2007). The intense water loss exposes large fragments of lake shorelines, creating shallows and mid-lake islands. This is a dangerous process in lake biogeochemistry, trophic state and biota functioning (Florsheim, Mount, Chin, 2008; Klimaszyk et al., 2015). The expert reports on the drying of lakes emphasize that this tendency is permanent with no chance for natural changes (Przybyłek, Nowak, 2011).

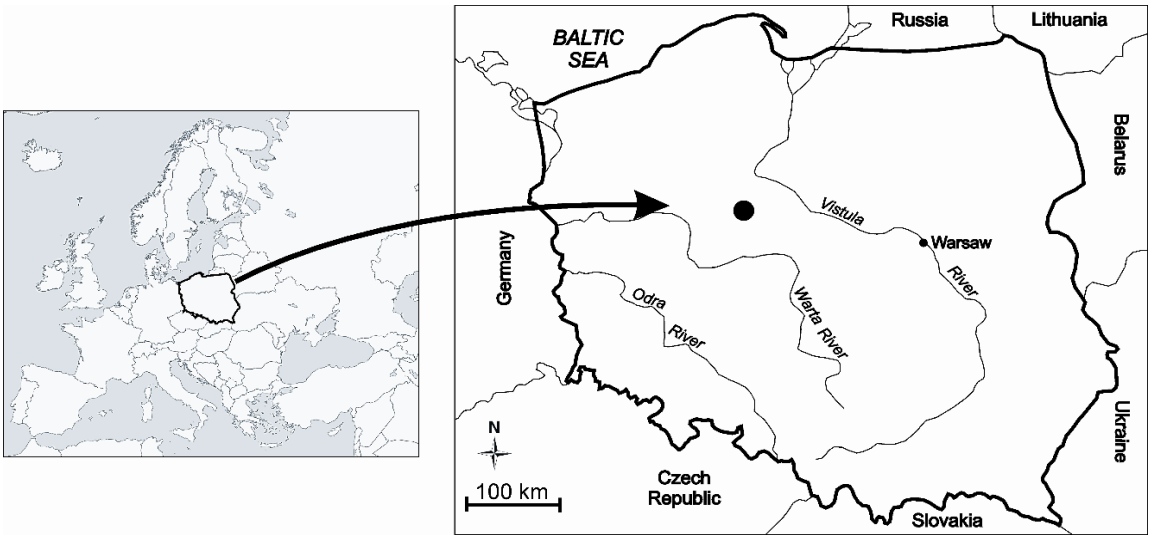

Figure 1. Location of study area.
Source: own study.

However, in the autumn and winter 2010/2011 that trend was unexpectedly reversed. During a few months (Nov.-Feb.) water level in the lakes increased so much that the dried up hydrological connections started functioning again and the islands, shallows and exposed banks were flooded.

Investigation of the effects of changes in the water regime on the water quality permits a distinction between the internal processes of lake functioning (e.g. natural increase of its trophic state, a seasonal succession of phytoplankton) and the external influence of the catchment area. Distinction and determination of these effects are crucial in lake management and allow scheduling of active protection measures. Based on the hitherto knowledge two hypotheses were put forward: (1) a direct result of the changes in the lake water level will be deterioration of water quality and trophic status of the lake, (2) the above-mentioned relation will be directly proportional to the size of the catchment area. This study aims to assess of the influence of short-term water level changes on the physical--chemical parameters and trophic state of the lakes.

2. Methods

The area of study comprises lakes located in the Gnieźnieńskie Lakeland: Budzisławskie (BL), Wilczyńskie (WL), Suszewskie (SL) and Wójcińsko-Kownackie (KL). These are relatively deep (max. depth above 20 m) dimictic lakes located in the natural postglacial valley within the Warta – Noteć Rivers watershed. All studied lakes belong to the valuable habitats of "Nature 2000" and are comprised within the special protection zone. These lakes are characterized by Charophytes meadows and are protected mainly because of their high floristic value and high water quality (Gąbka et al., 2011). BL is endorheic but it has underground connections with the other lakes of the valley (Ilnicki, 2008). All lakes are situated in the area of the depression cone influence however, WL is the closest to the depression pit. The thermal and circulation conditions of studied lakes are susceptible to the effects of climate and meteorological variability as indicated by the exposition index (ratio of the lake area to mean depth) (Table 1).

The main differences among the investigated lakes are in the area of the catchment. The potential for the catchment area effects on lakes was assessed using the Schindler's index (ratio of catchment area to lake volume) (Kolada et al., 2005). For BL the catchment is relatively small in relation to its lake area thus, the index is much smaller than for other lakes. The main source of biogenic substances is the arable land making up to 70% of the catchment areas. The lakes also received nutrients in the outflow from the wastewater treatment facility. The total annual phosphorus and nitrogen pool loading from the wastewater treatment plants is less than 5%, except for WL (22% P, 14% N, respectively (Joniak, unpublished data).

The mean annual precipitation (2002-2012) in the Wielkopolska region is relatively low, and it does not exceed 508 mm (527 mm in 1960-2002). Hydrological droughts are cyclic and take place at different intervals. The last hydrological drought before 2010 started in 2003 and lasted till 2006 (annual precipitation <500 mm). In this period the groundwater water table reached the maximum in early spring, while the minimum in December. In an extremely dry 2006 (annual precipitation 436 mm, compared to 500 mm in 2005) no such amplitude was noted, which indicated intensification of the hydrological drought. Replenishment of the underground water resources started in 2007, and in 2010 the underground water level reached the state from before the drought (723 mm of annual

precipitation in 2010). In 2010 (mainly in May and June), heavy floods took place in Poland due to intense precipitation. In the upper drainage areas of the Vistula and Odra rivers water level exceeded the alarm level (Pułyk, 2011).

Table 1
Morphometrically and catchment characteristics of lakes

Lake Parameter	Budzisławskie	Wilczyńskie	Suszewskie	Wójcińsko-Kownackie
Coordinates N E	 52°28"01' 18°03"45'	 52°29"19' 18°07"31'	 52°28"35' 18°04"55’	 52°29"52' 18°07"24'
Altitude [m a.s.l.]	99.5	99.0	99.0	98.9
Area [ha]	153.5	199.3	86.1	105.0
Max depth [m]	35.2	23.2	21.8	21.0
Mean depth [m]	10.8	7.3	6.5	6.4
Volume [mln m^3]	15.241	12.615	5.326	5.732
Exposition index	14.2	27.3	13.2	16.4
Catchment [km^2]	20.7	31.8	68.2	122.5
Schindler’s index	1.4	2.5	12.8	21.4

Source: own study.

The sampling and field measurements were carried out in August 2010 and 2011, respectively. In each investigated lake the temperature, dissolved oxygen and conductivity were measured at the deepest site of pelagial, at every 1 m along the whole water column, with the multiparametric probe (YSI 556, MPS). Water samples were collected with a submersible electric pump (Eijkelkamp) at a selected depth from the water column. Water turbidity (NTU) was measured by nefelometer (TN-100, Eutech). In the laboratory were analysed spectrophotometrically (Cadas 200 UV-VIS): chlorophyll a (ethanol method, ISO 10260), total phosphorus (TP – with molybdic acid after persulphate digestion, soluble reactive phosphates (SRP – with molybdic acid after filtration through membrane filters 0.45 μm), nitrate nitrogen (NNO3 – with sulphanilic acid), nitrite nitrogen (NNO2 – with 1-Naftylamine), ammonium (NNH4 – with Nessler method) and inherent water colour (after filtration through GF/F filters at 440 nm (Standard methods, 1998). The Kjeldahl method was used to analyse organic nitrogen (Norg) and concentration calculated as the difference between Nk and ammonium. Mineral nitrogen (IN) was the sum of nitrate, nitrite and ammonium nitrogen, and the total nitrogen (TN) was the sum of Norg and IN. The euphotic zone depth (Zeu) was measured using spherical quantum sensor LI-193SA with LI-1400 Datalogger (LI-COR Corporation, Lincoln, Nebraska, USA).

The trophic state of the lakes was evaluated based on the Carlson classification, using the Zeu depth (TSILt) instead of the Secchi depth (Carlson, 1977). The data on water levels of the lakes were obtained from a monitoring station (automatic stage-recorders) installed at the open-cast brown coal mine.

3. Results and discussion

In 2010 precipitation in Wielkopolska reached 130-150% of the mean monthly annual value. Extremely wet months were December, August and May, when precipitation exceeded 200% of the mean values (in the eastern part of the region precipitation reached 300-350% of the mean value) (Pułyk, 2011). Alarm levels were exceeded in all rivers of western Poland. Since the beginning of 2010 a tendency to increase water level has been observed in all lakes. Rapid changes were noted in late autumn with the culmination in winter and early spring 2011 (Figure 2). As early as in December 2010 renewal of water flow from the endorheic SL into KL was observed. Despite the large increase in its water level WL remained endorheic, similarly to BL, where the relatively lowest (+0.92 m) increase of water level was recorded. According to Bissolli et al. (2011), the frequency of extreme summer precipitation increased in Eastern Europe, while it decreased in Western and Central Europe. On the other hand, van den Bessalar, Klen-Tank, Buishand (2013) claims that intense precipitation increased in autumn, winter and spring in Northern Europe. Considering the geographical location of Poland, this may explain that the country is under a moderate influence of extreme rainfall during the whole year.

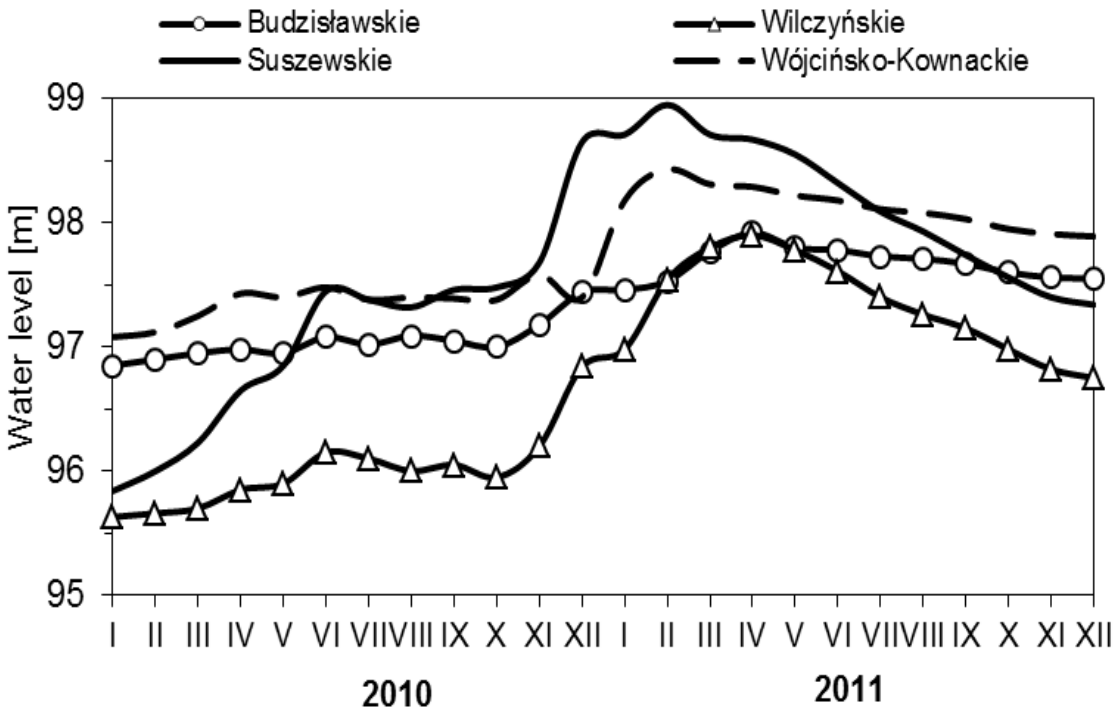

Figure 2. Annual changes of lakes water level (m a.s.l.) in 2010 and 2011.
Source: own study.

As a consequence of the water level increase the exposed banks, shallows and islands were flooded with the vegetation growing on them. The high water level lasted till May – June 2011 (Figure 2). In the summer of 2011 water level in all lakes was higher than in the summer of 2010; the most significant difference was observed in WL whose water level increased by 1.26 m, while the lowest (0.61) m in SL (Figure 2). The high rate of water escape from SL was most probably due to its location near the documented hydrogeological window permitting water to penetrate to the coal level (Przybyłek, Nowak, 2011).

In both periods complete thermal stratification was shaped in the studied lakes. Comparison of the thermal structure revealed insignificant differences in thickness of particular zones (especially epilimnion and hypolimnion) in SL and KL (Figure 3). Compared to 2010 the oxygen conditions deteriorated in three of the four lakes with large loss of oxygen in metalimnion and hypolimnion. Only in SL range of well aerated waters was greater than in 2010. The changes in water quality observed in the lakes in 2011, especially in WL indicated increased alimentation of mineral and organic matter. In the other lakes the values of abiotic parameters did not change so much to induce water quality deterioration.

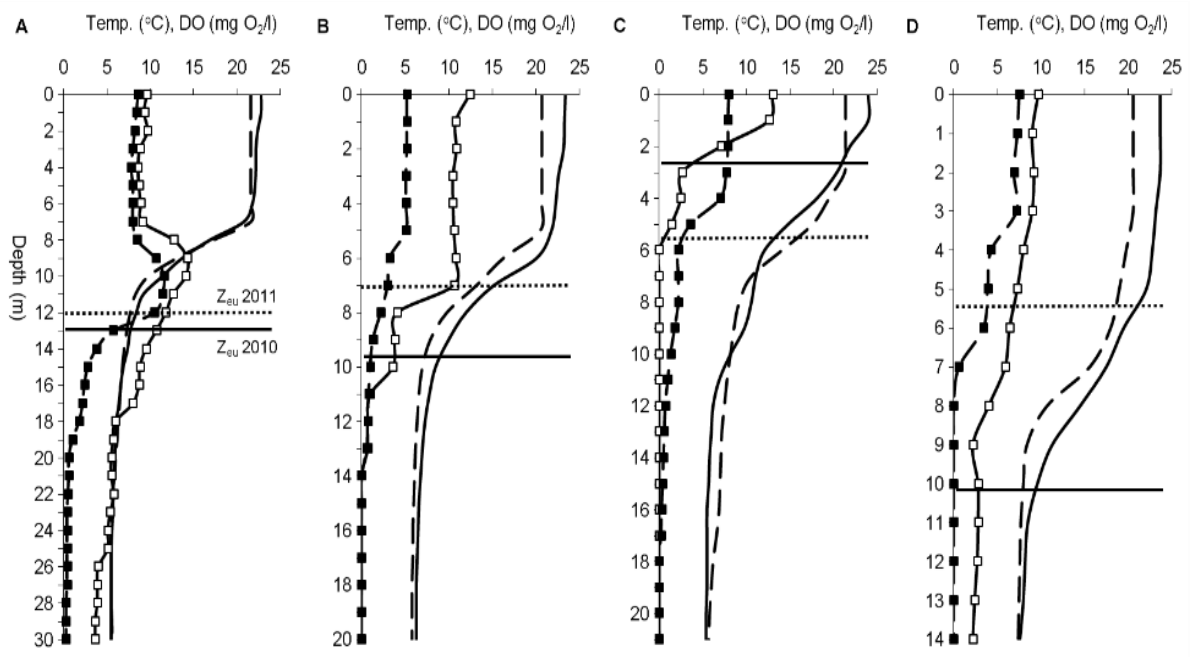

Figure 3. Vertical profiles of temperature (2010 solid line, 2011 dashed line), dissolved oxygen (2010 line with white marker, 2011 with black marker) and range of euphotic zone in vertical profile of Lake Budzisławskie (A), Wilczyńskie (B), Suszewskie (C) and Wójcińsko-Kownackie (D) in 2010 and 2011 (Z_{eu} 2010 – horizontal solid line, Z_{eu} 2011 – horizontal dotted line).
Source: own study.

The colour and turbidity of the lake water in 2011 were higher than in 2010, which resulted in deterioration of the light availability affecting the yield of photosynthesis and the depth of the trophogenic zone (Joniak et al., 2013; Sobczyński, Joniak, 2013). Although year-on-year in BL changes of water colour and turbidity in the euphotic zone were negligible (colour from 0.6 to 0.9 mg Pt L-1, NTU 0.7 to 1.6), the depth of Zeu was smaller by about 0.5 m. More remarkable changes were noted in WL where the increase of both parameters was higher (WC from 2.1 to 4.0 mg Pt L-1, NTU 1.4 to 3.6). In the other lakes the changes in water quality were much more visible: water turbidity in Lake Suszewskie was considerably lower (3.5 NTU compared to 12.4 NTU in 2010), while it was higher in KL (2.2 NTU compared to 0.9 NTU). In both periods water colour in SL was similar (6.8 and 5.2 mg Pt L-1, respectively) whereas higher in KL (1.7 and 5.5 mg Pt L-1, respectively). This type of changes suggested the inflow of groundwater and porewater water rich in colourful organic (mostly humic) substances from forested and arable areas (Blann et al., 2009; Szpakowska, 2003).

The intense water outflow from SL caused the reduction of nitrogen and phosphorus (by about 42% and 27%, respectively, compared to 2010) (Figure 4). The most visible effect of water dilution was an increase of the depth of well oxygenated zone (>4.0 mg O2 L-1) by over 5 m, whereas in KL it decreased to 4 m (Figure 3). Relatively smaller changes were noted in the case of electric conductivity, which was higher in all the lakes by about 5-8% (that is 405-730 μS cm-1 range of the mean value in vertical profile).

Concentrations of mineral and organic nitrogen compounds much increased, thus indicating changes in the homeostasis of the lake ecosystems. The scale of changes was directly proportional to the size of the catchment areas and was related to the transformations in their hydrological regimes. In WL and KL the concentration of mineral forms of nitrogen increased compared to those in 2010, but in the other lakes it did not change (Figure 4).

More considerable differentiation was noted in the concentration of the organic form which was higher in the majority of the lakes. Seasonal maxima of the Norg concentration corresponded to the periods of the highest abundance of phytoplankton (Asaeda, Lalith, Fujino, 2008; Sobczyński, Joniak, 2013). The exception was SL, where mean concentration of Norg decreased by almost 2 mg N L-1. The spatial distribution of Norg also changed: in 2010 the maximum was noted in epilimnion (6.7 mg N L-1), while in 2011 in hypolimnion (4.6 mg N L-1). On the one hand, the decrease of the Norg load indicated the favorable effect of the lake 'washing' by the renewed outflow, but on the other hand, it was a consequence of weather conditions, disadvantageous for algae development (lower temperature, large frequency of precipitation, water wave action etc.).

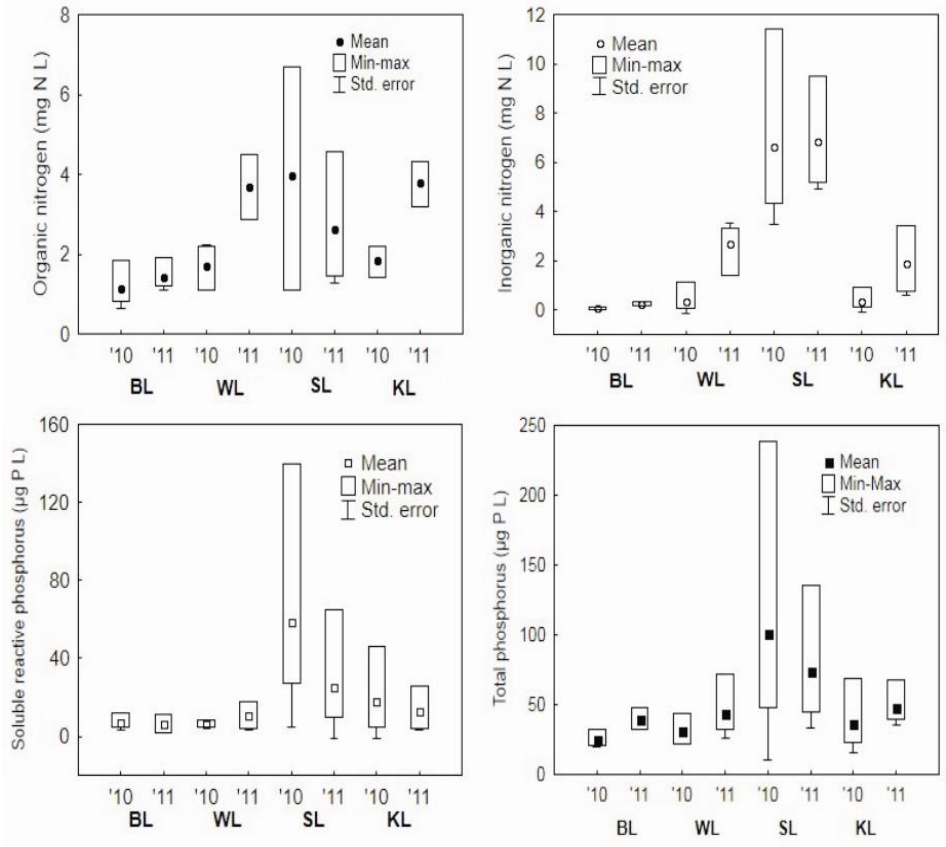

Figure 4. Comparison of variability the concentrations of nitrogen and phosphorus forms in water of the studied lakes in summer 2010 ('10) and 2011 ('11).
Source: own study.

Differences in the concentration of the total phosphorus were not so pronounced. In BL, WL and KL the TP concentration increased insignificantly and did not exceed 50 μg P L-1 (Figure 4). More significant changes were noted in SL, where in 2010 the mean TP concentration was 100 μg P L-1 (maximum 240 μg P L-1), while in 2011 the values were lower, i.e. about 20 μg P L-1 (maximum 140 μg P L-1). However, in KL the concentration of TP in 2011 was higher than in 2010, but this increase was not proportional to the inflow volume from SL. In the case of SRP lower concentration was noted in 2011 than in 2010, which meant that the in-flown load of phosphorus was accumulated or removed from the lake water. Based on the observations mentioned above and the increased water turbidity in KL it could be concluded that intense qualitative transformations of inflow matter took place in that lake. The state of water in KL can be compared to that in the zone of contact between the flowing and stagnant water, where precipitation and sedimentation processes occur as a result of a rapid drop in water velocity (Kufel, 1993). Accumulation of phosphorus and phosphates is particularly stable in summer at decreased flow and greater development of macrophytes (Pieczyńska, Kołodziejczyk, Rybak, 1999; Schneider, 2007).

Stabilization of the water quality parameters in BL, WL and KL was undoubtedly favoured by the presence of Charophyte meadows in the studied lakes. Charophytes assimilate carbon dioxide from water, which results in the precipitation of calcium carbonate and mineral phosphorus bonded in the crystalline form in calcareous incrustation or sediments (Kufel, Biardzka, Strzałek, 2013). These processes result in the absence of SRP, which lacks limited phytoplankton development.

Analysis of the obtained data revealed that the short-term increase of the water level in almost all the investigated lakes caused significant changes of their tropic state (Figure 5). In 2010 BL was oligotrophic, WL and KL were mesotrophic and SL was eutrophic. The oligotrophic state of BL was confirmed by the values of relevant indices and high oxidation of hypolimnion (Figure 3). Although the main parameter for evaluating the trophic state is the concentration of phytoplankton biomass expressed by chlorophyll, the lake trophic state is determined by the mean value of TSI. In 2011, adverse changes in trophy were noted in endorheic lakes.

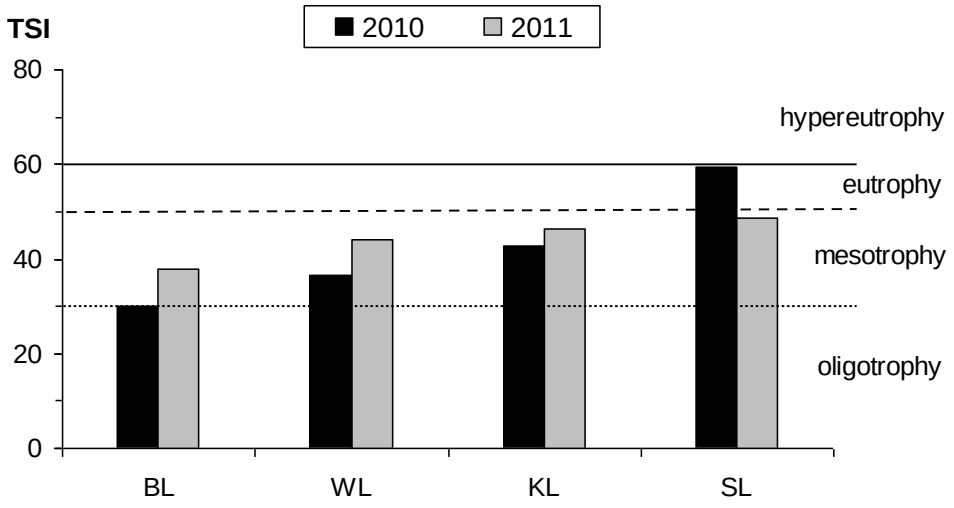

Figure 5. Comparison of the TSI value of lakes in 2010 and 2011.
Source: own study.

4. Conclusions

Climate change increases of the frequency of extreme events, especially rainfall, causing among others intensification of the surface runoff from catchment area into lakes. Our study proved that short-term extreme changes in the lake water level (even up to 3.5 m) may deteriorate water quality, especially in lakes without outflow. An increase in the concentration of nitrogen forms and deterioration of light availability (higher concentrations of turbidity, water colour and chlorophyll a, smaller range of photic zone) were noted in such lakes. An essential role of the catchment area in relation to the lake resistance to such drastic water level changes was confirmed. Among the studied lakes only in the lake with the smallest catchment area, the initial trophic state was preserved, which confirmed its greatest resistance to such disturbances. At the same time, the trophic state of the other lakes considerably changed, mainly from mesotrophic to eutrophic. Paradoxically, significant improvement of the water quality was noted in the lake with the largest catchment area after the natural surface outflow was renewed. The observed effects, especially those related to the deterioration of the light conditions have significant impact on the development and the depth of occurrence of Charophyte meadows in the studied lakes. Therefore, it seems that preservation of the natural values of lakes is possible only in conditions of stable water level and sustained use of their catchments. Concluding, in case of high eutrophicated lakes the increase of water level has positive impact on water quality and trophic state.

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The variability of heavy metals in PM 10 dust in the Podkarpackie Voivodeship

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Abstract: Air quality is an important factor affecting human, animal and plant health. Air pollution is a global problem, therefore the analysis of especially toxic pollutants contained in PM10 dust is an important element of environmental monitoring. The analysis of heavy metals content in PM10 dust allows for the observation of change trends. The results of the air monitoring published by CIEP were analyzed. The data was analyzed focusing on daily exceedances the norm and their potential impact on human, animal and plant health. The health risk assessment was estimated. The annual average content of heavy metals in PM10 dust in the Podkarpackie voivodeship did not exceed the target values of Ar – 6ng/m^3, Cd – 5ng/m^3, Ni – 20ng/m^3 and Pb – 0,5μg/m^3, respectively. The 24-hour averaged values for Cd were exceeded at the measuring station in Krosno, which potentially adversely affects living organisms. The analysis of changes in the content of heavy metals in the PM10 dust showed a downward trend in the content of heavy metals in the PM10 dust. A large reduction in pollution was observed in 2020, which could be related to restrictions on human movement and other restrictions introduced in connection with the COIVD-19 pandemic.

Key words: PM10 dust, air pollutants, heavy metals.

1. Introduction

Air quality is very important factor influences to health of people, animal and plants. In the air we breath exist a lot of variety pollutants which can be toxicity and mutagenicity and their impact can be observed after longtime exposition. The most dangerous for health is the particulate matter about size under 10 μm which during absorption mainly by the inhalation route get into the body and deposit the bronchi (Grzywa-Celinska, Krusiński, Milanowski, 2020). Currently air pollutants are global problem, therefore the analysis of especially toxic pollutants contained in PM10 dust is an important element of environmental monitoring.

PM 10 is a fraction of suspended dust with particle diameters smaller than 10 μm. As part of the State Environmental Monitoring (SEM), 2.5 dust with equivalent particle diameters below 2.5 μm is also measured. Atmospheric dust is a mixture of primary and anthropogenic pollutants. Primary pollutants include volcanic eruptions, earthquakes, forest fires, material of plant and animal origin, and other materials floating into the atmosphere as a result of processes occurring naturally in nature. On the other hand, the production, mining, fuel combustion, processing and communal-housing processes are classified as sources of anthropogenic dusts (Juda-Rezler, 2016).

The chemical composition of the dust depends, inter alia, on the meteorological conditions, geographic location, topography, land cover and the season of the year. The main components of particulate matter are mineral dust, sea salt, carbon, organic and elemental, secondary organic and inorganic aerosols, and trace elements (Juda-Rezler, 2016). Among the trace elements that can be found in PM 10 dust are arsenic, cadmium, nickel and lead

– determined under the SEM. In Poland, PM10 dust comes mainly from the energy sector and industrial processes. In the Podkarpackie Voivodeship, air pollutants are of anthropogenic origin, mainly from the communal sector, transport and industry (KOBIZE, 2021).

The release of heavy metals into the air occurs mainly from combustion processes in industry and the energy sector, and to a lesser extent from the municipal and housing sector. Heavy metals in the air can have a negative impact on the health of humans, animals and plants. As, Cd, Ni and Pb are classified by the International Agency for Research on Cancer (IARC) as a group of substances proven to be carcinogenic to humans. Heavy metals are a common pollutant in water, soil and air, therefore it is important from a health perspective to estimate the risk of health exposure. This is one of the reasons why they are analyzed as part of the State Environmental Monitoring (Juda-Rezler, 2016; Kabata-Pendias, Pendias, 2001).

In Poland, air pollution due to the protection of human health and plant protection is assessed with the help of the target levels specified in the Regulation Minister of the Environment on the levels of certain substances in the air (RME 2012) (Table 1).

Table 1

The levels of the substance in the air for gaseous pollutants are determined under the following conditions: temperature 293 K, pressure 101.3 kPa (RME 2012)

Parameter	Period of averaging results	Target level
PM 10 dust	daily	50 $\mu g \cdot m^{-3}$*
	annual	40 $\mu g \cdot m^{-3}$
As	annual	6 $ng \cdot m^{-3}$
Ni	annual	20 $ng \cdot m^{-3}$
Cd	annual	5 $ng \cdot m^{-3}$
Pb	annual	0,5 $\mu g \cdot m^{-3}$

*35 times acceptable frequency of exceeding the target level in a calendar year
Source: own study.

In the interests of health and the deteriorating air quality, the WHO tightened the air quality standards in 2021 by changing the guidelines (Table 2). However, the WHO recommendations are in no way binding on the European Union, so the countries are not obligated to respect them.

Table 2

The air quality guidelines according to WHO – before and after the change [WHO 2021]

Parameter	Period of averaging results	Unit	Guidelines 2005	Guidelines 2021
PM 2,5	annual	$\mu g \cdot m^{-3}$	10	5
	daily	$\mu g \cdot m^{-3}$	25	10
PM 10	annual	$\mu g \cdot m^{-3}$	20	15
	daily	$\mu g \cdot m^{-3}$	50	45

Source: own study.

The aim of the study is to analyze changes in the content of heavy metals in PM10 dust and to estimate their impact on human health. The results of the air monitoring published by CIEP were analyzed. The data was analyzed focusing on daily exceedances and their potential impact on human, animal and plant health. Health risk assessment was performed.

2. Materials and Methods

Description of the collecting the data

The analyzed data are the results of air monitoring measurements obtained by the Chief Inspectorate for Environmental Protection (CEPI) collected as part of the State Environmental Monitoring (SEM) in 2016-2021 for the Podkarpackie Voivodeship, available on the website Air Quality Portal CIEP. For analysis was chosen the data from measuring stations in which were investigated analyzes of the heavy metal pollution included in the PM 10 dust. Currently, in the Podkarpackie Voivodeship, measurements of heavy metals in PM10 dust are performed at 3 stations in Rzeszów (Rejtana Street, since 2013), in Krosno (Kletówki Street, since 2008), and in Mielec (Pogodna Street, since 2020). In 2019, measurements were completed in Jasło and Przemyśl, and in 2020 in Rymanów Zdrój and Stalowa Wola. The date availability for individual stations in analysez period is presented in Table 3.

Table 3
The summary of the analyzed points and available data

Year	Jasło	Krosno	Mielec	Przemyśl	RymZdr[1]	Rzeszów	StalWola[2]
2016	+	+	na[3]	+		+	na
2017	+	+	na	+	+	+	na
2018	+	+	na	+	+	+	+
2019	+	+	na	+	+	+	+
2020	na	+	+	na	+	+	+
2021	na	+	+	na	na	+	na

[1]RymZdr – Rymanów Zdrój, [2]StalWola – Stalowa Wola, [3]na – not available
Source: own study.

The analyzed data was divided into two periods: the heating season from October 1 to April 30 and the non-heating season from May 1 to September 30. In addition, an analysis of changes in air pollution with PM10 dust and metals contained in it during of the first lockdown time in Poland in 2020 was carried out.

The risk assessment was conducted according to US EPA methodology for four meatals: As, Cd, Ni and Pb included in PM 10 dust. This approach of estimation health risk is commonly used to description of different air pollutants. The analysis of the exposure to contamination with heavy metals contained in PM10 dust of adults (devided by gender) and children was carried out. The assessment took into account the pollutants absorbed by inhalation rout, for this purpose the daily inhalation dose was calculated – ADDinh. Additional used the non-carcinogenic risk – HQ, carcinogenic risk – CR and total carcinogenic risk as the sum of individual carcinogens – CRtotal.

The calculations were made in accordance with the following equations:

$$\mathrm{ADD_{inh}} = \frac{\mathrm{C} \cdot \mathrm{InhR} \cdot \mathrm{EF} \cdot \mathrm{ED}}{\mathrm{BW} \cdot \mathrm{AT}}$$

$$\mathrm{HQ} = \frac{\mathrm{ADD_{inh}}}{\mathrm{RfD}_{inh}}$$

$$\mathrm{CR} = \mathrm{ADD} \cdot \mathrm{SF}$$

$$\mathrm{CR_{total}} = \mathrm{CR1} + \mathrm{CR2} + \cdots + \mathrm{CRn}$$

The data presented in the table 4 and table 5 were adopted in the exposure scenario. Interpretation of the HQ, if HQ> 1 – adverse effects on human health can occur, and HQ<1 – there is no health risk. For the CR range 10-6-10-4 as accepted level – the low risk of cancer, above this value is a risk that requires protective measures.

Table 4
Exposure parameters for the health risk assessment

Parameter	Unit	Values		
		Child	Adults	
			Woman	Man
InhR – Inhalation rate	$m^3 \cdot day^{-1}$	10	20	20
IngR – Ingestion rate	$mg \cdot cm^{-2} \cdot day^{-1}$	200	100	100
EF – Exposure frequency	$day \cdot year^{-1}$	365	365	365
ED – Exposure duration	year	6	70	70
BW – Body weight	kg	16	65	78
AT – Average exposure time				
• for non-carcinogenic	days	ED·365	ED·365	ED·365
• for carcinogenic	days	70·365	70·365	70·365

Source: own study.

Table 5
The values of the reference dose and slope factor

Parameter	Unit	Metals			
		As	Cd	Ni	Pb
RfDinh (IRIS)	$mg \cdot kg^{-1} \cdot day^{-1}$	$3.0 \cdot 10^{-4}$	$5{,}0 \cdot 10^{-4}$	$2.0 \cdot 10^{-2}$	
SFinh (OEHHA)	$mg \cdot kg^{-1} \cdot day^{-1}$	$1.2 \cdot 10^{+1}$	$1.5 \cdot 10^{+1}$	$9.1 \cdot 10^{-1}$	$4.2 \cdot 10^{-2}$

Source: own study.

3. Results

The analysis of average concentrations of PM 10 in the atmospheric air in the heating and non-heating season in 2016-2021 showed that lower dust values occur off the heating season and decreasing concentrations over the years in this period. The highest values were observed for Krosno, Przemyśl and Rzeszów, and the lowest for Rymanów Zdrój.

In the heating season for Jasło, the values were in the range of 29,6-35,7 $\mu g \cdot m^{-3}$, for Krosno 26,1-39,7 $\mu g \cdot m^{-3}$, for Mielec 28,3-31,1 $\mu g \cdot m^{-3}$, for Przemyśl 28,5-38,8 $\mu g \cdot m^{-3}$, for Rymanów Zdrój 16,0-24,4 $\mu g \cdot m^{-3}$, for Rzeszów 23,6-38,0 $\mu g \cdot m^{-3}$, for Stalowa Wola 26,8-34,2 $\mu g \cdot m^{-3}$. Outside the heating season, the concentration range for Jasło was 13,6-21,2 $\mu g \cdot m^{-3}$, for Krosno 17,1-24,0 $\mu g \cdot m^{-3}$, for Mielec 18,1-18,5 $\mu g \cdot m^{-3}$, for Przemyśl 17,0-18,8 $\mu g \cdot m^{-3}$, for Rymanów Zdrój 12,3-18,6 $\mu g \cdot m^{-3}$, for Rzeszów 15,9-23,1 $\mu g \cdot m^{-3}$, for Stalowa Wola 18,8-19,5 $\mu g \cdot m^{-3}$ (Table 6).

In the analyzed period of 2016-2021, the target level of 6 $ng \cdot m^{-3}$ was not exceeded (Figure 1). The highest maximum values were recorded in Jasło, Krosno, Przemyśl and Rzeszów in 2017, they were respectively 3,99 $ng \cdot m^{-3}$, 5,23 $ng \cdot m^{-3}$, 4,06 $ng \cdot m^{-3}$, 4,17 $ng \cdot m^{-3}$ and it was 67%, 87%, 68% and 70% of the target level.

Table 6
The average value of PM10 dust in years 2016-2021 [μg·m^{-3}]

Year	Jasło		Krosno		Mielec		Przemyśl		RymZdr		Rzeszów		StalWola	
	HS	NH	HS	NH	HS	NH	HS	NH	HS	NH	HS	NH	HS	NH
2016	31.7	19.0	34.0	22.4	-	-	32.9	19.2	-	-	32.3	20.7	-	-
2017	35.7	17.9	39.7	20.8	-	-	35.7	18.8	24.4	15.4	38.0	19.6	-	-
2018	34.2	21.2	36.6	24.0	-	-	38.8	21.1	23.9	18.6	37.5	23.1	34.2	23.1
2019	29.6	13.6	32.7	19.0	-	-	28.5	17.0	19.6	12.3	30.2	16.5	29.6	19.5
2020	-	-	26.1	17.1	28.3	18.1	-	-	16.0	12.7	23.6	15.9	26.8	18.8
2021	-	-	31.9	17.9	31.1	18.5	-	-	-	-	30.3	16.1	-	-

HS – heating season, NH – non-heating season
Source: own study.

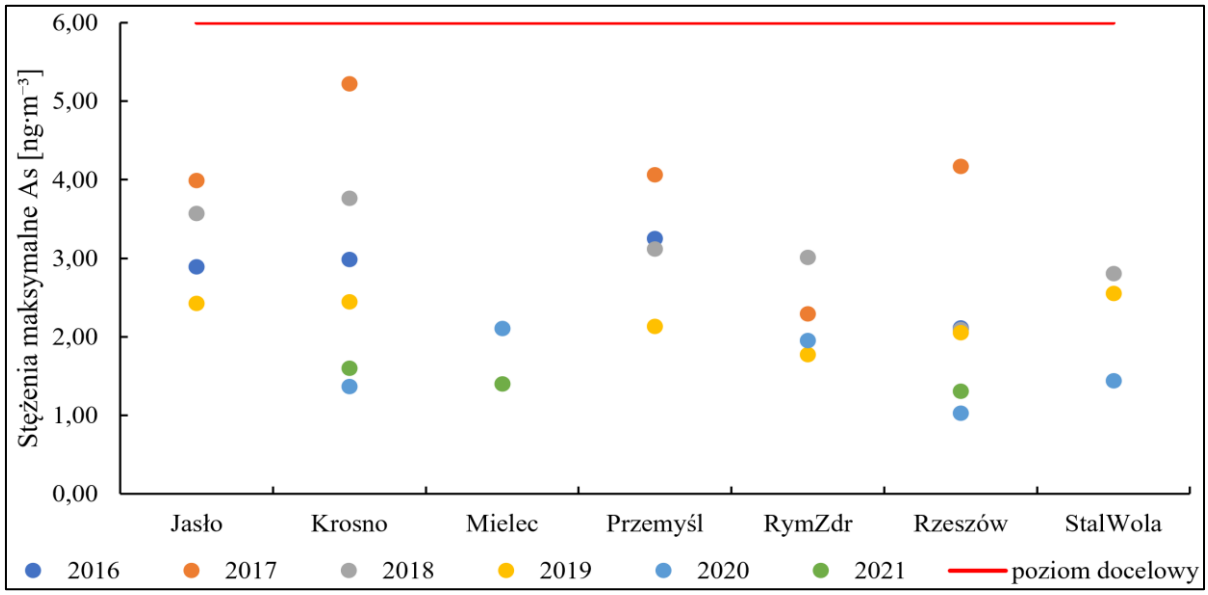

Figure 1. The maximum arsenic content in PM10 dust in 2016-2021.
Source: own study.

The average as values for the heating season were higher than those off the heating season. The average results obtained in the heating season were in the range of 0,93-1,60 ng·m^{-3} for Jasło, 0,59-1,97 ng·m^{-3} for Krosno, 0,65-0,62 ng·m^{-3} for Mielec, 0,72-1,38 ng·m^{-3} for Przemyśl, 0,55-0,86 ng·m^{-3} for Rymanów Zdrój, 0,53-1,22 ng·m^{-3} for Rzeszów and 0,63-1,15 ng·m^{-3} for Stalowa Wola. Off the heating season, the average values were in the range of 0,50-0,65 ng·m^{-3} for Jasło, 0,50-0,54 ng·m^{-3} for Krosno, 0,50-0,56 ng·m^{-3} for Przemyśl, 0,50-0,52 ng·m^{-3} for Rzeszów, 0,56-0,57 ng·m^{-3} for Stalowa Wola, while for Mielec and Rymanów Zdrój the average values were 0,50 ng·m^{-3} (Table 7).

The cadmium content in PM 10 in the analyzed period exceeded the target level in Krosno several times, and the highest values were also recorded for this point in the Podkarpackie Voivodeship (Figure 2). The maximum values recorded in Krosno in individual years are 7.19 ng·m^{-3} in 2016, 6.09 ng·m^{-3} in 2017, and 6.48 ng·m^{-3} in 2019, which corresponds to exceeding 44% in 2016, 22% in 2017 and 30% in 2019. In 2018, the value was 4.79 ng·m^{-3}, in 2020: 5.35% and a much lower value in 2021 – 0.70 ng·m^{-3}. Next the highest values were recorded in Jasło, they were in the range of 2.12-3.99 ng·m^{-3}. The value of 2,52 ng·m^{-3} was recorded in Stalowa Wola in 2020, while in the remaining measurement points the highest values were below 50% of the target level.

Table 7
The average value of arsenic in PM10 dust in years 2016-2021 [ng·m^{-3}]

Year	Jasło		Krosno		Mielec		Przemyśl		RymZdr		Rzeszów		StalWola	
	HS	NH	HS	NH	HS	NH	HS	NH	HS	NH	HS	NH	HS	NH
2016	1.34	0.61	1.30	0.53	-	-	1.13	0.50	-	-	0.89	0.52	-	-
2017	1.60	0.65	1.97	0.54	-	-	1.38	0.56	0.86	0.50	1.22	0.50	-	-
2018	1.47	0.50	1.29	0.50	-	-	1.34	0.50	0.70	0.50	0.94	0.50	1.15	0.56
2019	0.93	0.50	0.91	0.50	-	-	0.72	0.50	0.59	0.50	0.74	0.50	1.00	0.61
2020	-	-	0.59	0.50	0.62	0.50	-	-	0.55	0.50	0.53	0.50	0.63	0.57
2021	-	-	0.70	0.50	0.56	0.50	-	-	-	-	0.54	0.50	-	-

Source: own study.

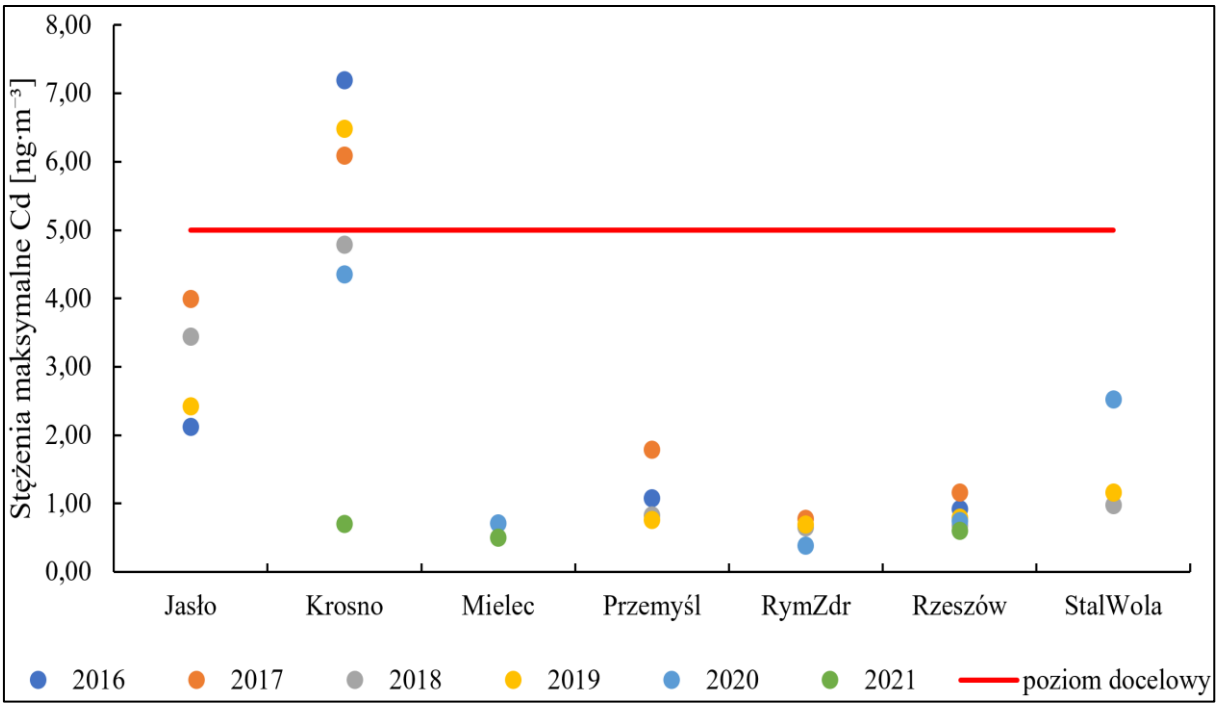

Figure 2. The maximum cadmium content in PM10 dust in 2016-2021.
Source: own study.

Off the heating season, at all measurement points, except for Krosno, in 2019 and 2020 lower average values of Cd content in PM 10 dust were observed (Table 8). During the heating season, the average values were in the range of 0,54-0,70 ng·m^{-3} for Jasło, 0,33-1,03 ng·m^{-3} for Krosno, 0,37-0,50 ng·m^{-3} for Przemyśl, 0,18-0,34 ng·m^{-3} for Rymanów Zdrój, 0,27-0,48 ng·m^{-3} for Rzeszów, 0,46 – 0,54 ng·m^{-3} for Stalowa Wola and at the level of 0,34 ng·m^{-3} for Mielec. Off the heating season, mean Cd contents were in the ranges of 0,25-0,34 ng·m^{-3} for Jasło, 0,15-0,79 ng·m^{-3} for Krosno, 0,12-0,19 ng·m^{-3} for Mielec, 0,19-0,30 ng·m^{-3} for Przemyśl, 0,12-0,22 ng·m^{-3} for Rymanów Zdrój, 0,12-0,26 ng·m^{-3} for Rzeszów and 0,20-0,45 ng·m^{-3} for Stalowa Wola.

The target level for Ni in PM 10 was set at 20 ng·m^{-3}. The highest values recorded in the analyzed period were 7.13 ng·m^{-3} for Przemyśl in 2017, 6,48 ng·m^{-3} in 2020 for Rzeszów and 5,54 ng·m^{-3} for Jasło and 5,95 ng·m^{-3} for Krosno in 2016 (Figure 3). The remaining highest values did not exceed 25% of the target level.

Table 8
The average value of cadmium in PM10 dust in years 2016-2021 [ng·m^{-3}]

Year	Jasło		Krosno		Mielec		Przemyśl		RymZdr		Rzeszów		StalWola	
	HS	NH	HS	NH	HS	NH	HS	NH	HS	NH	HS	NH	HS	NH
2016	0.62	0.34	1.03	0.40	-	-	0.43	0.21	-	-	0.44	0.22	-	-
2017	0.55	0.35	0.97	0.38	-	-	0.50	0.30	0.34	0.22	0.48	0.26	-	-
2018	0.70	0.35	0.73	0.44	-	-	0.45	0.19	0.31	0.16	0.38	0.19	0.53	0.27
2019	0.54	0.25	0.68	0.79	-	-	0.37	0.20	0.28	0.17	0.39	0.19	0.54	0.20
2020	-	-	0.33	0.68	0.34	0.19	-	-	0.18	0.12	0.27	0.18	0.46	0.45
2021	-	-	0.40	0.15	0.34	0.12	-	-	-	-	0.31	0.12	-	-

Source: own study.

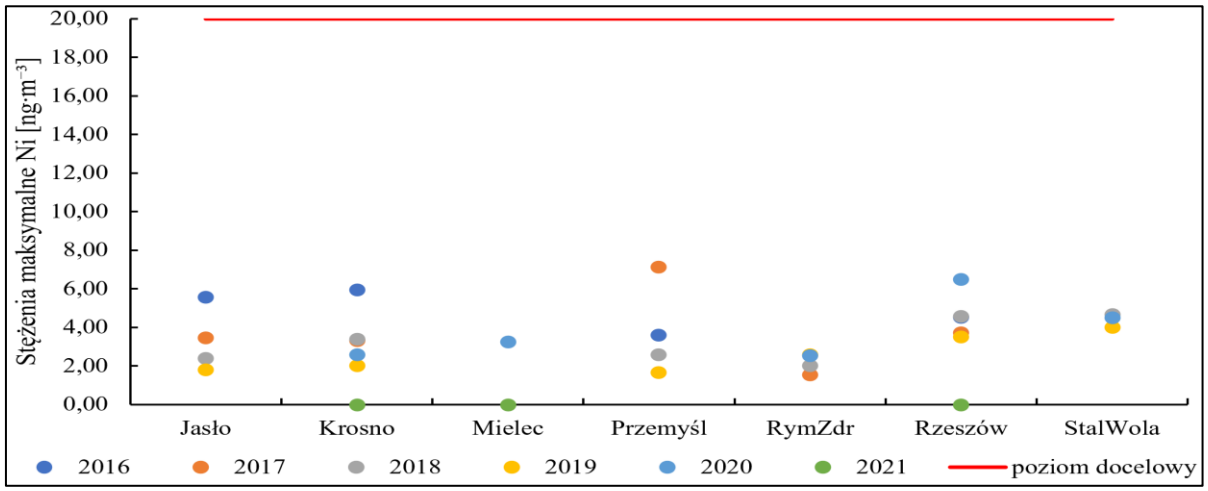

Figure 3. The maximum nickiel content in PM10 dust in 2016-2021.
Source: own study.

In the heating season, the average values for Jasło were within the range of 0,65-10,3 ng·m^{-3}, for Krosno 0,68-1,17 ng·m^{-3}, for Mielec 0,72-0,74 ng·m^{-3}, for Przemyśl 0,57-1,52 ng·m^{-3}, for Rymanów Zdrój 0,53-0,70 ng·m^{-3}, for Rzeszów 0,60-1,18 ng·m^{-3}, for Stalowa Wola 1,10-1,68 ng·m^{-3} (Table 9). Off the heating season, the average values of Ni in PM 10 dust ranged from 0,71-1,41 ng·m^{-3} in Jasło, 0,66-1,66 ng·m^{-3} in Krosno, 0,79-1,09 ng·m^{-3} in Mielec, 0,67-1,25 ng·m^{-3} in Przemyśl, 0,54-0,65 ng·m^{-3} in Rymanów Zdrój, 0,67-1,34 ng·m^{-3} in Rzeszów, 0,85-1,40 ng·m^{-3} in Stalowa Wola.

The maximum values of lead in PM 10 dust in the years 2016-2021 were at a very low level, not exceeding 15% of the target level value – 0.5 µg·m^{-3} (Figure 4). The highest maximum value was 0,060 µg·m^{-3} recorded in 2018 in Stalowa Wola, the remaining maximum values did not exceed 0,050 µg·m^{-3}.

In the heating season, the average Pb values in PM 10 dust did not exceed 0.022 µg·m^{-3}, while off the heating season they were below 0.010 µg·m^{-3} (Table 10). During the heating season, average values were recorded in the range of 0.013-0.220 µg·m^{-3} for Jasło, 0.007-0.019 µg·m^{-3} for Krosno, 0.007-0.013 µg·m^{-3} for Przemyśl, 0.004-0.011 µg·m^{-3} for Rymanów Zdrój, 0.007-0.016 µg·m^{-3} for Rzeszów, 0.012-0.019 µg·m^{-3} for Stalowa Wola and at the level of 0.009 µg·m^{-3} for Mielec. Off the heating season, the range of average values was 0,005-0,009 µg·m^{-3} for Jasło, 0,004-0,009 µg·m^{-3} for Krosno, 0.003-0.005 µg·m^{-3} for Przemyśl, 0.002-0.006 µg·m^{-3} for Rymanów Zdrój, 0.003-0.007 µg·m^{-3} for Rzeszów, 0.009-0.010 µg·m^{-3} for Stalowa Wola.

Table 9
The average value of nickel in PM10 dust in years 2016-2021 [µg m^{-3}]

Year	Jasło		Krosno		Mielec		Przemyśl		RymZdr		Rzeszów		StalWola	
	HS	NH	HS	NH	HS	NH	HS	NH	HS	NH	HS	NH	HS	NH
2016	0.94	1.41	1.12	1.66	-	-	0.93	1.25	-	-	0.93	1.34	-	-
2017	0.99	0.85	1.17	0.98	-	-	1.52	0.81	0.62	0.54	1.18	0.86	-	-
2018	1.03	0.93	1.02	0.97	-	-	0.93	0.78	0.70	0.61	1.05	0.83	1.68	1.40
2019	0.65	0.71	0.69	0.75	-	-	0.57	0.67	0.53	0.65	0.60	0.80	1.10	0.85
2020	-	-	0.73	0.66	0.74	0.79	-	-	0.61	0.63	0.91	0.67	1.41	1.16
2021	-	-	0.68	1.15	0.72	1.09	-	-	-	-	0.76	0.86	-	-

Source: own study.

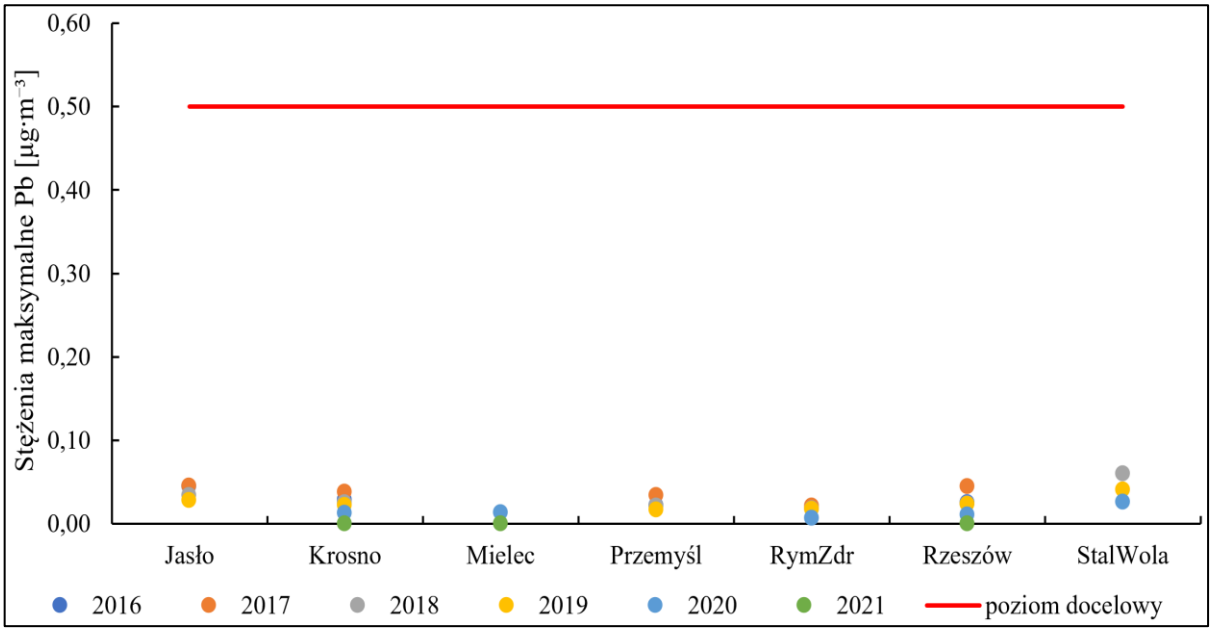

Figure 4. The maximum lead content in PM10 dust in 2016-2021.
Source: own study.

For As, during the restrictions in 2020, lower concentrations were recorded than in the corresponding period in 2019 and 2021. For Cd concentrations in PM 10, lower average 24-h values were recorded in 2020 than in 2019, a downward trend was also observed in 2021 for both cities. For Ni, significantly lower values were recorded during the introduced restrictions compared to 2019 and 2021. For Pb, a decrease in the average daily values was observed in 2020 compared to 2019.

Health Risk Assesment

Based on the calculated inhalation doses taken during the day, the product of HQ exposure for As was calculated, the results of which are presented in Table 12. Determined HQ values for children ranged from 3,75·10-6 to 4,11·10-3, while for women they ranged from 5,1·10-4 to 2,01·10-3 and for men from 4,76·10-4 to 1,68·10-3. All the values obtained are above 1 (HQ>1), which proves that there is no risk of exposure. Higher values were recorded for children than for adults. The greatest exposure for children is in Jasło, and the lowest in Rymanów Zdrój.

Table 10

The air quality assessment for PM10 based on the AQI in the selected period in Krosno and Rzeszow

Date	Krosno			Rzeszów		
	2019	2020	2021	2019	2020	2021
15 March	11.6	21.6	29.4	14.0	24.7	26.0
16 March	14.4	19.1	47.0	21.2	14.4	41.5
17 March	13.8	42.2	34.4	18.6	43.7	25.9
18 March	33.2	80.7	34.0	23.6	60.2	26.1
19 March	46.8	82.5	57.0	41.8	58.6	56.6
20 March	62.0	69.5	40.5	66.4	55.8	42.9
21 March	69.3	20.3	41.2	54.0	10.0	35.3
22 March	56.1	10.9	26.2	48.3	9.35	20.1
23 March	58.8	16.9	36.4	54.4	18.1	23.7
24 March	73.2	20.0	29.7	53.9	19.8	34.0
25 March	29.1	23.0	77.5	24.8	23.2	64.1
26 March	21.8	26.3	98.6	17.3	29.9	74.9
27 March	41.6	36.3	46.2	30.5	43.3	57.2
28 March	71.4	67.1	26.8	51.7	79.0	18.8
29 March	68.2	87.2	41.5	47.4	55.6	29.5
30 March	89.9	17.7	24.1	82.2	10.7	22.8
31 March	49.7	37.3	46.0	42.6	27.7	37.4
1 April	17.4	56.9	36.0	15.7	45.1	29.6
2 April	24.4	46.7	24.9	24.5	28.7	24.9
3 April	45.7	33.9	29.4	39.3	20.6	28.6
4 April	48.4	49.8	22.0	45.2	43.7	17.9
5 April	44.2	42.3	15.7	46.8	38.5	15.1
6 April	39.6	39.5	21.2	38.8	38.1	13.6
7 April	16.4	44.4	27.7	25.0	33.9	22.1
8 April	30.6	58.7	19.2	36,6	42.7	14.3
9 April	33.0	44.0	20.6	38,2	33.1	14.1
10 April	28.7	27.5	14.3	25.0	19.0	14.9
11 April	22.4	28.6	17.3	19.2	20.2	14.9

Colors corresponding to AQI classes: dark green – very good; green – good; yellow – moderate; orange – average; red – bad; maroon – very bad.

Source: own study.

Table 11

Non-carcinogenic risk values for As calculated for child, woman and man

Group	Value	Jasło	Krosno	Mielec	Przemyśl	RymZdr	Rzeszów	StalWola
child	min	1.04E-03	1.04E-03	1.04E-03	3.75E-06	3.75E-06	3.75E-06	4.57E-06
	max	3.34E-03	4.11E-03	1.30E-03	2.88E-03	1.79E-03	2.53E-03	2.39E-03
	mean	1.98E-03	1.71E-03	1.13E-03	1.41E-03	9.40E-04	1.15E-03	1.01E-03
woman	min	5.10E-04	5.10E-04	5.10E-04	5.10E-04	5.10E-04	5.10E-04	5.69E-04
	max	1.63E-03	2.01E-03	6.34E-04	1.41E-03	8.78E-04	1.24E-03	1.17E-03
	mean	9.69E-04	8.35E-04	5.55E-04	8.44E-04	5.98E-04	6.70E-04	7.66E-04
man	min	4.27E-04	4.27E-04	4.27E-04	4.27E-04	4.27E-04	4.27E-04	4.76E-04
	max	1.37E-03	1.68E-03	5.31E-04	1.18E-03	7.35E-04	1.04E-03	9.80E-04
	mean	8.11E-04	6.99E-04	4.65E-04	7.07E-04	5.01E-04	5.61E-04	6.41E-04

Source: own study.

The carcinogenic risks posed by As is on the acceptable level. For children in Jasło and Krosno obtained result on level 10^{-6} and nd lower in the remaining stations 10^{-6} (Table 13). The cancer risk for adults is on level 10^{-6}, the highest was calculated for Krosno.

Table 12
The value of carcinogenic risks posed by As

Group	Jasło	Krosno	Mielec	Przemyśl	RymZdr	Rzeszów	StalWola
child	1.03E-06	1.27E-06	4.00E-07	8.90E-07	5.53E-07	7.81E-07	7.38E-07
woman	5.88E-06	7.23E-06	2.28E-06	5.08E-06	3.16E-06	4.46E-06	4.21E-06
man	4.92E-06	6.06E-06	1.91E-06	4.25E-06	2.65E-06	3.73E-06	3.53E-06

Source: own study.

The calculated daily doses of cadmium by inhalation are higher for children than for adults, ranging from $1{,}63 \cdot 10^{-6}$ to $1{,}21 \cdot 10^{-3}$ (Table 14). A similar relationship is shown for the HQ, which in most cases is higher for children than for adults. Women are more exposed than men, the results obtained for them ranged from $7{,}18 \cdot 10^{-5}$ to $1{,}06 \cdot 10^{-4}$. The exposure for males ranged from $6{,}13 \cdot 10^{-5}$ – $1{,}02 \cdot 10^{-4}$. The highest exposure for children and adults was in Krosno, and the lowest in Rymanów Zdrój.

Table 13
Non-carcinogenic risk values for Cd calculated for child, woman and man

Group	Value	Jasło	Krosno	Mielec	Przemyśl	RymZdr	Rzeszów	StalWola
child	min	3.06E-04	1.85E-04	1.50E-04	1.86E-06	1.63E-06	1.80E-06	1.90E-06
	max	8.71E-04	1.29E-03	4.27E-04	6,.22E-04	4.27E-04	5.98E-04	6.66E-04
	mean	5.76E-04	7.28E-04	3.08E-04	3.26E-04	2.08E-04	2.95E-04	3.59E-04
woman	min	1.50E-04	9.03E-05	7.32E-05	1.17E-04	7.18E-05	7.41E-05	1.24E-04
	max	4.26E-04	6.29E-04	2.09E-04	3.05E-04	2.09E-04	2.93E-04	3.27E-04
	mean	2.82E-04	3.56E-04	1.51E-04	2.03E-04	1.37E-04	1.74E-04	2.50E-04
man	min	1.25E-04	7.56E-05	6.13E-05	9.80E-05	6.02E-05	6.21E-05	1.04E-04
	max	3.57E-04	5.27E-04	1.75E-04	2.55E-04	1.75E-04	2.45E-04	2.74E-04
	mean	2.36E-04	2.98E-04	1.26E-04	1.70E-04	1.14E-04	1.46E-04	2.09E-04

Source: own study.

The calculated cancer risk of Cd was higher for adults than for children (Table 15). For all studied groups, the highest was recorded in Krosno, while the lowest, at a very similar level, for Mielec and Rymanów Zdrój.

Table 14
The value of carcinogenic risks posed by Cd

Group	Jasło	Krosno	Mielec	Przemyśl	RymZdr	Rzeszów	StalWola
child	5.60E-07	8.26E-07	2.75E-07	4.00E-07	2.74E-07	3.85E-07	4.30E-07
woman	3.20E-06	4.72E-06	1.57E-06	2.28E-06	1.57E-06	2.20E-06	2.45E-06
man	2.68E-06	3.95E-06	1.31E-06	1.91E-06	1.31E-06	1.84E-06	2.06E-06

Source: own study.

Non-carcinogenic exposure caused by Ni occurs at the highest level in Stalowa Wola, and the lowest in Rymanów Zdrój. The HQ value for children ranged from 4,82E-7 to $5{,}26 \cdot 10^{-5}$, for women $9{,}13 \cdot 10^{-5}$ - $2{,}58 \cdot 10^{-5}$ and for men $9{,}22 \cdot 10^{-5}$ – $2{,}16 \cdot 10^{-5}$ (Table 16).

Table 15
Non-carcinogenic risk values for Ni calculated for child, woman and man

Group	Value	Jasło	Krosno	Mielec	Przemyśl	RymZdr	Rzeszów	StalWola
child	min	2.05E-05	2.05E-05	2.25E-05	3.27E-07	3.00E-07	3.39E-07	4.82E-07
	max	4.40E-05	5.18E-05	3.41E-05	4.76E-05	2.19E-05	4.18E-05	5.26E-05
	mean	2.94E-05	3.02E-05	2.62E-05	2.44E-05	1.46E-05	2.45E-05	2.96E-05
woman	min	1.00E-05	1.00E-05	1.10E-05	8.78E-06	8.07E-06	9.13E-06	1.30E-05
	max	2.15E-05	2.53E-05	1.67E-05	2.33E-05	1.07E-05	2.05E-05	2.58E-05
	mean	1.44E-05	1.48E-05	1.28E-05	1.43E-05	9.33E-06	1.37E-05	1.94E-05
man	min	8.39E-06	8.39E-06	9.22E-06	7.35E-06	6.76E-06	7.64E-06	1.08E-05
	max	1.80E-05	2.12E-05	1.40E-05	1.95E-05	8.96E-06	1.71E-05	2.16E-05
	mean	1.20E-05	1.24E-05	1.07E-05	1.19E-05	7.81E-06	1.15E-05	1.62E-05

Source: own study.

The calculated values of cancer risk revealed that the risk is scant between 10^{-8} and 10^{-7}. There is a lower risk for children than for men and women. Higher values were observed in Mielec, and lower in Rymanów Zdrój (Table 17).

Table 16
The value of carcinogenic risks posed by Ni

Group	Jasło	Krosno	Mielec	Przemyśl	RymZdr	Rzeszów	StalWola
child	6.87E-08	8.08E-08	5.32E-08	7.42E-08	3.41E-08	6.53E-08	8.21E-08
woman	3.92E-07	4.61E-07	3.04E-07	4.24E-07	1.95E-07	3.72E-07	4.69E-07
man	3.28E-07	3.86E-07	2.55E-07	3.55E-07	1.63E-07	3.12E-07	3.93E-07

Source: own study.

For lead, the obtained values are the highest among the analyzed metals. The range obtained for HQ is very wide, from $8{,}61 \cdot 10^{-5}$ to 1,13 for children, which means a higher value of HQ> 1, i.e. there is a risk of non-carcinogenic exposure (Table 18). For women and men, it is in the range $10^{-2} – 10^{-1}$.

The cancer risk by Pb was on safty level 10^{-8}-10^{-7} for all gorup (Table 19). For children higher level was observed in Jasło, Krosno and Stalowa Wola. The lowest risk values were calculated for Mielec.

Table 17
Non-carcinogenic risk values for Pb calculated for child, woman and man

Group	Value	Jasło	Krosno	Mielec	Przemyśl	RymZdr	Rzeszów	StalWola
child	min	2.53E-01	2.33E-01	2.35E-01	7.95E-08	8.61E-08	1.29E-07	2.60E-07
	max	1.13E+00	9.96E-01	4.44E-01	6.95E-01	5.97E-01	8.53E-01	9.66E-01
	mean	6.61E-01	5.24E-01	3.39E-01	3.26E-01	2.45E-01	3,63E-01	4.19E-01
woman	min	1.24E-01	1.14E-01	1.15E-01	7.72E-02	5.64E-02	7.48E-02	2.26E-01
	max	5.51E-01	4.87E-01	2.17E-01	3.40E-01	2.92E-01	4.17E-01	4.73E-01
	mean	3.23E-01	2.56E-01	1.66E-01	1.91E-01	1.48E-01	2.15E-01	3.08E-01
man	min	1.04E-01	9.56E-02	9.64E-02	6.46E-02	4.72E-02	6.27E-02	1.89E-01
	max	4.62E-01	4.08E-01	1.82E-01	2.85E-01	2.44E-01	3.49E-01	3.96E-01
	mean	2.71E-01	2.15E-01	1.39E-01	1.60E-01	1.24E-01	1.80E-01	2.58E-01

Source: own study.

The carcinogenic risk total calculated for all included in the scenarios metals is the probability of cancer in the entire life. For the analysis performed, it was in the acceptable range from 10^{-6} to 10^{-4} (Table 20).

Table 18
The value of carcinogenic risks posed by Pb

Group	Jasło	Krosno	Mielec	Przemyśl	RymZdr	Rzeszów	StalWola
child	4.87E-08	4.30E-08	1.92E-08	3.00E-08	2.58E-08	3.68E-08	4.17E-08
woman	2.78E-07	2.46E-07	1.09E-07	1.71E-07	1.47E-07	2.10E-07	2.38E-07
man	2.33E-07	2.06E-07	9.16E-08	1.44E-07	1.23E-07	1.76E-07	2.00E-07

Source: own study.

Table 19
The value of total carcinogenic risks

Group	Jasło	Krosno	Mielec	Przemyśl	RymZdr	Rzeszów	StalWola
child	1.71E-06	2.22E-06	7.47E-07	1.39E-06	8.87E-07	1.27E-06	1.29E-06
woman	9.75E-06	1.27E-05	4.26E-06	7.96E-06	5.07E-06	7.24E-06	7.37E-06
man	8.16E-06	1.06E-05	3.57E-06	6.66E-06	4.25E-06	6.06E-06	6.18E-06

Source: own study.

4. Conclusions

In this study was analyzed the variability of the content of selected heavy metals in PM10 dust in the Podkarpackie Voivodeship. The concentrations of PM 10 dust in the heating season and off the heating season in the analyzed period showe a significant difference between these periods. Off the heating season, a lower concentration of PM 10 makes the air less polluted and clearly indicates that heating houses has a direct impact on air pollution. These results are confirmed by the KOBIZE report (2019), which indicates the energy sector as one of the main sources of air pollution.

The analysis of As, Cd, Ni and Pb in PM 10 dust in the Podkarpackie Voivodeship in 2016-2021 showed a decreasing trend of maximum and average values for most of the analyzed cases. As, Ni and Pb did not exceed the target level defined in RME (2012). For Cd, the target level was exceeded for an average of 7 days, which increased exposure during this time.

The conducted analysis of health exposure to heavy metals in PM 10 dust showed that in one case indicates harmful effects on human health in Jasło in the scenario with the maximum average concentration. For the remaining cases, the HQ value was below 1, which means that there is no probability of negative health effects resulting from long-term exposure to analyses metals in PM 10.

The obtained HQ values for As are lower or comparable with the literature data.

The higher HQ values for As were obtained in the study by Liu, Shang and Wang (2018) examined metals in PM 2.5 dust in the Taiyuan suburb of China. The measured values for children and adults were – $1.42 \cdot 10^{-1}$. These studies also showed lower dermal exposure values and higher oral exposure values for children.

The performed CR assessment showed that the calculated values for the maximum average monthly doses of metal smell do not exceed the acceptable level of 10-4. Comparable values for As and higher for Pb and Ni were obtained Liu et al. (2018) and Trojanowska & Świetlik (2012). The cancer risk results for Ni for children were higher

that in study conducted by Rybak, Wróbel, Bihałowicz and Rogula-Kozłowska (2020), where estimeted the level of cancer risk in rang $5{,}2\cdot10^{-10}$–$1{,}1\cdot10^{-9}$ in Katowice and $4{,}1\cdot10^{-10}$ –$1{,}2\cdot10^{-9}$ in Wroclaw. On the other hand, the higher results in the studies for children, also in the streat road dust, in Lublin were obtained by Zglobicki and Terlecka (2021) – $1.8\cdot10^{-4}$ – $1.7\cdot10^{-4}$. The higher values were obtained for cadmium than those obtained for the cities of the Małopolskie Voivodeship in the study presented by Wieczorek et al. (2021).

Summaraizing was observed a positive trend of decreasing pollutant with PM10 dust and metals contained in them over the analyzed period, which is clearly illustrated by the data from the list of average monthly concentrations of PM 10 in the heating session and off the heating season. There was no clear relationship between declining air pollution and the impact of the lockdown in 2020 on these changes.

The health risk assessment performed showed no harmful exposure except one case and no cancer risk. It is worth noting that, the results of the risk assessment concern only 4 metals and only one inhalation route of exposure. For a full health risk assessment, consideration should be given to all components contained in PM 10 as well as other routes of exposure, e.g. through the dermal, water and food intake.

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"We know each other for so long and he's never gonna give you up" – review of persistent plastic particles as a big unknown in present environment's effect on human health

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Abstract: Scientific research confirmed occurrence of micro- and nanoscopic particles of synthetic polymers in almost every ecosystem worldwide. The omnipresence of plastic can be an enormous danger for human health. Based on the review of currently available scientific literature, the effect of micro- and nanoplastic on human health was assessed, taking into the consideration environmentally present substances that can interact with synthetic polymers. It was confirmed that there is a premise towards a theory of combined negative effects of plastic particles together with environmental pollutants on human health. The effect of synthetic polymers on human health is in the center of researchers' attention. There are lots of studies being conducted right now, with the aim to fully determine plastic's effect on human health. To achieve such a milestone, much more research is needed to be conducted.

Key words: microplastic, nanoplastic, environment, pollution.

1. Introduction

The creation of polymers, substances obtained by linking hundreds or thousands of small molecules together, should be awarded to nature itself. Natural predecessors of synthetic polymeric materials, also known as plastic, are the foundation of all life. A few can be named, like deoxyribonucleic acid (DNA) and ribonucleic acid (RNA). Humanity has discovered and made use of the natural polymers as materials since many centuries before Christ. At that time, ancient people started creating some basic items with the use of natural rubber or cellulose. For many years, those substances could not be properly categorized by alchemy, and later chemistry. Doctor Thomas Graham thought they were a unique organization of matter, which could not go through the finest filters, and named them "colloids" (American Chemical Society [ACS], 1993). Our understanding and use of natural polymers grew exponentially since the 19th century. Paired together with proper chemistry knowledge, inventors modified natural polymers to make entirely new materials. In 1839, Charles Goodyear designed a way to acquire a much more resistant rubber, than one known at that time, by mixing natural rubber with sulfur (Andrady, Neal, 2009). John Wesley Hyatt and Count Hilaire de Chardonnet equipped humanity with new materials, which used derivate of natural polymer found most commonly in plants – cellulose nitrate (ACS, 1993). However, these modifications did not stop there, as people really wanted to create their own material. In 1907, Leo Hendrik Baekeland made history with the invention of the first fully man-made polymer, the first plastic – Bakelite (ACS, 1993).

This milestone marked the creation of a new and booming industry, which grew big over the course of the century. Plastic began to be present in every area of day-to-day life – starting with clothes and packages, through appliances, to even cutlery and cosmetics. Even nowadays, many people use various items, not realizing that they are made of plastic.

Numerous types of new materials were synthesized, and many found an immense popularity in the industry. Humanity's dependence on plastic grew more and more over the years. In 2019, European demand for plastics was measured to be of 50.7 million tonnes. The most sought out plastic materials were polypropylene (PP), polyethylene (PE), polyvinyl chloride (PVC), and polystyrene (PS) (Andrady, Neal, 2009; PlasticsEurope, 2020).

Cumulatively, since 1950, people have produced about 10 billion tonnes of plastic, most of which were used in packaging, building and construction. However, this popularity led to a problem. Many of the synthetic polymers were designed to be resistant, but it also meant that they could withhold the effects of the environmental exposure for many years. In 2018, there were 359 million tonnes of plastic produced worldwide, from which only 21.3% (https://www.statista.com/topics/5401/global-plastic-waste/#dossierKeyfigures, accessed: 15.04.2022) were recycled. The unrecycled plastic items found their way into the natural environment, occupying our landfills and filling our oceans. As of 2018, The Great Pacific Garbage Patch was predicted to be about 79 thousand tonnes of plastic litter, which took up 1.6 million km^2 of area. Thanks to its resistance, plastic litter can occupy the environment for hundreds or even thousands of years. Presence of man-made polymers in these quantities can have a catastrophic effect on the ecosystem (Andrady, Neal, 2009; PlasticsEurope, 2020; Lebreton et al., 2018).

2. Microplastic

Aging processes are an effect of the environmental exposure to the plastic. They can be caused by the temperature, oxygen, air, water or sun radiation. Various types of synthetic materials have varying resistances when it comes to aging in the environment. Some, like polyethylene, are resistant to most, having one or two weaknesses. Others, like biodegradable polymers, are rather fragile and could not stand the elongated exposure to the natural environment. Aging processes cause plastic to deteriorate in their physical and chemical properties, which can variously affect the environment. Aforementioned polyvinyl chloride due to its aging loses its flexibility and gains brownish color, as it releases an important part of its structure, chlorine, in a form of highly corrosive HCl. On the surface of polyethylene, due to sun radiation, many free radicals can form, which can then interact with substances present in the environment or other plastic materials unpredictably. One of the more important effect of aging processes to plastic is its fragmentation, which leads to creation of small in diameter fragments called microplastic (Cole et al., 2011; Harvey, 2005).

Microplastics (MPs) are usually defined as bits of plastic, varying in size from 1μm to 5mm, while even smaller fragments are called nanoplastics (NPs) (Campanale, Massarelli et al., 2020). MPs can be divided into two categories, based on how plastic particles find their way into the environment. First, we have primary microplastic that is released to the environment in its tiny form. Polymeric pellets found in cosmetics are example of this type of MPs. Then we have secondary microplastic that consists of fragments of macroplastics, created through their aging. It has been estimated that the major sources of this type of MPs in the ecosystem are washing synthetic textiles and attrition of tires (Campanale et al., 2020; Friot, Boucher, 2017).

Due to irresponsible plastic waste management, macropolymers can be found in almost every ecosystem on the planet. As they take up a lot of area, they also are affected by the environment, which leads to releasing many micro- and nanoplastic particles. This

omnipresence of man-made pollutants is worrisome. They have been found in the soil, food, and water. The amounts of microplastic found in various sources were compiled in the Table 1 (Campanale et al., 2020; Cox et al., 2019).

Table 1
The amounts of microplastics found in various sources

Name	Amount of MPs found	Name	Amount of MPs found
Seafood	1.48 MPs/g	Alcohol	32.27 MPs/L
Sugar	0.44 MPs/g	Bottled water	94.37 MPs/L
Honey	0.10 MPs/g	Tap water	4.23 MPs/L
Salt	0.11 MPs/g	Air	9.80 MPs/m^3

Source: "Human Consumption of Microplastics", K.D. Cox, G.A. Covernton, H.L. Davies, J.F. Dower, F. Juanes, S.E. Dudas, 2019, *Environmental Science and Technology, 53*(12), pp. 7068-7074.

3. The accumulation of plastic particles in the environment

Depending on their size, MPs and NPs can find their way into the cells of living organisms. It has been confirmed that synthetic polymer fragments characterized by the diameter smaller than 1 μm, also known as submicron plastic particles, can be taken in by the cells much easier than their larger counterparts (Campanale et al., 2020). Process of such an uptake is called endocytosis and it can be divided into several mechanisms that allow entrance to various types of plastic fragments. Phagocytosis is one of those mechanisms. It is based on the "swallowing" of the nanoplastic by the cellular membrane. Phagocytosis is a way of entry for NPs and MPs larger than 500 nm. The biggest particles recorded to be uptaken were even 2.0 μm in diameter. Smaller micro- and nanoplastics enter the cell by the way of pinocytosis. This type of mechanism is mainly divided into macropinocytosis, clathrin-mediated and caveolin-dependent endocytosis. Macropinocytosis is quite similar to phagocytosis. Because of the surge of actin, cellular membrane ruffles, creating a sort of waves that engulf smaller nanoparticles and allow entrance into the cell. Clathrin-mediated and caveolin-dependent endocytosis are based on the reactions between receptors and NPs. Due to the binding process between them, cell react by releasing appropriate proteins that mediate the internalization of nanoparticles (Kik, Bukowska, Sicińska, 2020; Zhao, Stenzel, 2018).

These findings raised a concern among researchers across the globe, as such a firm presence of an anthropological pollutant in the environment can have highly adverse effects on humans. There are three main ways of entry for submicron polymer particles to the human body: by ingestion, inhaling or skin contact. It has been estimated that in a year, people are exposed to tens or even hundreds of thousands of particles of MPs. It is difficult to estimate the human exposure to NPs, as such an analysis falls outside of the scope of widely available technology, however Zhou et al. (2021) was able to perform quantitative analysis of polystyrene and poly(methyl methacrylate) NPs within bodies of aquatic animals with the use of pyrolysis gas chromatography paired with mass spectroscopy. The alkaline digestion and protein precipitation were used on the tissues of Zebra snail and Corbicula fluminea to extract nanoplastics, which were then characterized. In recent studies, microplastic particles of various polymers have been also estimated in human lungs, using micro-infrared spectroscopy, and blood, with the use of the aforementioned pyrolysis – gas chromatography paired with mass spectroscopy. This is the most worrying

fact, as it means that plastic particles of a sub-micro size have already infiltrated circulatory and respiratory systems of human beings. Although there are technological difficulties regarding the quantitative and qualitative analysis of MPs and NPs in the whole human body, it should be noted, that people may be filled to the brim with plastic particles and due to the current limitations of technology and knowledge, people may not even know it (Campanale et al., 2020; Cox et al., 2019; Jenner et al., 2022; Leslie et al., 2022).

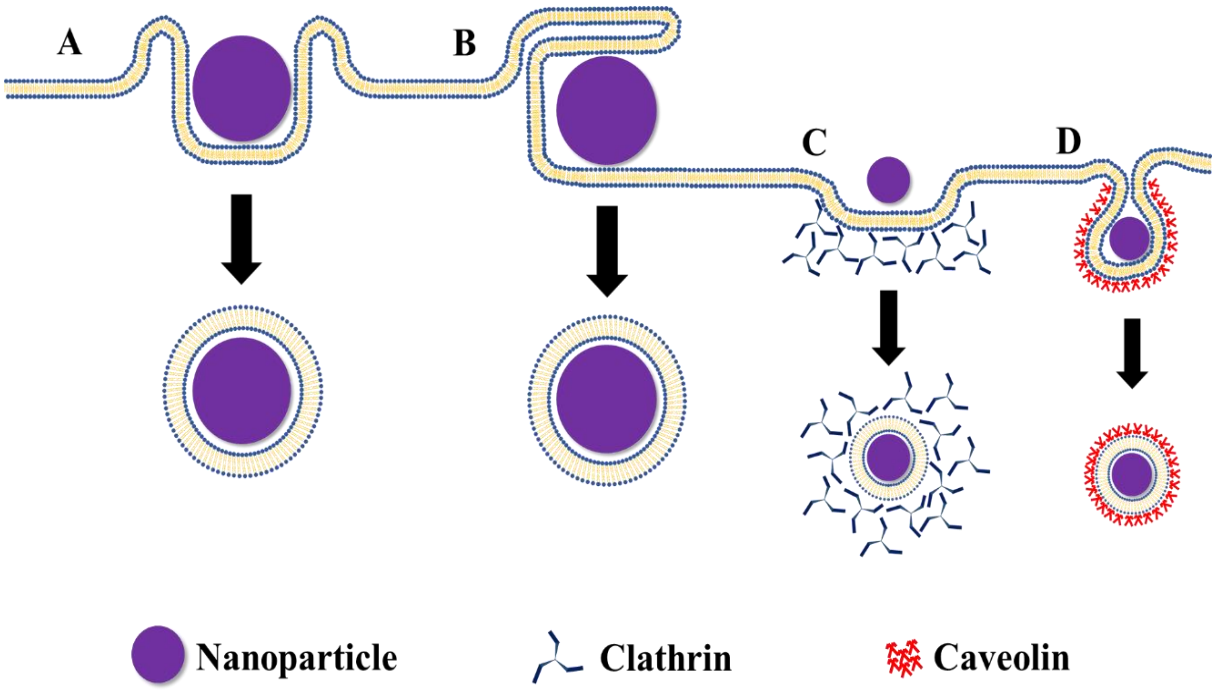

Figure 5. Imagining of possible endocytosis pathways of nanoparticles.
(A) Phagocytosis; (B) Macropinocytosis; (C) Clathrin-mediated endocytosis; (D) Caveolin-dependent endocytosis.
Source: own work based on "Entry of nanoparticles into cells: The importance of nanoparticle properties", J. Zhao, M.H. Stenzel, 2018, *Polymer Chemistry*, *9*(3), pp. 259-272.

4. Effects of the submicron polymer particles

The types of the effects that micro- and nanoplastics can have on the environment are divided into physical, caused by the size and amount of present plastic particles, and chemical, accounting for all substances that MPs and NPs can mobilize (Campanale et al., 2020).

4.1. Physical effects

The areas most exposed to this type of negative effects of micro- and nanoplastic are seas and oceans, as there the accumulation of these particles is strong. However due to the plastic pollution worldwide, every ecosystem is exposed to the aggregation of MPs and NPs. Because of their size and weight, plastic particles can either float on the water surface or drown. Lighter polymer fragments could fall victim to severe sun radiation, microorganisms, or physical damaging. These processes can lead to an engrossment in the particles' weight, causing them to migrate into the lower sea levels. There, they can accumulate in the seabed or penetrate the food chain, as aquatic animals mistake them for plankton. Microplastic of bigger sizes can be disposed with animals' excrement, which could

allow plastic exposure for reducents. Smaller polymer particles can accumulate in organs of aquatic animals, while plastic fragments of submicron size can even penetrate cells. On the land, similar processes can take place. Plants growing in the soil polluted with plastic accumulate smaller polymer fragments in their cells, which then are eaten by the livestock. The animals can also accumulate high amounts of micro- and nanoplastics in their bodies before they are consumed by those above them in the food chain. Humans may be the most exposed to the plastic accumulation in their organism. As omnivores and being a top of the food chain, it means that people have to bear the effects of MPs and NPs till the rest of their life (Alimi et al., 2018; Cole et al., 2011; Ebere, Wirknor et al., 2019; Song et al., 2019).

In the body of living organism, submicron polymer particles can have an adverse effect on cellular level. Studies have shown that the strength of negative consequences of micro- and nanoplastic accumulation can vary due to the shape, size, and type of nanoplastic that entered the cell. Many studies have been conducted in both animal and human cell trials. As investigated by researchers, the polystyrene nanoplastics can have a horrifying, genotoxic, mutagenic, and cytotoxic effect on the cells of the aquatic animals. Liu et al. (2021) confirmed the occurrence of changes to 208 genes of Daphnia pulex due to PS NPs exposure for 96h. This induced the oxidative stress and changed the immune defense and glycometabolism. Similar results were acquired by Guimarães et al. (2021). They exposed the fingerlings of Ctenopharyngodon idella with polystyrene nanoparticles for 20 days. This was enough to cause oxidative stress, DNA damage, erythrocyte damage and inhibit proper function of antioxidant system. It was also confirmed that the higher concentration of NPs, the bigger its effects were. As it comes to human cell trails, as reported by Busch et al. (2021), PVC particles of about 1μm in diameter, while exposed to the triple culture model, mimicking human intestine, incited a release of cytokine protein 1L-1β and caused a loss of epithelial cells. Such findings were confirmed and investigated more deeply by Weber et al. (2022). They exposed human monocytes and monocyte-derived dendritic cells to polyvinyl chloride nanoplastic of various sizes, shapes, and concentrations, which affected the release of cytokine.

4.2. Chemical effect

One of the advantages of plastic is its ability to change the properties of the material due to presence of various additives. With the right amount of substances and correct way of synthesis, the perfect polymer material for any type of need can be achieved. These types of additives include dyes, plasticizers, antioxidants, heat stabilizers and slip agents. Over the course of a century, many different substances have found use as an addition to the synthetic polymer materials, like bisphenol A or phthalates. However, due to the developments in technology and overall knowledge, many of these additives were marked to be too dangerous for human health and were changed out in the production for safer alternatives. This does not mean unfortunately that plastic particles containing these dangerous substances disappeared over night, as many of them found their way into the landfills or oceans, where they leach out these harmful chemicals. It should also be stated that these safer alternatives to the additives in plastic can also be harmful when their concentration is increased, e.g. during the accumulation of MPs and NPs containing them (Campanale et al., 2020; Cole et al., 2011; Hahladakis et al., 2018).

Leaching of the chemicals contained in the submicron polymer particles is only the tip of the iceberg. Studies shown that small plastic fragments can adsorb many substances present in the environment before they find their way into the living cell. As many natural compounds may not be harmful, in the ecosystem there are many anthropological pollutants that can find their way into the human body and accumulate there. The surface charge of plastic particles has a great effect on the adsorption rate of substances on their area. While producing synthetic polymer materials, many additives can change the whole surface of the product, by incorporating additional function groups to it. To fully represent the plethora of plastic that can interact with human body, corporations producing lab-quality plastic nanoparticles, to be used in experiments, sell their products nonfunctionalized, pristine, and functionalized with amine, carboxyl, sulfate and hydroxyl groups, to name the few (https://www.polysciences.com/default/catalog-products/microparticles-particles/polystyrene-microspheres, accessed: 15.04.2022).

Because of their hydrophobic nature, micro- and nanoplastics have an affinity to adsorb organic pollutants on their surface. This is a worrying tendency, as such substances are characterized by higher toxicity, than their inorganic counterparts, and have a trend to be accumulated into the fat tissues when the human body is exposed to them. As explored by Bakir, Rowland, Thompson (2014), PVC and PE microparticles can adsorb on their surface many harmful compounds, like perfluorooctanoic acid or di-2-ethylhexyl phthalate. They have also investigated the desorption rate of these substances in the gut and in the nature. Human intestines are coated with the natural surfactant, which unfortunately speeds up the release of harmful organic pollutants into the body. Higher toxicity of microplastic with adsorbed compounds was also reported by Rubin, Zucker (2022). They have checked the interactions between PS MPs and triclosan. It was confirmed that the surface charge affected the concentration of adsorbed substance greatly and "polluted" microplastic expressed much higher toxicity, while the human cell cultures were exposed to it. However, the surface charge is not the only thing affecting the adsorption process. Ma et al. (2019) investigated how the size of NPs affects adsorption of triclosan on polyvinyl chloride. As it turns out, the smaller the plastic particles are, the stronger adsorption capacity was. Authors stated it may be the effect of higher specific surface area and stronger hydrophobicity. These findings create a distress, as it could mean that smaller plastic particles, which can infiltrate the human body with an ease, could be riddled with a high concentration of organic pollutants.

Antibiotics should be highlighted among the trace organic compounds that can adsorb on the surface of micro- and nanoplastic. Due to the widespread usage of these types of medicine and not appropriate disposing of them, many of the over-the-counter antibiotics have been found in the ecosystem. They can negatively affect the environment on their own, however, gaining mobility by adsorption on MPs and NPs creates a whole additional problem. A few of the scientific authors claim that the microplastic present in soil and water can actually contribute to the antibiotic resistance of microbiome. Such a situation is highly dangerous, as it might lead to the creation of a viral "super bacteria", resistant to every antibiotic that is currently known to humanity, which can lead to a grim scenario (Guo, Wang, 2019; Laganà et al., 2019; Li, Zhang, Zhang, 2018; Ma, Sheng, O'Connor, 2020; Moore, Millar, Moore, 2020; Polianciuc et al., 2020; Yang et al., 2019).

Organic compounds are not the only pollutants that can be adsorbed on the surface of micro- and nanoplastics. Heavy metal ions can also be mobilized by submicron polymer particles in the environment. Although their adsorption is quite marginal with fresh MPs and NPs, the aging processes of these plastic fragments can enhance adhesion of heavy metal ions to them. In small doses those ions may not be harmful, that in a higher doses an prolongated exposure to them could lead to many diseases (Campanale et al., 2020; Guo, Wang, 2019; Yang et al., 2019).

As it was mentioned before, microplastics can interact with microorganisms. Thus, many species of said microbiome can also be mobilized by the MPs and NPs in the natural environment. Stated by Richter et al. (2021) bacteriophages can travel on the polypropylene labware. This may not only affect the conducted research, but is a base to believe that microbiome around the world can be negatively affected by the omnipresence of micro- and nanoplastics (Dussud et al., 2018).

The effects of the MPs and NPs are multi-faceted. Much of the research presented in this article was performed under the model conditions, which are not like conditions of the current world. Many various trends of plastic behavior in the environment were described, however it is still not enough to state with certainty just how much damage to the human health plastic particles can cause or is causing right now. To start with pollution, the natural environment is bridled with synthetic waste that is destroying natural landscapes and is filling our oceans and seas. Micro- and nanoplastic cause many of the beloved and endangered species of the animals to bear many, many diseases. And to end it all, plastic can even cause changes on the cellular levels, not only to the wildlife, but to people too. Every single part of human life is affected or dependent on plastic and it looks like it's not going to change soon.

5. Conclusions

Recent findings regarding the plastic effects on the environment and human health are worrisome, to say the least. The raging problem considering the high production numbers and low recycling numbers of synthetic polymer waste is not about to be resolved in one day. However, every day billions of microplastics and nanoplastics are released into the environment. Additionally, humans are exposed to many of them every single day. The omnipresence and uncertainty of it all makes it so dangerous as it is. There are still technological limitations to the types of the analysis that are needed to be conducted in order to full assess micro- and nanoplastics. With the current knowledge, one of the most talked hypothesis among the researchers is that submicron polymer particles react jointly with substances contained within them and on their surface on the cell, causing much damage. The need for more research is evident as many of the presented articles are still a model trials. In the real environment, we can never be sure what can attach to the plastic particles and what can gain mobility into our bodies.

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Heat transfer phenomena on the propulsion system and solar panels' working parameters

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Abstract: The solar PV systems are becoming increasingly abundant, prominent and as their demand grows, the requirement for an even more efficient and higher output solar PV panels is also increasing. While the efficiency of the solar PVs depends on the specific design/materials of the PVs themselves, it is also influenced by the external factors of incident sunlight, temperature, humidity etc. and internal factors like heat transfer due to the propeller motor getting heated up, inside the solar PV circuit and its controller, due to the flow of higher values of current, short circuit etc. This can in turn have a significant effect on the solar panels' working parameters and the performance of the propulsion system of solar powered boats. Hence, the internal heat transfer needs to be measured and its effects analyzed so that there is a better understanding of how the output performance of the solar PVs is getting affected, especially when they are being used to power vehicles, boats etc. and the efficiency of the solar PVs is of utmost importance. Thus, improvements and modifications can be implemented to obtain the best results.

Key words: heat transfer, PV panels, propulsion system, solar parameters, KLS (solar PV controller), MPP, MPPT (Maximum Power Point Tracking, used to refer to individual panels with their inverters).

1. Introduction

The ever-increasing push to switch to clean energy and sustainable mobility has driven not only the automotive industry but also the maritime industry to explore powering ships/boats with renewable sources including solar energy. Several small-to medium scale boats, yachts etc. have been tested to run using only solar energy and will prove to be a promising alternative since the development in solar PV cells has also advanced significantly.

This paper approaches the heat transfer phenomena on the propulsion system of a solar- powered boat and the study of its various parameters including its effects on the engine, the motor, and the performance of the boat. The boat, designed by the "PWr Solar Boat Team", is eco-friendly since it is powered using solar PV panels rather than a conventional diesel-engine and does not pollute the air or the river(s).

Temperature affects the working parameters of the solar PVs. If there is a reverse current of a certain value in the from the solar controller, shaded cells in the panel will not be in reverse-biased mode, also causing the bypass diode to not conduct and hence rendering permanent hotspot damage to the cell(s). Also with a higher temperature, the parameter which gets affected is the open-circuit voltage Voc, causing it to decrease.

The MPP (Maximum Power Point) in a graph of current vs voltage.

There needs to be an optimal value of Isc and Voc to obtain the best MPPs.

- At an array temperature of 25°C, we can observe the highest MPP.
- At 50°C, the Voc is reduced and hence MPP is shifted.
- Similarly at 75ºC, the Voc is reduced further and the MPP again shifts backwards.

From research, it is known that the solar PVs perform best at low temperatures and lose their efficiency at higher temperatures. While most of the light shining on the surface of the panels is converted to heat. It is necessary to ensure that the solar panels are working at an optimal operating temperature which involves using such panels with the right material, that is adapted to higher temperatures as well as cooling down the panels. While this is due to the external factor of sunlight, the solar panels can also get heated internally either due to internal heat transfer or high values of current, short circuit etc. The internal heat transfer in our case is primarily from the following factors:

1. Propeller motor which gets heated up as it is continuously working.
2. The KLS (Solar PV controller), which is responsible for charging and regulating the voltages and current from the panels going to the batteries and can get heated up.

Both the above components have shown to impact the values of the observed respective temperatures and hence the circuit (battery) voltages and currents.

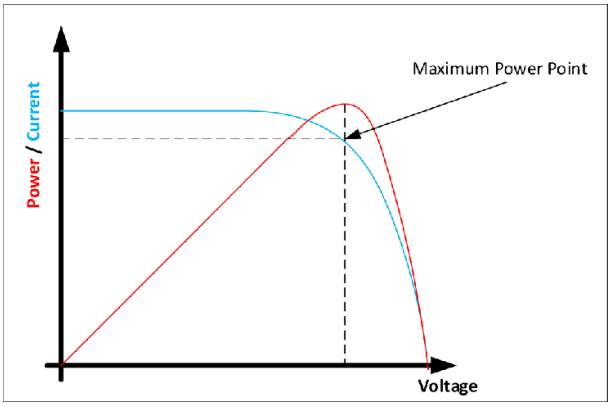

Figure 1. PV Current vs PV voltage graph for MPP.
Source: "Providing Primary Frequency Response from Photovoltaic Power Plants – Scientific Figure" on ResearchGate. Retrieved from: https://www.researchgate.net/figure/Maximum-power-point-of-a-PV array_fig2_328686167 (accessed: 16.04.2022).

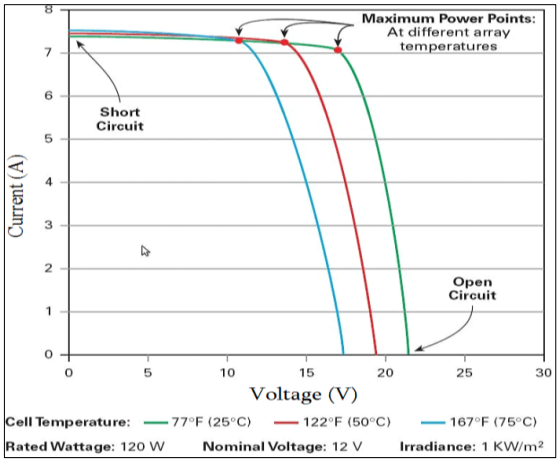

Figure 2. Maximum Power Point: a – determination of MPP; b – MPP depending on the temperature of a PV panel.
Source: "Study of Load Characteristics of Various Types of Silicon PV Panels for Sustainable Energy Efficient Road Pavement – Scientific Figure" on ResearchGate. Retrieved from: https://www.researchgate.net/figure/Maximum-Power-Point-a-determination-of-MPP-b-MPP-depending-on-the-temperature-of-a-PV_fig2_335914078 (accessed: 16.04.2022).

2. Research problem and method

Data of various working parameters of the solar panels was collected during the official test run of our boat on the Odra River, and useful results were obtained which helped to improve the solar boat's performance for future solar-boat racing competitions, including in the Netherlands. Furthermore, recently further data was collected after some basic tests to analyze the performance and efficiency of the "solar boat".

In the initial tests, basically three PV panels, named MPPT1, MPPT2, MPPT3 were used, and they were connected in series, to form a single PV circuit (string). The testing time for the circuit was about 3 hours. The sum of the energies for the 3 MPPTs is 75.52Wh.

- From the measured values of Power and Energy for the MPPTs, we can observe that the MPPT4 has the highest total energy output i.e., 45.58Wh, with an average energy of (5.74E-04) Wh and average power being 23.04W.
- The second highest output is from MPPT3, with the sum of energy being 29.89Wh, while having an average energy of (3.76E-04) Wh, and the average power being 26.6W.
- The least measured energy output is from the MPPT1, having sum of energy of 0.04Wh, and average energy of (4.566E-07) Wh, and average power equal to (3.15E-03) W.

The max power output of MPPT4 was 31.87W, for MPPT1 0.43W and for MPPT3 36.48W.

The material used during the manufacturing of the motor has a low coefficient of heat conduction. That is why there were some issues reading the temperature from the motor and hence some of the values are not reliable. Higher currents flow as the rotating speed of the propeller is increased.

3. Observations from the test data collected during the boat's launch

The solar controller (KLS) for the MPPTs was previously installed in a wooden box (insulator) without a cover for the boat. The heat exchange that took place happened only through the dissipation of heat to the environment through the metal surface of the KLS housing, which depends on the heat conduction coefficient, characteristic for a given material. One of the photovoltaic panels was above the KLS and there was a gap between the PV panel and the box containing the KLS.

Despite the gap, the airflow may not be sufficient to compensate for the heat removal. Therefore, in the new box – Power Box, fans were provided (fans 49.27 m^3/h), whose task was to provide ventilation, and a specially designed outlet from the fans designed to create turbulent air flow, because the turbulent flow facilitates the heat exchange. The heat dissipated therefore, to a great extent can be assumed to be roughly equal to the power loss on KLS. Therefore, to measure the efficiency of the panel, an increase in current should match an increase in temperature.

Moreover, the heat generated by electrical equipment is typically undesirable. Although we would expect the transformation into mechanical energy, it is the outcome of the transition of electrical energy into heat energy as losses. Heat generation is a concern at larger currents (which is why transformers are used on high-voltage lines) – in power plants, an extremely high current is generated; to avoid transmission losses, a transformer

is used to increase the voltage, lowering the current. The current acts as a heat producer in this situation. The temperature causes the conductors' electrical conductivity to decrease, resulting in a deterioration in the quality of the power delivered, represented as an excessive voltage drop.

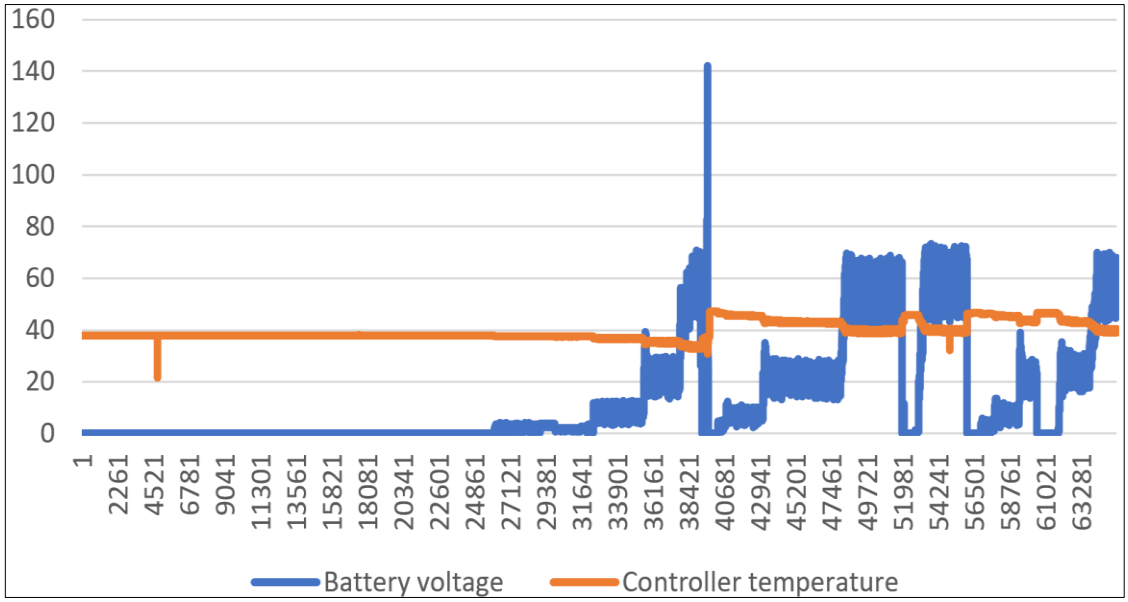

Figure 3. Battery voltage vs KLS controller temperature.
Source: own study.

The above figure 3. indicates the relation between the battery voltages and the KLS controller temperature, we can observe that there is a sudden spike in the values of the voltage, 141.7V, and till that point the controller temperature is constant, however after this point the temperature values rises to about 47.2°C, and then generally stays constant, decreasing to 45.2°C and then around 44,43°C.

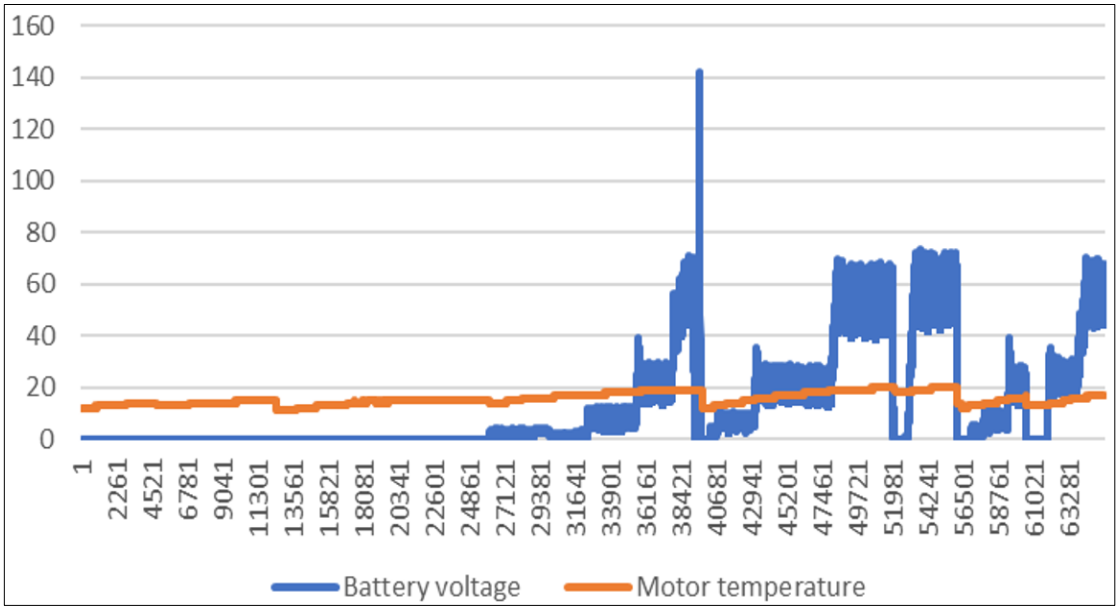

Figure 4. Battery Voltage vs Motor temperature.
Source: own study.

The above figure 4. indicates the relation between the battery voltage and motor temperature, we can observe that the motor temperature remains constant at a value below 20°C. At the point where there is a sudden spike in the battery voltage, the motor temperature rises to 20°C and then starts to drop again to about 17°C, increasing gradually to 20°C when there are similar spikes of about 70,75V in the battery voltage.

The above figure 5. presents the relation between both current and motor temperature and as a result it indicates that the motor temperature remains stable around 10-20°C, and current shows a sudden spike of 3000mA (this is attributed to the sudden pressing of the engine throttle) and reaches a peak point, suddenly drops to 100mA and gradually increases to 250mA. Furthermore, current also shows ascend and descend. Proportional to the acceleration and deceleration of the solar boat. Since the boat propeller is submerged and this is a possible reason for not observing the frequent changing of the motor temperature.

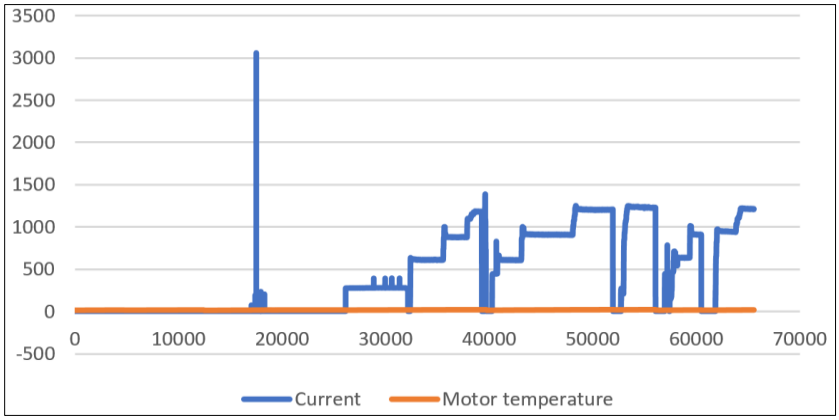

Figure 5. Current vs Motor temperature.
Source: own study.

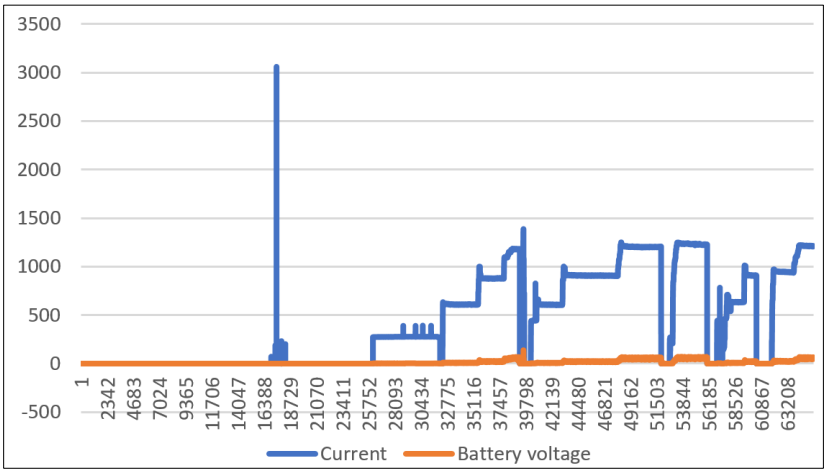

Figure 6. Current vs Battery voltage.
Source: own study.

The results in figure 6. indicates the relation between both current and motor temperature. Moreover, there is a sudden current spike at 3000mA, but the battery voltage remains stable, it then starts fluctuating around 1000mA and reaches a peak value at the current spike of 1900mA. Furthermore, it shows slight ascending and descending afterwards. The current shows related results as shown in Figure 5.

4. Conclusions

As a result of the study showed us that both control and motor temperatures are generally stable. For the controller temperature we can observe that it starts to increase when there are fluctuations in battery voltage, reaches the value of 42°C degrees, and it generally remains constant around 40-41°C if there are any changes in the voltages. But this can affect the Voc, causing it to decrease and hence resulting in a lower MPP, which will reduce our boat's efficiency.

In terms of motor temperature, it does not reach any significantly high level. Overall, it remains at the same value. The material used for motor construction has a low coefficient of heat conduction and due to this reason, we are not able to measure the temperature values accurately. Motor needs to be replaced with the one that has a higher coefficient of thermal conductivity.

To maintain the optimal KLS (controller) temperature, we can easily integrate a better heat-sink and more powerful fans to have an improved cooling of the KLS.

We analyzed and presented results for heat transfer phenomena on the propulsion system and solar panels' working parameters. Based on observation of the analysis, we can conclude that the propulsion system and the solar PV's working parameters get affected by the heat transfer phenomena. As we have observed, the battery voltage and current have slight fluctuations due to these factors. Although, the external factor of the solar arrays heating up and then resulting in a decrease in Voc and MPP is significantly higher than the impact from heat transfer.

To sum up, if we consider all the determined results presented in the figures this will help in designing better solar PV controllers and propeller motors which will have a great impact on improving the efficiency of solar boats.

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Section II

Intelligent IT and mechatronic solutions as a guarantee of reliability and safety of systems of means of transport and logistics

Software encryption as a smart low-cost method prevention against cyber attack in automotive embedded systems

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Abstract: This paper focuses on identifying potential threats of attacks on embedded systems in automotive vehicles using an additional intruder module. The main objective of the article is to show that cyberattacks can lead to taking control of an electronic control module in a vehicle. In addition, considering the specifics of the automotive industry and the associated extensive cost savings in manufacturing, a simple low-cost method for protecting data from certain type of attacks during transmission on the CAN bus is proposed.

Key words: automotive, cybersecurity, embedded systems, encryption.

1. Introduction

Nowadays, all motor vehicles are complex mechatronics constructions, controlled by multiple electronic control units (ECUs) that work together via bus communication. Dozens of ECUs which are connected to each other via bus systems are responsible for providing functionality. For better equipped versions of cars, the number of electronic control units is close to one hundred and sometimes even bigger. The security of the information transmitted on the bus between the individual modules is an important aspect of embedded system design. Often, for modules that do not have a direct impact on vehicle safety, production costs determine the abandonment of popular integrated circuits with hardware encryption. In the automotive industry, where product volumes are counted in millions of components, the price of a single microprocessor is critical. Even a few euro cents of savings on a single cheaper part equates to millions of euros of savings for a company. The very rapid development of electric cars is an additional trigger to look for new methods of ensuring the security of data collected in systems. Methods that will not allow to eavesdrop the data, use it to destabilize the vehicle or even to seize control over it. The priority should be to verify that there is definitely no possibility to take control of any embedded system used in the car. The main objective of this article is to identify potential threats in embedded systems used in automotive applications, verify during the experiment that the possibility of their occurrence exists and to find low-cost solutions to prevent them without significantly increasing production costs.

2. Research problem and research method

An electric vehicle, commercially available in Poland, was used for the tests. The subject of the experiment was to investigate the possibility of driving the signal contained in the CAN frame, i.e., destabilisation of vehicle behaviour or taking control over the tested electronic executive module in the vehicle.

In a motor vehicle, the safety-critical systems are undoubtedly the electronic control modules: braking, turning or acceleration. Therefore, the electronic module subjected to attacks was the steering controller of the electric vehicle under study. The control module of the steering system that was tested is connected to the CAN bus, so the tests started by logging the traffic on the corresponding bus and performing a frame analysis.

In automotive CAN bus transmission systems, dedicated End To End protection (E2E) mechanism is used, especially for signals of safety relevant features. The protocol allows detection transmission errors, but was not designed for encryption. It is therefore unable to protect data transmission from attack. When using End To End Protection protocol, 16 key values have to be known. As the functionality of turning the steering wheel is considered to be significant from the security point of view, it was expected to be necessary to find hidden key values with reverse engineering algorithm. After the analysis of the recorded frames, it was shown that E2E is not implemented in the tested vehicle to support the transmission of this module, which significantly reduces the security level in terms of the physical layer of transmission. In other words, it seemed possible to replay the sequence of frames that were logged, without changing the byte values of the original frame sent by the vehicle.

A professional MicroDAQ E2000 device, which has built-in CAN FD bus interfaces, Ethernet communication, and 128 MB of EEPROM memory, was employed to conduct the tests. The non-volatile memory was for storing the recorded transmission frames. Ethernet bus transmission was provided to communication with the device, and a shared memory mechanism was incorporated to eliminate possible transmission delays. This device is also characterized by very fast signal processing time – it can transmit a full 64-byte CAN FD frame along with checksum calculation from the data field for End To End Protection mechanism in less than 1 millisecond. Therefore, it can be concluded that it is capable of being transparent to the vehicle communication system.

The experiment focused on the following two types of attacks:

A. replaying of pre-recorded control information:

The experiment began with recording the transmission of the frames responsible for controlling the steering module. While driving with the lane assist function active, the centre line of the carriageway separating the 2 lanes was crossed several times. With the lane assist function active, the car responded immediately by turning the steering wheel so that the car returned to the correct lane. The frames that appeared on the CAN bus when the described scenario occurred were logged to a file using the test device. The acquired scenarios generated and recorded while using the lane assistant function were used in a further stage of the work.

The tests were performed using two different module architectures of the CAN bus. Figure 1 shows an intruder module connected in parallel to the bus using only one CAN interface. In this case, it is possible to receive frames transmitted on the bus and to send defined frames on the bus. However, it is not possible to replace the frame content or to block the original frame sent by the vehicle.

Figure 2 shows the intruder module connected serially to the bus, i.e. operating in the bridge mode, forwarding frames from one side to the other via two CAN interfaces. In this case, full functionality is available, understood as receiving frames, sending defined frames on the bus, exchanging the contents of frames and blocking frames.

The recorded transmission in the form of CAN frame was reconstructed by sending the stored frames on the CAN bus in the original order and maintaining the time intervals between subsequent frames.

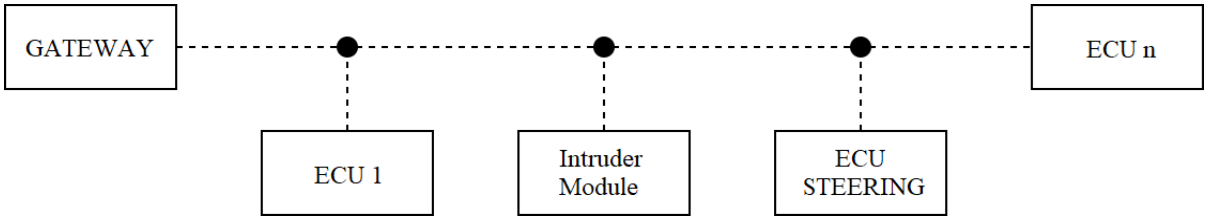

Figure 1. Architecture of electronic control units under the attack without blocking original car frames for steering.
Source: own study.

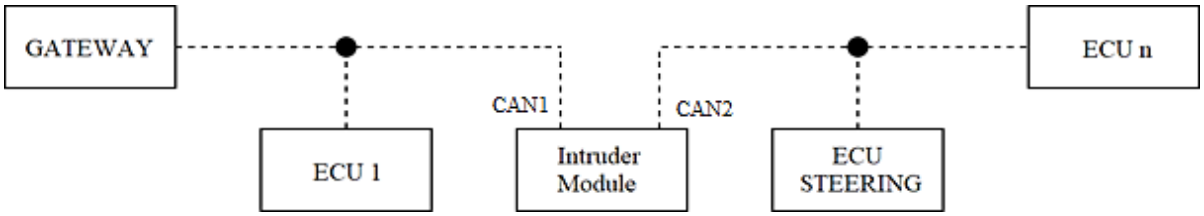

Figure 2. Architecture of electronic control units under the attack with blocking original car frames for steering.
Source: own study.

B. brute force attack:

In this case, the architecture shown in Figure 1 was used. An additional intruder module sent all subsequent combinations of signal values to the control module. Using a reverse-engineering method, the effect of the transmitted byte values on the circuit response was analysed in detail. It was found that although the frame length is 24 bytes, the control information is transmitted on a maximum of 4 bytes. Therefore, to limit the number of possible combinations in the "brute force" test, the generated data was limited to only 4 bytes of the frame.

Even after adopting the simplification of generating 4-byte combinations of messages sent during the attack, the time required for the test, which would be counted in years, could not be accepted as too large. The control frames are sent every 20 milliseconds, which gives a time required for a full test of about 3 years. Time = (2^32)/50 = 85,899,345.92 seconds = 994 days Therefore, another simplification was applied, generating all possible combinations for 2 bytes instead of 4, which reduced the test time to about 30 minutes, including the time needed for automatic car error clearing using the OBD (On-board Diagnostics) connector. The remaining 2 bytes were filled with values according to the applied test case, shown in Table 1.

Each of the four test cases presented above was run and executed completely independently, under the same conditions from the point of view of the attacking intruder module. As for the test conditions of communication via the vehicle CAN bus, unfortunately they are different in each case due to the current state of the vehicle and small-time differences resulting from momentary delays in the processed signals.

3. Results

In both stages of the test cases, i.e. when replaying pre-recorded scenarios obtained by activating the lane assist system or using the brute force method and then sending them to the bus in the form of CAN frame, it was possible to destabilise the vehicle and, in some cases, temporarily take control of the steering wheel control module.

Table 1
Test cases description for brute force attack

Test case	Byte 1	Byte 2	Byte 3	Byte 4
1	generated B1	generated B2	generated B1	generated B2
2	generated B1	generated B2	generated B2	generated B1
3	generated B1	generated B2	negated bits of generated B1	negated bits of generated B2
4	generated B1	generated B2	negated bits of generated B2	negated bits of generated B1

Source: own study.

In the case of replaying pre-recorded CAN frames, i.e. sending them to the CAN bus in the same order and time intervals using the architecture shown in Figure 1, it was possible to turn the steering wheel in the same way as it happened during the pre-recorded scenario. However, every approx. 1 second, the smooth movement of the steering wheel was interrupted, even by a gentle jerk. The steering wheel movement was then continued. The described fact of interrupting the smooth steering has to do with the fact that, in the tested vehicle, when lane assist is not active, the CAN frame responsible for steering wheel is sent cyclically every 1 second. Thus, during the playback of the recorded scenario, the control module receives every 1 second the original message from the vehicle to remain at rest. Unfortunately, it is not possible to block the original message, which is due to the architecture of the test system under study.

When replaying pre-recorded CAN frames, i.e. sending them on the CAN bus with the order and time intervals using the architecture shown in Figure 2, it was possible to turn the steering wheel in the same way as during the pre-recorded scenario. As in the previous case, there was a destabilization of the steering wheel movement every approximately 1 second. However, in this case, thanks to the adopted architecture of the test system and 2 independent interfaces of the CAN bus, it was possible to introduce a lock of the original frame sent every 1 second by the vehicle. It was simply not transmitted to the other side of the bridge. Then, when the test cases were repeated, it was possible to reproduce the steering wheel turning smoothly, exactly as it was recorded during the active lane assist system.

In the case of a brute force attack, i.e. generating all possible combinations of ones and zeros on 2 bytes and duplicating them explicitly or negatively on another 2 control bytes, it was sometimes possible to move the steering wheel. However, it was not a smooth movement, but a slight, gentle vibration. Unfortunately, the vehicle often entered the error state, and it was necessary to perform the procedure of clearing the errors from the tested module thanks to OBD connector. The module error clearing procedure itself is not time-consuming, but considering the number of attempts necessary to perform during this experiment, it apparently prolonged the time needed for testing.

4. Conclusions

Analysing the collected signals transmitted over the CAN bus, it should be concluded that it is necessary to use additional protection against the possibility of substitution of transmitted data. Two types of attacks were carried out, each of them proved to be so effective that it was possible in some cases to destabilize the operation of the vehicle, and even to take control over the functionality of turning the vehicle. It should be mentioned here that it is one of the key functionalities responsible for security in the vehicle.

When playing back pre-recorded scenarios, it was possible to take control of the steering wheel control module each time. It was not always a perfect, full reproduction of the recorded situation, but it was possible to turn the steering wheel every time. The problem was the original CAN frames generated by the vehicle destabilized the scenario playback process for a very short period of time. Importantly, it was still possible to maintain an active takeover of control of the module. To take control and play the scenarios uninterrupted, it was necessary to use an intruder module device connected to the bus in bridge mode, shown in Figure 2, which was able to isolate the original frames from the vehicle and lock them in such a way that they are not visible to the steering wheel turning executive module.

The simplest way to take control of a vehicle is to listen to the messages sent over the bus in certain situations, record them, and then send them to destabilize the vehicle. In the experiment conducted, a lane assist was used to obtain the turning control sequence. However, this is not the only possible functionality that can be attempted to attack and take control over in this way. The exactly same mechanism can be used to investigate the autonomous braking of a vehicle equipped with active radar. Then, when approaching an obstacle, the activity can be recorded on the CAN bus at the moment the vehicle starts braking. The additional complication should be expected in the form of transmission protection using the End To End Protection mechanism. This generates the need to recalculate the CRC checksum after changing the value of the data bytes in the CAN frame. Additionally, to be able to calculate the checksum value, it is necessary to know the values of the 16 keys used in the algorithm. These keys are stored in the non-volatile memory of each electronic control module that uses E2E.

However, it is possible to generate these keys from a sufficient number of stored logs and process them in a reverse engineering algorithm, described by Gajdzik, Sternal, Timofiejczuk, Przystałka (2021), because the algorithm for calculating the CRC is public. To secure electronic modules against replay attacks, it is necessary to add an element of the so-called freshness factor. In the process of securing data transmission, it is responsible for the fact that a given command is active only within a certain time window. With this approach, registering a signal on the bus with a life cycle of 1 second will prevent the same electronic module from being controlled by replaying the registered sequence on the bus after that time has elapsed.

In the case of brute force attacks, where all possible combinations of bit values are generated and sent, the only way to fully prevent them is to operate an error counter mechanism. It determines how many times an incorrect or forbidden signal value can be sent before the transmission is blocked for a certain time. Such solutions have been known for a long time among PC users, but it is not possible to implement them in the car industry. This is since these are real-time systems, which always, in every situation, must control

the work of assigned elements and communicate with the rest of the system. Attacks of this type are relatively easy to detect and often generate errors in modules, which significantly hinders their destructive action.

In conclusion, based on the conducted research and obtained results, it is possible to conclude that it is possible to protect data transmission against attacks such as playback of pre--recorded frames on the CAN bus. For effective protection, it is necessary to use an encryption mechanism combined with the so-called freshness factor, a value that will vary over time.

Considering the factors that are important in the automotive industry or the special emphasis on the lowest possible production cost, a relatively simple encryption method that does not need much computing power should be used. Table 2 shows the proposed elementary encryption algorithm, which involves negation of bits in each byte of the transmitted frame for which the corresponding key bits have a logical value of 1. The value of the 8-bit key is stored in the non-volatile memory of each ECU connected to the CAN bus. The same bit negation process is then repeated for the freshness factor value, also called the time window in which the value is valid.

Table 2
Example application of the proposed encryption

Value	Hexadecimal value	Binary value
original byte	0x7D	01111101
key (mask for negation)	0xC3	**11**000**11**
encrypted byte – step 1	0xBE	10111110
time window	0xF1	**1111**000**1**
final encrypted byte	**0x4F**	01001111

Source: own study.

In the future, attention should be paid to the development of the proposed solution to higher layers of the vehicle system, whereby in means of a special supervisor module and using artificial intelligence methods it will be possible to recognize this type of attacks. Of course, then the requirement of low cost will not be met, but it should be noted that it is not necessary to implement such a bus supervisor for each module, just one with several CAN interfaces for the entire system.

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Review of performance indicators used in transport and forwarding companies

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Abstract: Companies providing transportation services use performance indicators and measures to verify their performance levels of quality. There are many examples of transportation process efficiency measures available in the literature. In this paper, a compilation and description of selected quantitative and qualitative indicators are performed. The article presents an overview of measures and performance indicators from the quality assessment of the transport process. In order to verify the performance measures currently in use, a questionnaire survey was conducted among representatives of companies providing transportation services. The results of the survey allow us to gather information on the opinions of representatives in selected transportation service companies on the performance measures used. The literature review performed and the survey conducted to provide a view of the performance measures used in a selected group of transportation service companies.

Key words: transport, transport process, performance indicators, performance measures.

1. Introduction

Transport is one of the most important tasks in the supply chain. On the market there are transport, logistics and forwarding companies, which deal with the organization and implementation of transport services. Each of these types of TSL company has a significant impact on the transport process. Maintaining the competitive position of the transport service on the market is connected the need to optimize tasks in the transport process and constantly improve the level of efficiency.

Companies need awareness, that is, information that summarizes the effectiveness of implemented activities. Performance measures and indicators are tools that allow control and monitoring of the achieved results. Ensuring high quality of offered services by logistics, transport and forwarding companies requires them to research the level of effectiveness of the transport process and an appropriate management system, in which data from measurements are converted into information necessary for further optimization activities.

In the literature there are many scientific and research papers, including case studies, that present indicators used in companies providing transport services.

This paper presents a set of selected indicators and performance measures that allow verifying the level of quality of the offered services, adjusted to the specificity of enterprises providing forwarding and/or transport services in the field of road transport of goods. The selection of indicators was based on the analysis of literature and interviews with the employees of transport, forwarding and logistics companies who have the necessary knowledge on the indicators used in companies from the TSL sector.

The aim of the publication is to review the indicators and measures used in logistics, transport and forwarding companies to assess transport efficiency. The analysis performed concerns only non-financial indicators influencing the quality of the transport process. In addition, the paper will present the result of a survey, presenting the frequency of use of efficiency indicators selected by the authors, which are designed to assess the quality of the transport process.

2. Logistics, transportation and forwarding companies

In the TSL trade, three basic types of activity can be identified: logistics, transport and forwarding. It should be stressed that in the basic consideration these are three different terms, but due to the progress of the market and competitiveness, more and more often services of more than one activity are performed within one company (Bartczak, Barańska, 2016).

A transport company is defined as an enterprise which professionally carries out the transportation of people or goods by means of transportation adapted to this purpose. Functioning of the transport company is conditioned by possession of appropriate rights confirmed by documents such as: carrier's license, license for international carriage of goods for hire or reward, list of owned vehicles (Krawczyk et al., 2007; Rudzińska, Piekarski, Dudziak, 2012). A transport company is related to the concept of transport activities because its scope is consistent with the services offered by such companies, and this involves the transportation of cargo from the shipper to the consignee, including loading and unloading activities (Skowronek, Sarjusz-Wolski, 2012). Due to the scope of the work, the formulation of the transport activity will be used only in relation to the companies carrying out road transport of goods.

A forwarding company can be defined as a company which provides a forwarding service understood as a set of tasks consisting in performing organization-consulting or organization-legal activities. This is a narrower definition of forwarding, which does not include the physical and technical manipulation of the shipped cargos. Forwarding in a broader sense is based on the performance of all necessary actions to organize the transport of cargo from the shipper to the consignee. It should be stressed that this service does not include only transport (Bartczak, Barańska, 2016; Salomon, 2013). Forwarding companies perform forwarding activities, which include: wide range of legal and technological consultancy, help with the choice of the means of transport, insurance of the shipment, carrying out all formalities and preparation of documents in connection with: contracts and settlements with transport carriers and customers, possible customs clearance and handling of complaints (Skowronek, Sarjusz-Wolski, 2012).

The widest range of services is provided by companies that offer comprehensive logistics services such as logistics operators and logistics centers (Krawczyk et al., 2007). The main purpose of such companies is to improve the flow of logistic processes. The basic functions and tasks of such companies include the coordination and realization of transport and cargo handling, warehousing and stock management, manipulation activities, etc. (Skowronek, Sarjusz-Wolski, 2012). Logistics service is interpreted as an activity whose purpose is to provide for the logistical needs of business entities and the public. Logistics services can be operational, administrative, service, financial, consulting and communication and information flows (Krawczyk et al., 2007). Comprehensive services offered by logistics companies are characterized by flexibility, so they are adapted to customer needs.

In the literature, the previously mentioned concept of a logistics operator, is defined as a company providing services which consist in taking over from suppliers and/or recipients tasks in which one or more logistics functions are performed. As a result of such activity there is a flow of goods and information between the participants, that is the supplier and the recipient in any part of the supply chain (Fechner, 2007). Another definition shows that a logistics operator is defined as a service company that works for the benefit of another entity. The services provided in this way include the organisation or supervision of the flow of goods and information and the coordination of processes in the supply chain. The scope of activities performed for the client, depends on the order that has been accepted for realization (Zelkowski et al., 2018).

In this work, the attention is focused on the transportation organization and implementation services offered by companies providing logistics services.

At the end of this chapter, it is important to highlight the fact that there are many more definitions of logistics, transport or forwarding activities in the research literature, but they are not cited in this paper.

3. Efficiency in transportation

"Efficiency is an ambiguous concept and is interpreted differently in the social and economic sciences, and also by management practitioners and theorists" (Skrzypek, 2012, p. 313). The term efficiency (in management) is variously defined by researchers (Puszko, 2018), but referring to the Polish language dictionary, efficiency is explained as: productivity, effectiveness (Dubisz, 2018). However, extending the knowledge of the concept of "Efficiency" by reviewing the literature, it should be added that terms such as: effectiveness of action or positive result, as well as the the terms: productiveness, usefulness or the previously described productivity and effectiveness can also be used as a definition of efficiency, however, in this case it should be emphasized that the concept of efficiency is a concept with the broadest meaning in relation to the others mentioned above (Mesjasz-Lech, 2012; Skrzypek, 2012; Wilczyński, 2014).

Efficiency is a concept that allows to reflect the relationship between effects, objectives, inputs and also costs in structural and dynamic aspects (Skrzypek, 2012). Using the term Efficiency in relation to the activities performed as part of the company's activities, attention should be paid to the result of these activities, that is, the effect and its relationship with the company's aims and the inputs incurred to get it (Skrzypek, 2012). An effective action is an activity that leads to the achievement of a purpose with optimal use of resources (Wilczyński, 2014). A beneficial result of the performed activities positively influences the efficiency (Skrzypek, 2012).

Effective operation in the case of transport, forwarding and logistics companies (in the field of subsystem; transport) is related to achieving the highest possible level of quality efficiency of the transport process, which is the main service offered by such companies. Efficiency as the relationship between inputs and effects, indicates the necessity of inputs to accomplish the highest possible result and to achieve the set aim.

The prerequisite for effective transport is the effectiveness of transport processes, which is at the same time the basic requirement for effective company operation. Maintaining this efficiency requires checking the effects of activities, which can be achieved by using systematic assessments. Logistics indicators for transport can be the basis for such

assessments. The use of them can enable more rational control of the transport processes, because positive and negative trends resulting from the appraisal will be recognised early (Twaróg, 2004).

The use of assessments will lead to the collection of data. A necessary action is to process these data into information, because then knowledge is created. The right way to manage such knowledge will lead to optimization of inputs and increased efficiency of the company. The use of performance measures and indicators in enterprises will lead to improved results and, in effect, enterprise development. The study of the relationship between inputs, results and goals, as well as appropriate management of the company will allow it to achieve success and provide a basis for improving its market position.

4. Performance indicators used in companies

Transportation, which is a basic and essential logistics subsystem, should be monitored and its components reviewed (Twaróg, 2003). The use of such tools as measures and performance indicators allows to view and verify the degree of implementation of the adopted goals and key actions for the company, and moreover enable their evaluation.

One of the ways to assess the effectiveness of the process, including the transport process is to use indicators (indicator method). The choice of indicators for process evaluation should be made in such a way as to present the actual changes that take place in the process and result from the flow of materials and information, at the same time giving the possibility of supervision of the process (Waściński, Zieliński, 2015). Indicators considered as a set of analytical tools, introduced into the enterprise will enable measurement and evaluation of transport processes, presenting the actual state of the process in a reliable way (Dohn, Witnik, 2020).

In order to correctly define and list the indicators and measures for a transportation process, it is first necessary to pay attention to the purpose of the transportation process and its most important functions and parameters. In order to correctly define and list the indicators and measures for a transportation process, it is first necessary to pay attention to the purpose of the transportation process and its most important functions and parameters. The transport process is the process of moving goods from the point of shipment to the point of receipt, using means of transport. The organizational, executive and commercial activities influence the correct transport process (Gaschi-Uciecha, 2018). The most important parameters of the transportation process include: customer satisfaction, process time, on-time delivery, quality, and process cost (Łukasik, Kuśmińska-Fijałkowska, Olszańska, 2017; Łukasik, Olszańska, 2016). The requirements for transport by logistics include low cost, ability to handle small shipments, effective and safe transport organization, reliability, and on-time delivery (Woźniak, Kukiełka, 2011). Management of the transport process involves the need to constantly develop and improve the efficiency of the organization of freight transport in order to fulfill the needs of customers in the market. This purpose requires not only monitoring but also analysis and optimization of the elements of this transport process. It is also important to plan and control the process according to customer requirements (Łukasik et al., 2017).

The possibilities of assessing the transport subsystem have been repeatedly described by researchers of this subject, and indicators and measures allowing for assessing the quality of this process have been defined, among others, by H.-Ch. Pfohl, M. Nowicka-Skowron, J. Twaróg and D. Kisperska-Moroń (Dziaduch, Konkol, 2009).

Indicators for the transport logistics subsystem were defined, among others, by H.-Ch. Pfohl. This author's solution is presented in the following diagram – Figure 1, where the presented measures of qualitative and quantitative evaluation of the transport system are shown (Pfohl, 1998; Twaróg, 2003). The basic measures according to the presented graphic are: transport time, transport reliability, number of damages during transport and transport flexibility (Dziaduch, Konkol, 2009; Twaróg, 2003, 2004).

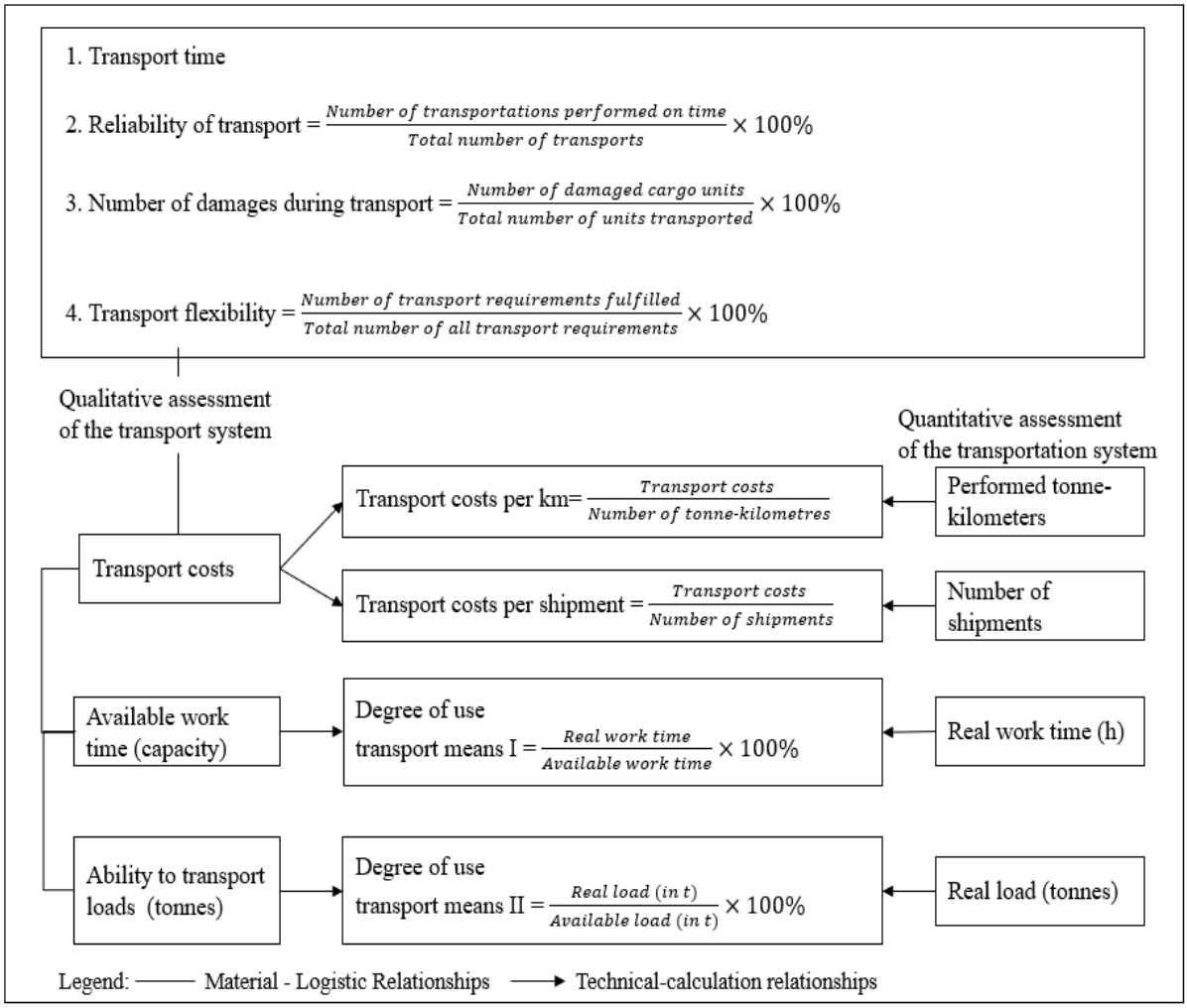

Figure 1. Performance indicators by H.-Ch. Pfohl.
Source: "Logistyczne wskaźniki oceny transportu w przedsiębiorstwie produkcyjnym", J. Twaróg 2004, *Logistyka, 2*, 27-30.

According to the publication of M. Nowicka-Skowron transport is a key subsystem of logistics can be analyzed and assessed using quantitative and qualitative indicators, called partial indicators, which are presented in Figure 2. Such indicators allow for a quantitative and qualitative assessment of the transportation system (Nowicka-Skowron, 2000).

It is also important to present criteria and indicators of logistics transport service quality by J. Twaróg. This author formulated such criteria as: delivery quality, delivery reliability, delivery fast, delivery on time, transport readiness, flexible delivery, delivery responsiveness, delivery rhythmicity, delivery openness, and delivery reliability. Formulas and measures of these criteria are presented in the Table 1 (Twaróg, 2003).

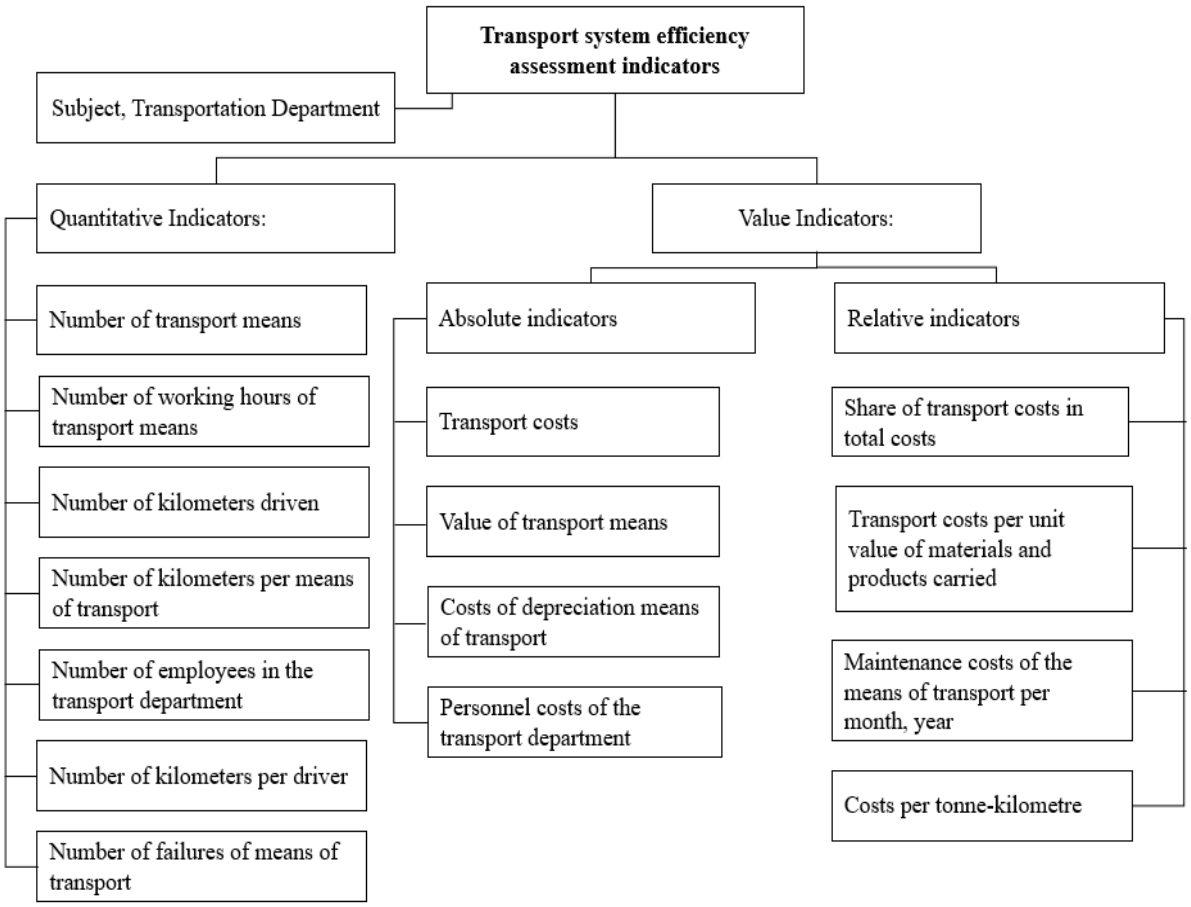

Figure 2. Transportation system performance evaluation indicators.
Source: *Efektywność systemów logistycznych*, M. Nowicka-Skowron, 2000, Warszawa: Polskie Wydawnictwo Ekonomiczne; *Mierniki i wskaźniki logistyczne*, J. Twaróg, 2003, Poznań: Instytut logistyki i magazynowania; „Logistyczne wskaźniki oceny transportu w przedsiębiorstwie produkcyjnym", J. Twaróg, 2004, *Logistyka*, *2*, 27-30.

J. Twaróg developed and presented in his paper also indicators for evaluating the transport logistics subsystem, which he divided into quantitative and qualitative measures. The quantitative indicators included simple quantitative measures, that is: tonne-kilometres performed, number of shipments, real working time of transport means, load transported in tons. The first group also included indicators such as transport costs per tonne-kilometre, transport costs per shipment, use of working time and the degree of capacity use of the transport means. The second group is the qualitative indicators, which are: transport reliability and transport flexibility, and the share of damage during transport. The set of all these indicators is shown in Table 2 (Twaróg, 2003). Another publication by this author also presents such indicators as transport time, transport logistics costs and the share of transport logistics costs in turnover (Twaróg, 2004).

Assessment of the transport logistics subsystem using quality and productivity measures is a theory described by D. Kasperska-Moroń. In this case, quality measures can be used to assess the effectiveness of the research process related to the achievement of the objective, and these are: punctuality of delivery, completeness and damage-free delivery, accuracy of transport documentation, and punctuality of response to commercial questions and complaints.

Table 1
Criteria and indicators of logistic transportation service

Criterion	Indicator formula	Measures
Delivery quality	$\frac{Delivery\ volume\ acceptable\ to\ the\ customer}{Total\ volume\ of\ delivery}$	The level of customer satisfaction with the quality of the delivery received, describes the degree of customer satisfaction
Delivery reliability	$\frac{Share\ and\ frequency\ of\ complained\ deliveries}{Total\ number\ of\ deliveries}$	Level of complaints and damage occurring during shipment
Delivery fast	Time between registration and order processing	Average delivery time
Delivery on time	The degree of probability of achieving the agreed delivery date	Proper implementation of all activities during the order cycle
Transport readiness	Share of transportation means that can immediately fulfill the order	The level of availability of transport means for the recipient
Flexible delivery	Level of reaction to changes in requirements from the customer when submitting orders	Openness of the company to changes in orders and needs from the recipient
Delivery responsiveness	$\frac{Number\ of\ delivery\ items\ delivered\ ahead\ of\ time}{Total\ number\ of\ elements}$	Advance time on which discounts may depend
Delivery rhythmicity	$\frac{Number\ of\ days\ in\ the\ analyzed\ period}{Number\ of\ delivery\ days}$	Regularity of deliveries during the accepted term
Delivery openness	$\frac{Number\ of\ customer-satisfying\ delivery\ information}{Total\ information\ in\ this\ field}$	Contract progress necessary to achieve effective service and trust with each other
Delivery reliability	$\frac{Unregulated\ "returns\ of\ goods"}{Totality\ returns\ of\ goods}$	Comprehensive handling of returns

Source: *Mierniki i wskaźniki logistyczne*, J. Twaróg, 2003, Poznań: Instytut Logistyki i Magazynowania.

For the first indicator, that is, on-time (punctuality) delivery, the number and percentage of orders delivered on time is taken into account. Completeness and error-free delivery is explained as the percentage of shipments that were delivered to the customer as complete and undamaged. Freight documentation accuracy, which is measured as the proportion of error-free documents, is expressed as a percentage. The final measure is the timeliness (or punctuality) of responses to sales inquiries and complaints. It is measured by verifying the reaction time to sales inquiries, which should be in accordance with the defined customer service standards – in this case, the measurement takes into account responses delivered within a time acceptable to the customer and which are satisfactory to the customer. The measurement of this indicator for complaints will research the percentage of complaints resolved in a timely manner. Productivity measures can be used to manage

processes and get information what is the relationship between inputs and results. The transportation productivity measures developed relate to overall transportation management, which is categorized into proprietary transportation management, management related to the purchase of transportation services, and overall transportation management, and the measures relate to productivity, degree of use, and performance results. Productivity measures also include such groups as general measures of work, general measures of equipment and measures of fuel consumption (Kisperska-Moroń, 2006).

Table 2
Indicators for assessing the logistics subsystem "transport"

No.	Indicator definition	Indicator formula	Unit
A Quantitative indicators			
1	Simple quantitative measures		
	– tonne-kilometres performed		tkm
	– number of shipments		
	– real work time of means of transport		h
	– load transported in tonnes		t
2	Transport costs per tonne--kilometre	$\frac{Transport\ costs}{Number\ of\ tonne-kilometres}$	PLN/tkm
3	Transport costs per shipment	$\frac{Transport\ costs}{Number\ of\ shipments}$	PLN/piece.
4	Use of working time	$\frac{Working\ time\ used}{Available\ working\ time} \times 100$	%
5	Degree of use of transport capacity	$\frac{Real\ transported\ load\ in\ tkm}{Possible\ load\ to\ transport\ in\ tkm} \times 100$	%
B Qualitative indicators			
1	Transport reliability	$\frac{Number\ of\ on-time\ transport\ performances}{Total\ number\ of\ transports} \times 100$	%
2	Transport flexibility	$\frac{Number\ of\ transport\ requirements\ fulfilled}{Total\ number\ of\ transport\ requirements} \times 100$	%
3	Share of damage during transport	$\frac{Number\ of\ damaged\ transport\ units}{Total\ number\ of\ transport\ units\ carried} \times 100$	%

Source: *Mierniki i wskaźniki logistyczne*, J. Twaróg, 2003, Poznań: Instytut logistyki i magazynowania.

Further studies and publications on this topic by authors such as T. Gajewska, draw attention to the importance and practical application of the indicators described in the literature such as on-time delivery (punctuality), completeness and error-free delivery, accuracy of transport documentation and on-time responses to commercial questions and complaints (Gajewska, 2016).

Another example is the developed list of indicators used in the study of a company providing transport services, and these are: transport reliability, number of damages during transport, transport flexibility, transport costs per kilometer, transport costs per carriage, degree of use of transport means, degree of use of working time, failure of transport means, number of kilometers per transport means and delivery readiness (Gaschi-Uciecha, 2018; Waściński, Zieliński, 2015).

Indicators should be considered as a set of tools that allow for the analytical measurement and assessment of logistics processes or systems and subsystems. The main task of indicators is to reliably and adequately represent the actual state of a measurement (Gaschi-Uciecha, 2018).

5. Survey description

The aim of the survey was to determine which indicators and measures described in Section 4 are used by logistics, transportation, and freight forwarding companies performing transportation service. The indicators and measures that allow verifying the efficiency of transport process realization, which were included in the survey, were chosen on the base of literature analysis, interviews with representatives of logistic, transport, forwarding companies and authors' own experience. The indicators in the survey were categorized into quantitative and qualitative.

On the basis of the above-mentioned assumptions and the author's approach to the analyzed subject of the paper, qualitative indicators of non-financial character were selected to research the quality of the transport process. The list of qualitative indicators to assess the efficiency of the transportation process that was included in the survey are:

- on-time (punctuality) delivery;
- completeness of deliveries;
- transport flexibility;
- transport reliability;
- no load damage during transport;
- quality of delivery;
- failure of means transport;
- delivery readiness;
- accuracy of shipping documentation;
- complaints and returns;
- unfulfilled orders;
- degree of use of transport means;
- degree of use of working time.

The author's proposed list of quantitative indicators for measuring the efficiency of the transportation subsystem is as follows:

- number of working hours of means of transport;
- number of kilometers driven;
- number of kilometers per means of transport;
- number of kilometers per driver;
- number of shipments handled (or transport units);
- number of damages during transport;
- transport volume weight;
- number of complaints.

The indicators presented above represent a comprehensive set of measures for assessing the transportation process. A wide range of suggestions was prepared in order to give respondents the opportunity to choose such indicators that are used in the company, without limiting their response options.

6. Analysis of survey results

The survey was conducted during March-April 2022. This survey was carried out on a sample of 100 randomly selected companies. The survey received 59 representatives from transportation companies, 20 responses from freight forwarding companies, and 21 answers from logistics companies, as shown in the Figure 3.

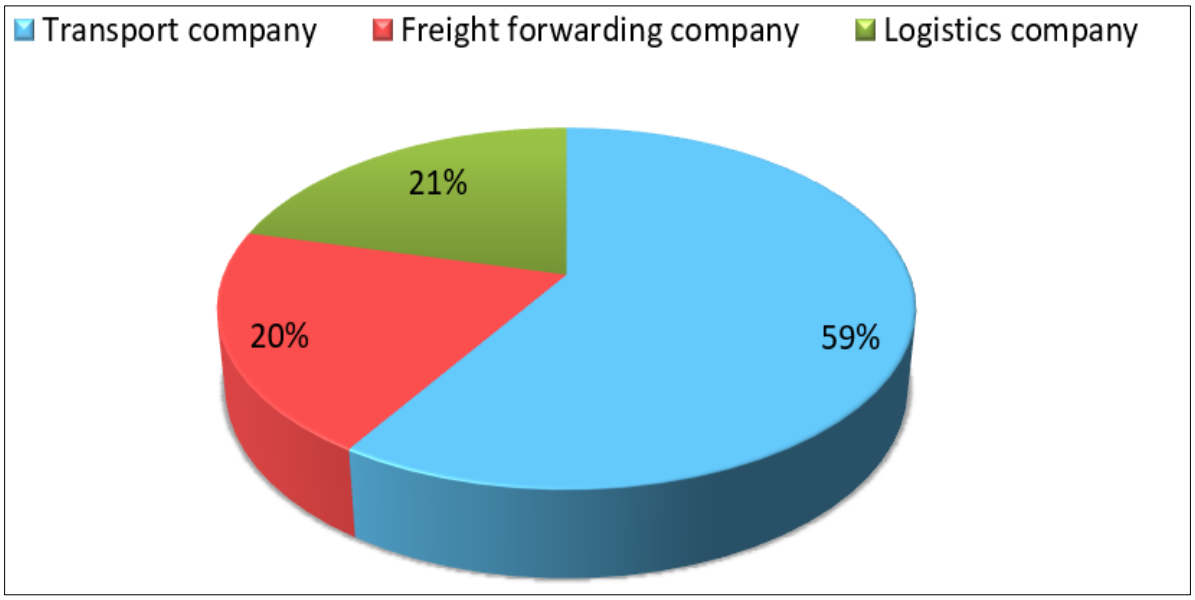

Figure 3. Structure of responses according to the surveyed companies.
Source: own study.

Responses to the survey were provided by employees in positions such as transportation manager, transportation planning specialist, transportation specialist, logistics specialist, shipping specialist, freight forwarder, and logistician. The diversity of positions in which the survey respondents work indicates the differentiation of people who work with transportation indicators and measures in a company; this may be due to the type of company, the size of the company, and the organization of work in the company, among other factors.

In the questionnaire there was a list of indicators and quality measures affecting the efficiency of the transport process (presented in section 5), the respondents were asked to mark which indicators they use in the company. The overall results are shown in the Figure 4 below.

The above results represent the frequency of use of each indicator in the surveyed companies. The survey shows that the most frequently used indicator is: on-time delivery (punctuality) – 98% of respondents indicated that they use this indicator, completeness of delivery – 97% of confirmed answers and in third place with a result of 93% are three indicators: reliability of transport, quality of delivery and complaints and returns. The most rarely researched and monitored by means of indicators is the area of orders not fulfilled – 71%.

The second set of indicators, the quantitative measures used by companies to evaluate the transport process were also subjected to a frequency of use assessment. The results of the responses are presented in the Figure 5.

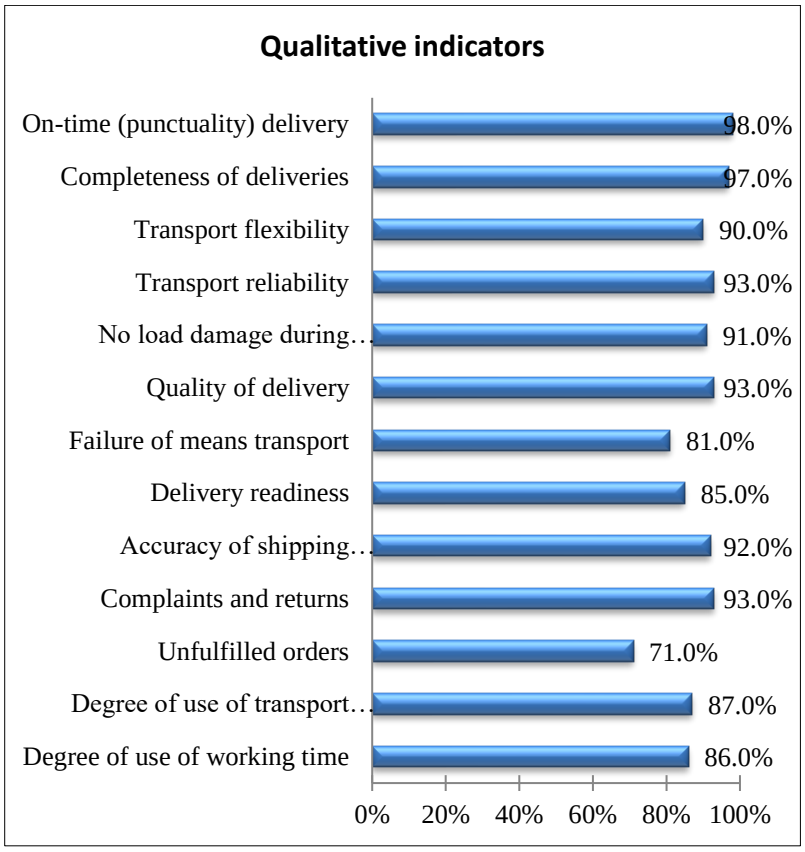

Figure 4. Graph representing respondents' answers – qualitative indicators.
Source: own study.

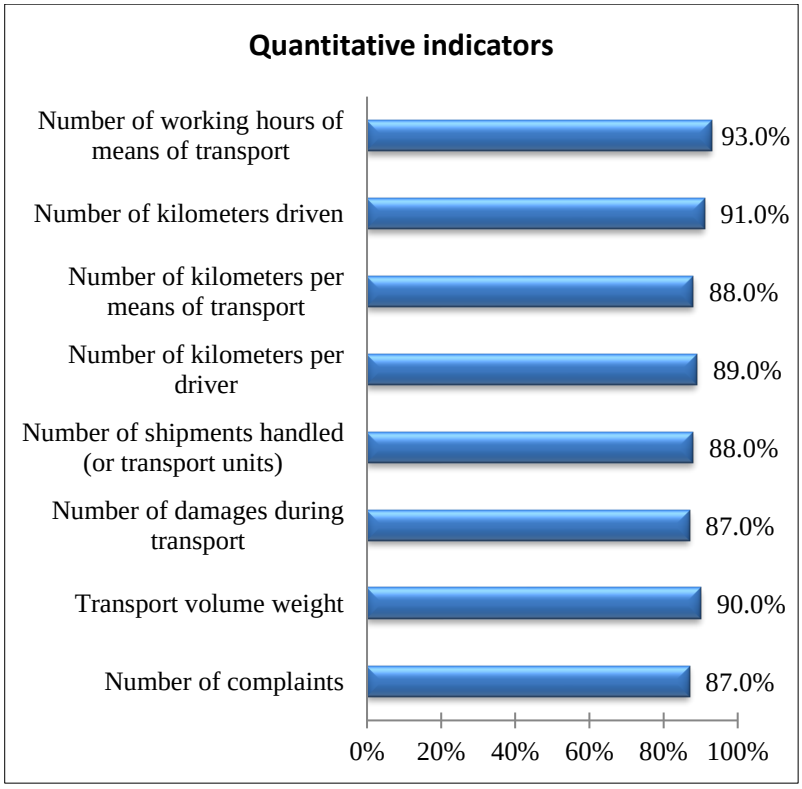

Figure 5. Graph representing respondents' answers – quantitative indicators.
Source: own study.

The respondents' answers indicate that the most frequently used quantitative indicator in the surveyed companies (overall) is the number of hours of transport means (93%). In second place was the indicator verifying the number of kilometers driven (91%), while the third most frequent indicator is the mass volume of transport (90%). The least frequently used indicators according to the respondents are the number of damages (87%) and the number of complaints (87%) this means that these areas are the least controlled in the companies.

The results of the study show that all indicators have relatively high results – the lowest value is 71%. It means that enterprises mostly use the indicators described in the literature when researching the efficiency of the transportation process in the company.

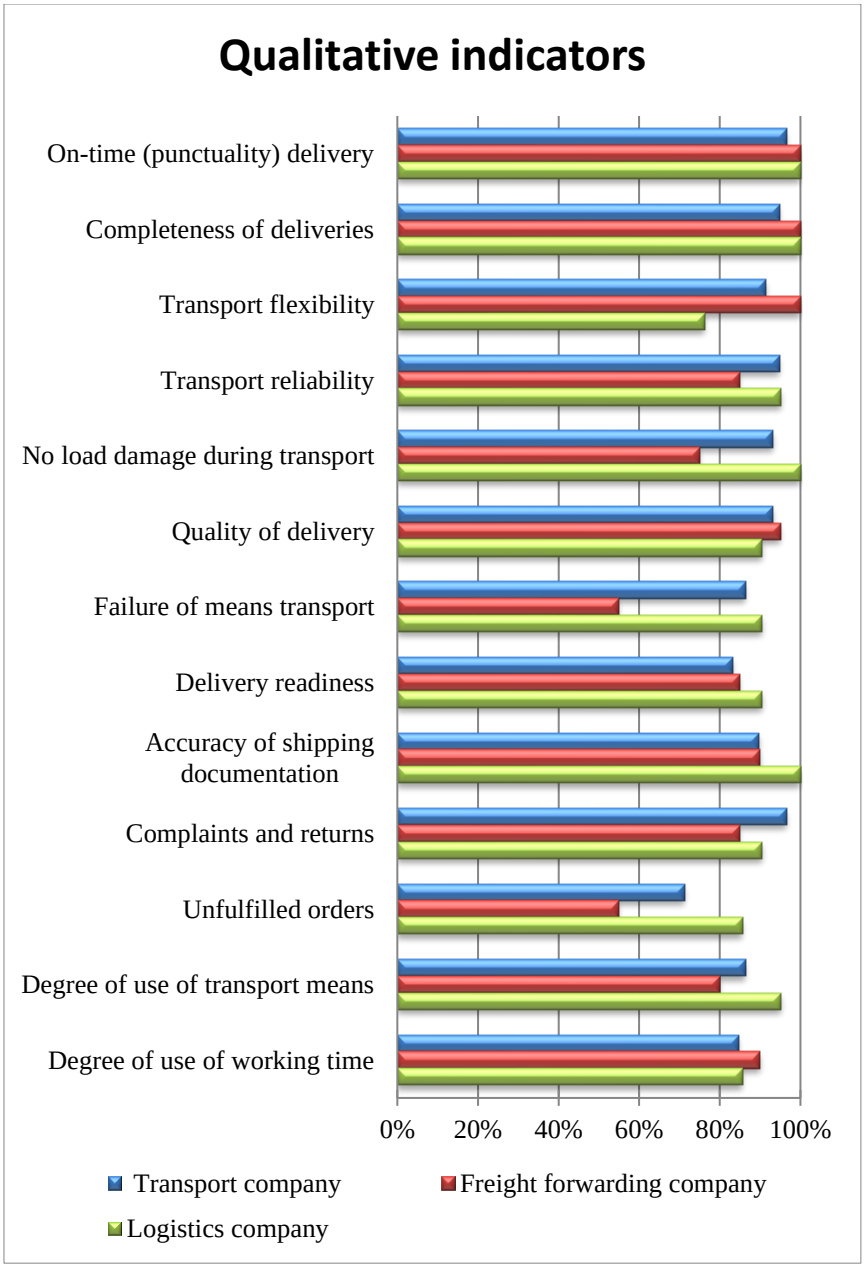

Figure 6. Quality indicators – answers from representatives of transport, logistics and forwarding companies.
Source: own study.

Further research verified the relationship between the frequencies of the indicators and the group from which the respondents came. For qualitative indicators, statistically significant differences occurred with three indicators. Freight forwarding companies, compared to transport and logistics companies, are more likely to use an indicator that measures transport flexibility. However, the indicators: no load damage during transport and failure of means transport are used less frequently by forwarding companies than by transport and logistics companies. The percentage of responses expressed by respondents from each group is shown in Figure 6.

The research verified the relationship between the type of company marked in the questionnaire and the frequency of using quantitative indicators. Responses to the survey indicated that company type did not significantly differentiate the quantitative indicators. The proportion of responses is shown in Figure 7.

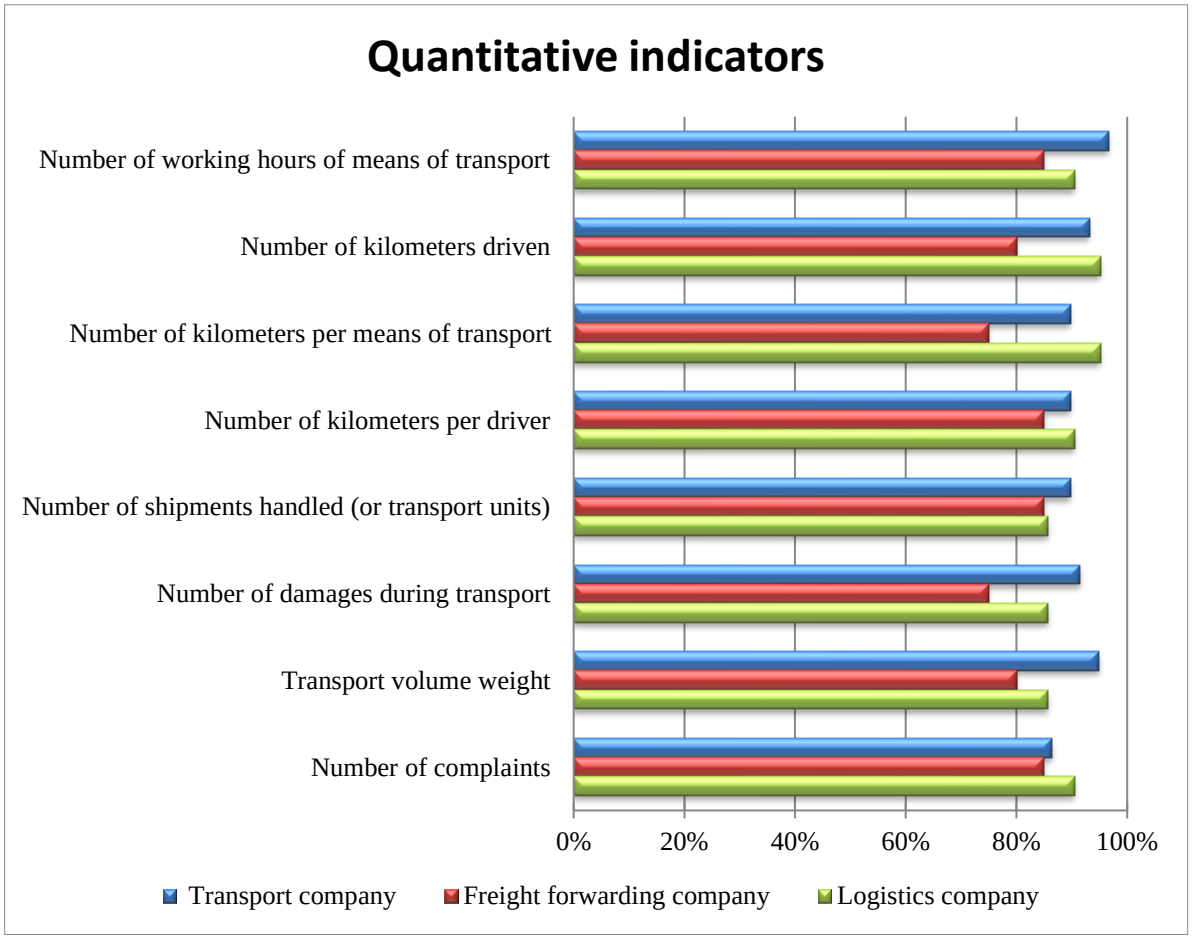

Figure 7. Quantitative indicators – answers from representatives of transport, logistics and forwarding companies.
Source: own study.

The above responses and their descriptions indicate that statistically significant differences occurred for only three quality indicators. The data on which indicators are used more and less often in each enterprise may depend on the work organization and functionality of the company.

7. Conclusions

Improvement of the transport process is the aim of transport, freight forwarding and logistics companies. Monitoring of the effects of the realized process is possible by making proper measurements and their assessment. A tool enabling such verification is a set of indicators which, if properly selected, will allow for efficient and successful research of processes in a company.

The performed literature review and questionnaire survey allow to conclude that companies mostly use the indicators described in the literature when researching the efficiency of the transport process. The most frequently used performance indicator in the surveyed group of companies is on-time (punctuality) delivery, while the least frequently used is the number of unfulfilled orders. The paper also presents differences in the use of performance measures depending on the type of company studied. The results shown in the paper are the basis for the continuation of further research in the field of transport efficiency, among others, in order to verify in more detail the dependence of the application of the measures described by the authors.

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Testing of embedded systems in the automotive industry

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Abstract: The functional testing of embedded systems is essential for the safety of automotive vehicle exploitation. The aim of this work is to analyze the flickering test results of embedded systems to automate their verification. The research was conducted to analyze embedded system test results tending to flicker. The tests were performed in real time, in the Hardware in the Loop environment. The analysis included the empirical probability of result flickering and their causes. The research has provided information on the empirical probability of the phenomenon of the results flickering, their influence on the testing process quality and the possibilities of its elimination depending on the recognized root cause. Automating the verification of results would definitely improve the quality and optimize the testing process. It seems reasonable to implement augmented intelligence algorithms here.

Key words: vehicles exploitation, embedded systems, functional safety, testing.

1. Introduction

Ensuring quality, safety and reliability of operation of both individual components and the whole system is a priority task in the automotive production process. The ISO26262 standard and the ASPICE standard define the consecutive phases of software development, which are represented schematically by the V model.

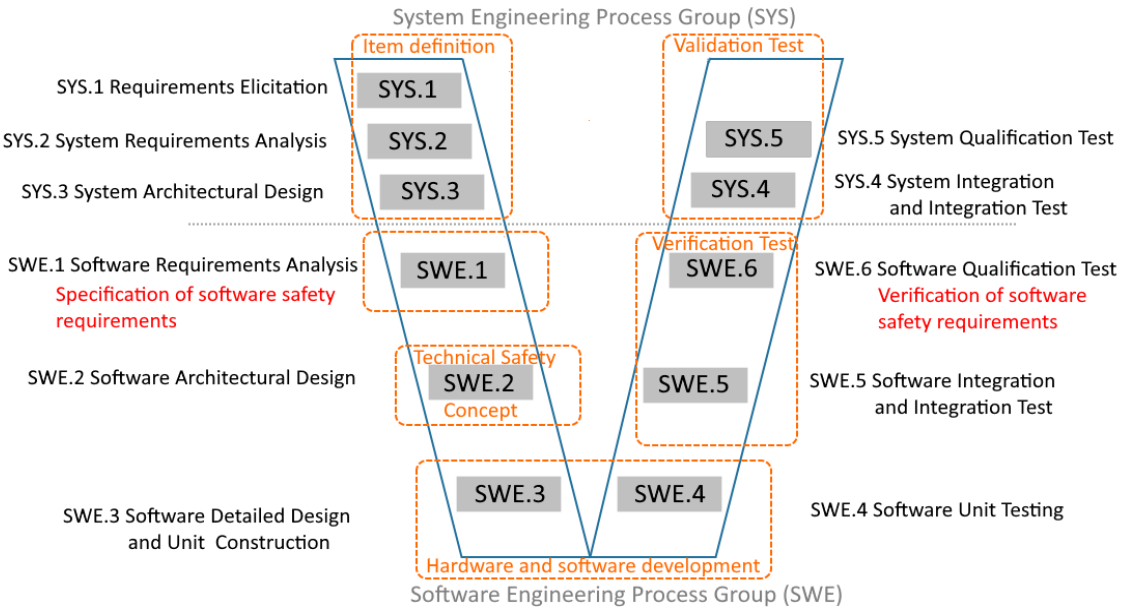

Figure 1. Software development lifecycle model based on ISO26262 and ASPICE v3.1.
Source: „Ewolucja testowania systemów wbudowanych w motoryzacji wraz z wprowadzeniem nomy ISO 21448:2019 Pojazdy drogowe – Bezpieczeństwo zamierzonej funkcjonalności", A. Gnacy-Gajdzik, P. Przystałka, 2021b, *Utrzymanie Ruchu, 2*, 7-16.

To ensure its safe exploitation, it is necessary to test what has been designed, implemented and manufactured, at all the mentioned levels of product development. According to the aforementioned standards, the following techniques are used at each phase, as shown in Table 1.

Table 1
Test phases and techniques

Test phase	Test technique
SWE.4 Software Unit Testing	Model in the loop Software in the loop
SWE.5 Software Integration Test	Software in the loop Processor in the loop
SWE.6 Software Qualification Test	Hardware in the loop
SYS.4 System Integration Test	Hardware in the loop
SYS.5 System Qualification Test	Hardware in the loop Vehicle in the loop

Source: own study.

The challenge of testing is to identify the maximum number of software defects at the earliest possible stage of testing. The later a defect is found, the more difficult it is to analyze and fix it, and thus the costs of the whole process increase tremendously. SWE.4 and SWE.5 level tests are easy to automate and are often incorporated into the Continuous Testing process. However, starting at the SWE.6 level, where the integration of hardware performance with embedded software is verified, the test environment can contribute to a negative test result. A singular, isolated system functionality cannot be tested at this level. The aim is to have the individual test scenarios as minimal as feasible to eliminate the possibility of the environment influencing the test results. However, such an approach is not always applicable. Inducing errors in the system to test its reaction to their presence invariably entails the risk of a negative test result, even though the embedded system under test behaved correctly. Therefore, the negative results obtained are analyzed at this phase. This is a time-consuming and expensive part of the testing process at levels SWE.6 and above. So-called flickering test results, i.e., positive and negative results with several repetitions of test execution, are a frequent phenomenon. In this case, the aberrations appearing in the diagnostic system are the cause of the negative test result, not the malfunction of the embedded system under test as it might appear. The process of analyzing flickering test results is resource-intensive, especially since various independent causes usually contribute to this phenomenon. Automating this step would definitely improve the quality of the automotive embedded systems diagnostics process and optimize it.

2. Research problem and research method

A study was conducted to determine the feasibility of automating the analysis of negative test results. The first step was to examine tests producing negative results for their flickering. The tests were performed in a real time in the target ECU of embedded systems used in high-voltage electric vehicle battery controllers. The Hardware in the Loop (HiL) simulation shown in Figure 2 was used during this research. The tested device was

connected to real sensors (e.g., voltage and current sensor of high voltage battery) and actuators (e.g., relays), electrically emulated cells of high voltage battery and other elements (e.g., Hall sensor, temperature sensors). The remaining part of the vehicle – e.g., communication signals on CAN buses, vehicle speed values were simulated by Canoe software of Vektor Informatik company. In this simulation, a vehicle model prepared in Simulink was also involved.

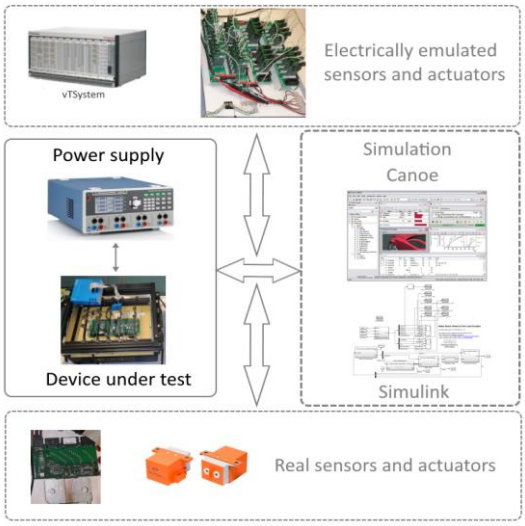

Figure 2. Simulation Hardware In the Loop applied in the research.
Source: own study.

3. Results

In the initial phase of the study, 216 test cases assigned to 18 functional modules were performed. A 22.69% negative result was received. It was intended that the negative test cases would be repeated in the second phase to confirm this result. However, it was extended to all previously performed test cases. The previously performed tests were repeated 10 times. The tests within the module were performed in a random order to make the current results acquired independent of previous results. 74 positive results (representing 34%), 15 negative results (representing 7%), and 128 flicker results (59%) were obtained (Gnacy-Gajdzik, Przystałka, Sebzda, 2021).

The next step of the research work was focused on identifying possible causes of false-negative test results. Out of 128 tests with results indicating flickering, 25 were randomly selected for the purpose of the study. The reports of performed experiments, logs containing signals from communication buses and values of measured physical parameters at specific moments of time were analysed. The tests were given identifiers – consecutive integers. Based on the reports of their tenfold execution, attributes such as weight, probability and mode were determined. The weight allows determining which element of the test case is affected by the error occurring. Five values were defined for this attribute (blocking, critical, major, minor, insignificant). The probability determines how often a test result flickers (the number of negative results in a given sample). Mode, on the other hand, is introduced to indicate the test cases whose modification can affect the flicker frequency. In other words, the normal mode means that it is impossible to eliminate the flicker phenomenon by modifying the test case. Redundant mode means that the error causing

the flicker occurs in a part of the test case that can be omitted or modified – this is closely related to the weight. Redundancy can only occur if the aberration is insignificant, meaning it does not affect the test environment or the system under test. In contrast, non-complete mode means that there are omitted steps in the test case whose execution may affect the occurrence of a negative test result. This is related to the blocking and critical weights. The information obtained at this stage will be used in the developing methodology for developing automated test cases.

Subsequently, based on the author's algorithm, log files were analyzed and possible causes of flickering test results were extracted (Gnacy-Gajdzik, Przystałka, 2021). For the test cases subjected to the test, five possible causes of negative test results and hence flickering results were extracted:

- communication – a negative result caused by errors on the communication buses;
- tolerance – a negative result caused by values exceeding the assumed tolerance values;
- fluctuation – negative result caused by fluctuation of current, temperature;
- time – a negative result caused by exceeding the assumed time frame for processing the change of signals;
- other – other reasons.

The aforementioned analysis is a preparatory step for further research that aims to apply augmented intelligence algorithms to the automatic process of analyzing negative test results. It was assumed that the aberrations causing the flickering results originate from the test environment. To confirm this, the environment was modified by introducing a vehicle model into the HiL simulation. This provided random variability in the signals coming from the car associated with its driving cycle, the ability to control the load on the communication buses with signals containing variable values corresponding to the actual driving situation, and to generate delays in the embedded system's responses to changes. A research experiment was conducted by executing 8 of the previously studied test cases. The work was divided into two stages: in the first stage, the tests were performed in the original test environment, while in the second stage, the tests were performed in an environment supplied with a vehicle model to allow for the introduction of variability in the test environment. Each test case was performed 10 times and the flicker rate of the result was determined. This process was repeated 10 times. This determined the average for empirical probability of result flickering, its median and standard deviation.

From the graphs in Figure 3, it can be seen that by using the vehicle model in the test environment, the phenomenon of flickering results has increased.

4. Conclusions

The analysis carried out provided information on the empirical probability of the occurrence of flickering results, their impact on the quality of the testing process and the possibility of their elimination.

The described sensitivity of embedded software test results to changes in the environment is a detrimental phenomenon. It will be considered in further works on the methodology of developing automatic test cases. In parallel, research will be conducted to introduce augmented intelligence algorithms into the test process. Their task will be to analyze negative test results and verify their correctness.

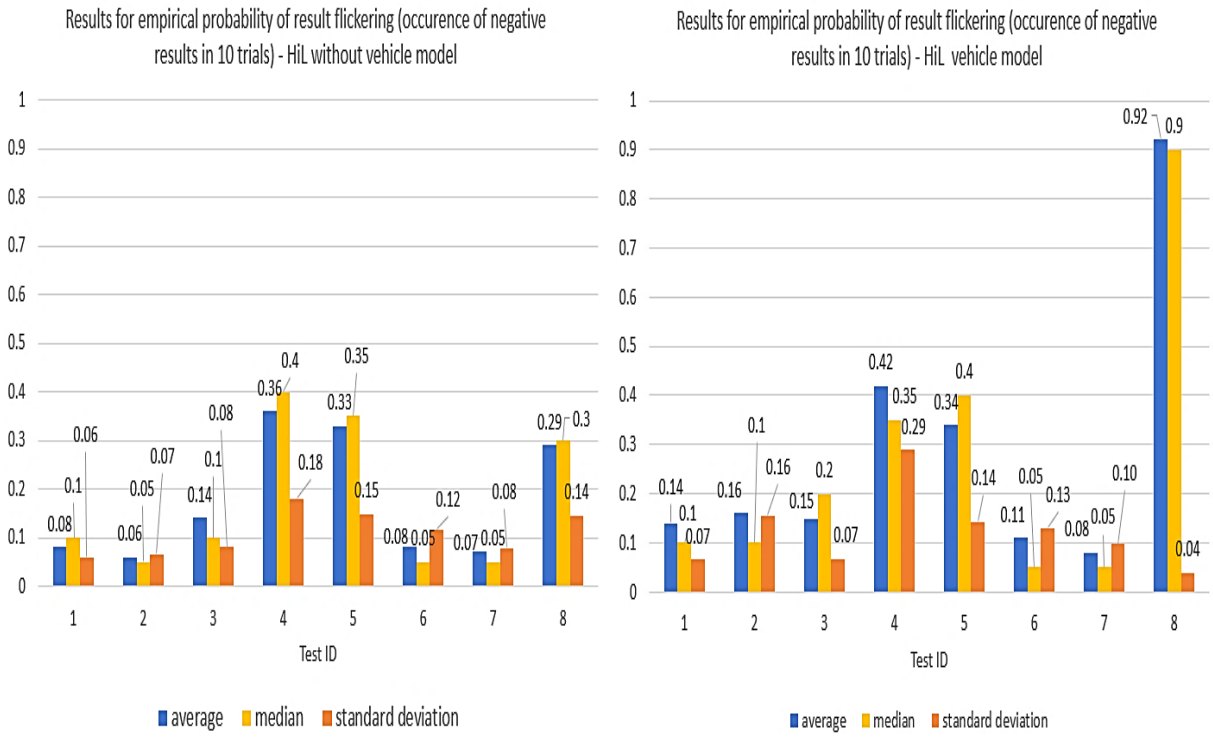

Figure 3. Comparison of the test environment influence on test results flickering. Source: own study.

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Failure Mode and Effect Analysis (FMEA) in risk assessment of rail vehicles

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Abstract: The paper describes the methodology of approach to the procedure of performing risk assessment using the Failure Mode and Effects Analysis (FMEA), according to the latest edition of the PN-EN IEC 60812:2018 standard. The paper notes the application of the analysis for assemblies and subassemblies of rail vehicles, where it is increasingly used, according to the requirements of railway companies. An example of the application of the FMEA method is presented for the draw-and buffing gear of a coal car of normal construction. After the decomposition of the system and the determination of the functions performed by the object and the possible risks, an analysis was carried out, which showed that the values of the Risk Priority Number (RPN) for individual causes of failure do not exceed the critical value of RPN=150 according to the above-mentioned standard. As a result, taking preventive measures to reduce the risk of hazards is not necessary. Therefore, the examined system should be considered safe.

Key words: FMEA, safety assessment, rail vehicles.

1. Introduction

The Failure Mode and Effects Analysis (FMEA) in the rail transport sector plays an important role in developing evidence for the safety requirements of products (vehicles, infrastructure, signalling equipment), particularly at the design stage. The FMEA analysis is one of many methods for estimating explicit risk. The purpose of the FMEA is to assess the risks associated with the hazards and to take action to reduce or eliminate them, primarily for hazards relevant to the railway system. The FMEA method in relation to various systems and technical objects is widely described in literature (Kaczor, Szkoda, 2014; Fuć et al., 2019; Satora, Szkoda, 2019) and standards, for example:

- MIL-STD-1629A Procedures for Performing a Failure Mode, Effects and Criticality Analysis;
- BSI BS 5760-5:1991 Reliability of systems, equipment and components. Guide to failure modes, effects and criticality analysis (FMEA and FMECA), IMO MSC Resolution 36(63) Annex 4 – Procedures for Failure Mode and Effects Analysis;
- PN-EN IEC 60812:2018-12 – Failure modes and effects analysis (FMEA and FMECA).

It is a proposed tool in the RAMS procedure according to the PN-EN 50126-1:2018-02 standard. It provides a systematic approach to identify the causes and effects of potential inadequacies at the local (component) as well as global (system) level. This method requires the involvement of a team of engineers of different specialties (designers, safety engineers, analysts, others) who, using their collective knowledge and experience, develop the analysis documentation. An important feature of this method is that it is cyclic, which means that it should be carried out in every phase of the railway product's life cycle and also after significant modifications of the product, which might have an impact on changing safety requirements. It can be applied at many levels of an object

(system, subsystem, element), and therefore the knowledge of the reliability structure of the object of analysis is required. This is particularly the case for highly complex objects, which undoubtedly include railway systems. This in turn requires reference to other normative documents, such as:

- EN 61078:2017-01 – Reliability block diagrams;
- EN 61025:2007 – Failure tree analysis (FTA).

The presented methods can be used interchangeably and the decomposition of an object should be performed until the required level of detail of the object structure is reached. In this way, each individual element can be assigned specific functions and hazards and the impact of specific types of failure on the local (component) and global (system) effect can be analysed.

2. Methodological basis for FMEA analysis

The FMEA method is a quantitative method in which the risk of occurrence of each identified hazard type is estimated by means of the *RPN* (Risk Priority Number) index, expressed by the following relation (PN-EN IEC 60812:2018-12):

$$RPN(z_k) = \prod_{i=1}^{3} r_i(z_k) => RPN = S_k \cdot O_k \cdot D_k$$

where:

R_1 *(from*$_k$*)* – risk component corresponding to the hazard impact criterion S (Severity),
R_2 *(from*$_k$*)* – risk component corresponding to the hazard probability criterion O (Occurrence),
r_3 *(from*$_k$*)* – risk component corresponding to the hazard detectability criterion D (Detection),
k – type of hazard.

The above elements are generally rated on a scale of 1 to 10 based on the adopted classification criteria. The *RPN* risk assessment index thus takes values from 1 to 1000. Various techniques for categorising the risk components are proposed in standards and literature. The number of categories, their scale and description should be tailored to the specific test object in order to ensure comparability with vehicles of a similar type operated under similar conditions.

a) Identification of types of unfitness

The types of unfitness of complex objects should be identified on the basis of:

- operating conditions,
- specifics of the individual elements,
- operating phases,
- assumed service life,
- impacts on other elements.

In the case of new elements of which the objects are composed, the types of unfitness may be identified on the basis of properties and historical data of other elements in technical service. As proposed in the standard (PN-EN IEC 60812:2018-12), the preferred approach to identifying types of unfitness is to refer to the target functionality due to possible different requirements or operating conditions.

b) Identification of causes of unfitness

In the FMEA analysis, the causes of unfitness are often presented in relation to the properties of the analysed object, such as: physical, mechanical, electrical, other properties. Therefore, the causes of component unfitness can be e.g.:

- use of material with inadequate strength properties,
- incorrect assembly,
- lack of concentricity,
- use of the wrong lubricant,
- exceeding of permitted operating parameters,
- operator error,
- other.

c) Identification of the consequences of unfitness

The effect of unfitness is an unexpected change in the correct functioning and/or loss of functionality of an analysis object. The effect may relate to the occurrence of one or more types of malfunctions. At the level of an element (local), e.g. a malfunction of an automatic door opener in a vehicle may result in passengers having to open the door manually. At the object level (global), e.g. a malfunction of the automatic door release button on a vehicle may cause an extended exchange of the passenger flow and prevent the scheduled journey time from being achieved.

3. Criteria for assessing unfitness

The criteria for assessing unfitness refer to three classifications, related to its significance (degree of impact), its frequency of occurrence and the possibility of its early detection. For each of the classifications, a project team consisting of safety, structural, analytical and other specialists establishes a scale and rules for assigning the appropriate S, O, D value to a given incidence of unfitness.

This chapter focuses on an alternative classification, proposed as an example in the latest version of the standard (PN-EN IEC 60812:2018-12). Due to the fact that this standard does not impose the necessity of using an identical classification, the current approaches are most often used in the industry. This does not mean that the FMEA analysis carried out in this way will be incompatible with the latest version of the PN-EN IEC 60812:2018 standard.

a) Severity classification

The classification of the significance of the component's unfitness for the correct operation of the system should be made on the basis of:

- construction, principle of operation and conditions of use of the component;
- functionality (the set of functions performed);
- established customer requirements;
- local requirements and regulations in the area of operation of the facility;
- manufacturer's warranty coverage.

Table 1
Example of the Severity (S) index for the classification of hazards in rail transport according to PN-EN IEC 60812:2018-12

Unfitness significance ranking (S)	Description
1	Possibly insignificant risk. No human injury expected.
2	One person with minor injuries
:	:
6	Critical, one fatality or multiple severely injured
7	Catastrophic, several fatalities
8	Catastrophic, many fatalities

Source: own study.

b) Occurrence index

The classification of the incidence of unfitness can be made on the basis of:
- generally available standards, such as MIL-STD-1629A;
- determination of the influence of environmental factors, mechanical, electrical stress range, etc. (linear, exponential, other relationship) (linear, exponential, other);
- test/operational trial data;
- service data;
- unfitness data of other elements of a similar class.

It is important for the estimation of the incidence of failure to specify the operating time to which this incidence refers.

Table 2
Example of the Occurrence (O) index classification for railway applications according to PN-EN IEC 60812:2018-12

Frequency ranking (O)	Description
1	Prevalence (λ) less than or equal to 1 in 100 000 years
2	1/100000 years > $\lambda \geq$ 1/30000 years
3	1/30 000 years > $\lambda \geq$ 1/10 000 years
4	1/10 000 years > $\lambda \geq$ 1/3 000 years

Source: own study.

c) Detectability index

The possibility of earlier detection of unfitness can be realised at the stage of:
- design;
- production (manufacturing);
- operation (ongoing maintenance, planned maintenance).

Table 3
Example of Detectability Index (D) classification for railway applications according to PN-EN IEC 60812:2018-12

Detectability ranking (D)	Description
1	Avoidance of consequences is almost always possible, for example by means of independent technical systems
2	Avoidance of consequences is often possible due to favourable conditions
3	Avoidance of consequences is sometimes possible due to unfavourable conditions
4	Avoidance of consequences is virtually impossible

Source: own study.

d) Risk matrix

The risk matrix allows the relationship between the selected indices and the level of risk to be determined. For example, Table 4 shows the relationship between the probability of unfitness and the level of significance (for the recipient).

Table 4
Example of risk matrix according to PN-EN IEC 60812:2018-12

Probability	Level of significance			
	Catastrophic	Serious	Marginal	Insignificant
5: High	Unacceptable	Unacceptable	Undesirable	Acceptable
4: Medium	Unacceptable	Unacceptable	Undesirable	Acceptable
3: Low	Unacceptable	Unacceptable	Undesirable	Acceptable
2: Very low	Unacceptable	Undesirable	Undesirable	Acceptable
1: Unlikely	Undesirable	Acceptable	Acceptable	Insignificant

Source: own study.

4. Example of FMEA analysis application

As an example of an FMEA failure mode and effects analysis for use in rail transport, the relevant elements of the risk assessment of damage to the elements of the draw- and buffing gear of a normal coal car are presented. This technical object is shown in Figure 1.

Figure 1. Coal car of normal construction.
Source: authors' materials.

The draw- and buffing gear components are primarily designed to transmit longitudinal forces resulting from traction power generation, including mechanical coupling between coupled railway vehicles. In addition, they make it possible to mitigate collision forces due to the running of the vehicles and to maintain an adequate distance between the vehicles.

In the classic solution, shown in Figure 2, at each end of the vehicle, the non-crossover draw gear consists of a screw coupling connected by a pin to a draw hook, which is mechanically connected via a draw gear to the end face of the vehicle's supporting frame (the 'blade'). The elements classified as a buffing device are two buffers attached to the end face of the stand symmetrically about the longitudinal axis of the car.

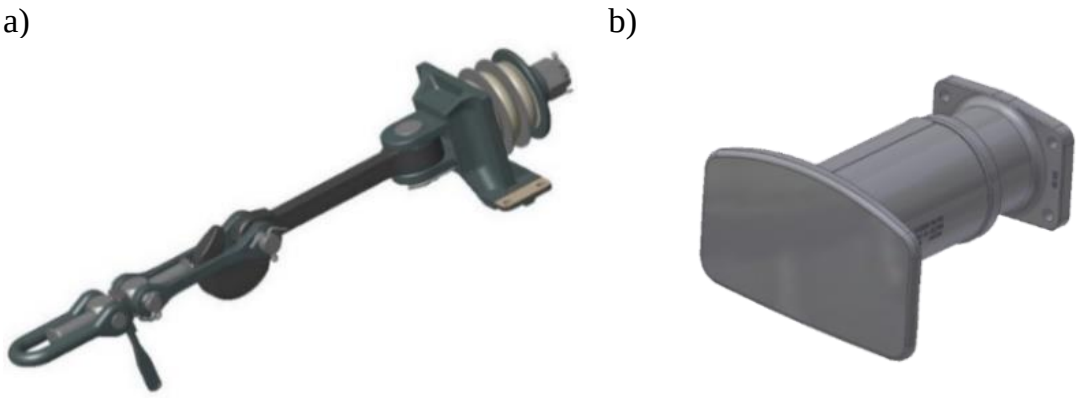

Figure 2. The draw- and buffing gear: a) screw coupling, draw hook and draw gear, b) buffing gear. Source: AXTONE S.A.

Figure 3 shows a schematic diagram of the draw- and buffing gear of a normal-sized coal car.

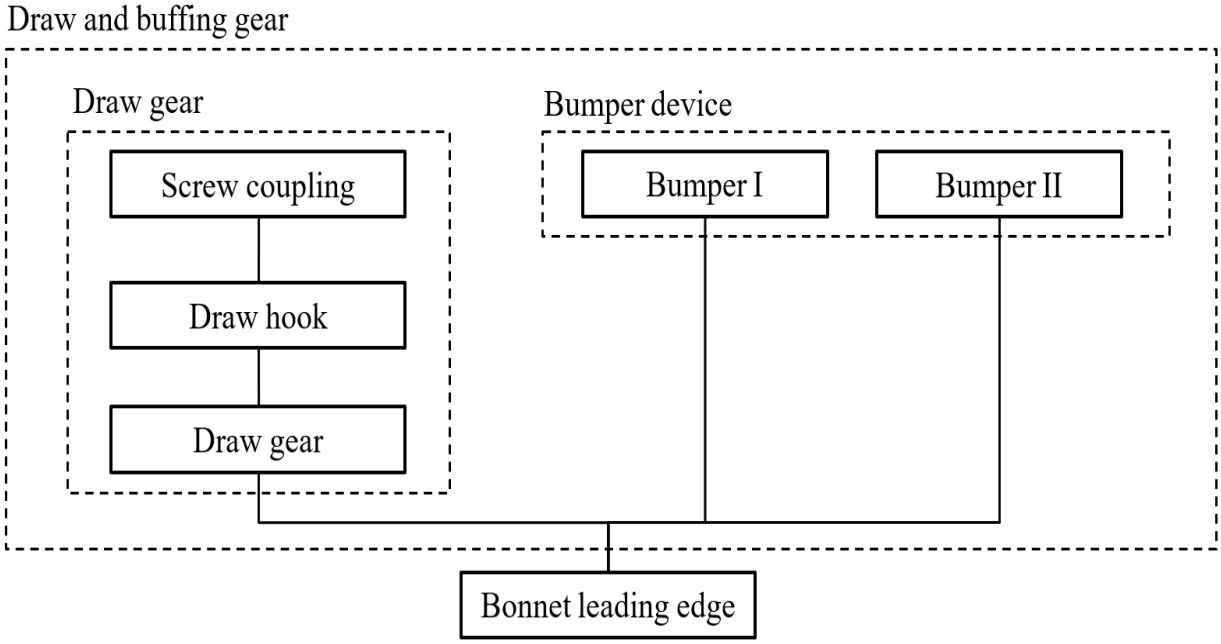

Figure 3. Basic elements of the draw- and buffing gear of a normal coal car. Source: own study.

The draw-and buffing gear is responsible for carrying out the function of:
F1 – transmission of longitudinal forces,
F2 – mitigation of longitudinal forces.

Failure of the draw-and buffing gear is associated with the possibility of the following hazards:
H1 – total loss of functionality,
H2 – functional deterioration.

Due to the optimisation of the vehicle design with respect to weight limitation and reduction of the number of components that must be serviced as part of the planned activities in accordance with the maintenance cycle defined in the documentation of the maintenance system of the particular car type, the reliability structure of a normal coal car is serial. Therefore, when one of the components becomes unserviceable, the whole vehicle (considered as a system) becomes unserviceable too. On the basis of PN-EN IEC 60812:2018-12, an FMEA sheet has been developed to assess the risk of failure of the draw- and buffing gear of a normal coal car. To determine the risk index, an approach based on the product of the parameters S, O, D has been used. These elements were evaluated on a scale from 1 to 10 on the basis of the adopted classification criteria – Tables 5-7. The risk assessment index *RPN* thus takes values from 1 to 1000.

Table 8 shows the FMEA sheet based on which the risk assessment of damage to the draw-and buffing gear of a normal coal car has been made. The RPN values do not exceed the critical figure which is equal to RPN=150. Therefore, the analysed system should be considered safe.

Table 5
Classification of the Severity Index S

Severity S		**Scoring**
The effects of the hazard are irrelevant to the level of safety. No cost.		1
The impact of the hazard may be minor and only lead to a slight reduction in safety (e.g. disruption to traffic flow) and/or costs:	up to EUR 10000	2
	up to EUR 50000	3
The consequences of a hazard occurring can be quite significant and lead to reduced safety (e.g. incident, injured, etc.) and/or costs:	up to EUR 100000	4
	up to EUR 250000	5
	up to EUR 500000	6
The consequences of a hazard occurring can be severe and lead to a significant reduction in safety (e.g. train accident, serious injuries, etc.) and/or costs:	up to EUR 750000	7
	up to EUR 1000000	8
The consequences of a hazard occurring can be very serious and lead to a drastic reduction in safety (e.g. major train accident, fatalities, etc.) and/or costs:	up to EUR 2000000	9
	above EUR 2000000	10

Source: own study.

Table 6
Classification of the O (Occurence) Frequency Index

The incidence of unfitness O	Frequency [1 error/ vehicle km]	Scoring
The probability of a hazard occurring is negligible, practically non-existent	1/2500000	1
The probability of a hazard occurring is low. The causes of the hazard are very rare	1/1750000	2
	1/1250000	3
The probability of a hazard occurring is medium. The causes of the hazard occur sporadically from time to time.	1/850000	4
	1/600000	5
	1/350000	6
The probability of a hazard occurring is high. The causes of the hazard are rare.	1/125000	7
	1/75000	8
The probability of a hazard occurring is very high. It is almost certain that the hazard will occur	1/50000	9
	1/25000	10

Source: own study.

5. Conclusions

The paper presents an application example of FMEA analysis according to the new approach proposed in the PN-EN IEC 60812:2018 standard. The draw- and buffing gear of a coal car of normal construction was used as an object of analysis. The conducted analysis showed that the values of the RPN index do not exceed the critical value equal to 150 according to the mentioned standard. This means that it is not necessary to take preventive measures to reduce the risk of hazards. The system is considered safe.

Table 7
Classification of the early detectability D (Detectability) index

Earlier detectability D	Scoring
The probability of detecting a hazard is very high. Disclosure of the cause of the error is certain.	1
	2
The probability of detecting a hazard is high. The control measures in place reveal the cause of the error. Symptoms of the cause are observed.	3
	4
Average probability of hazard detection. The control measures in place may be able to reveal the cause of the error. Symptoms indicating the possibility of a hazard can be identified and determined.	5
	6
Low probability of hazard detection. It is very likely that the control measures in place will not reveal the cause of the error. Determining the cause of the error is very difficult.	7
	8
Negligible probability of detecting a hazard. Virtually impossible to determine the cause of the error.	9
	10

Source: own study.

Table 8
FMEA sheet for risk assessment of failure of a draw- and buffing gear of a normal coal car

System	Subsystem	Cause of unfitness	Share in total number of incidents	Damage intensity [damage/km]	Function	Hazard	S	O	D	RPN
Coal car of normal construction	Bumper device	damaged bumper disc, bush, scabbard or spring	15.1%	5.20E-07	F2	H1	1	6	7	**42**
		clearly different buffer types at the same end of the car	0.6%	2.12E-08	F2	H2	1	7	2	**14**
		bumper disc clearance exceeded	3.1%	1.06E-07	F2	H2	1	5	7	**35**
		incorrect or defective fixing to the headstock	31.7%	1.09E-06	F2	H1	3	5	8	**120**
	Draw gear	screw coupling	30.8%	1.06E-06	F1	H1	3	4	8	**96**
		draw hook	12.6%	4.35E-07	F1	H1	1	5	7	**35**
		draw gear and split coupling	0.9%	3.18E-08	F1	H1	1	7	7	**49**
		hook guidance components	1.8%	6.37E-08	F1	H2	1	3	5	**15**
		bolts and other coupling components	3.4%	1.17E-07	F1	H1	1	4	5	**20**

Source: own study.

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Quantitative and qualitative analysis of the periodic technical tests at selected vehicle control stations

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Abstract: Technical inspections are the main element affecting the safety of road traffic, and the supreme legal act regulating the system of technical inspections of vehicles is the Act of 20 June 1997. Law on Road Traffic. (Journal of Laws of 19 August 1997). During technical inspections, defects can be identified, which are divided into three groups: minor defects, significant defects and defects that pose a risk. (Notice, 2015). The aim of the study will be to perform an analysis and answer the following questions: Does the age of the vehicle affect the result of the periodic technical inspection? Is there a relationship between the brand of the tested vehicle and the result of the technical inspection? From the available research tools, the Statistica program was chosen for the qualitative and quantitative analysis. By analysing data from selected District Vehicle Inspection Stations, information on the technical condition was obtained with a breakdown into the defects found. Based on the results, it was found that there is a strong relationship between vehicle age and technical condition. As a result of the study, the failure rate of selected vehicle brands was reviewed.

Key words: automotive diagnostics, vehicle technical inspection, defects, technical condition verification.

1. Introduction

Diagnosis of road vehicles is related to the on-going assessment of their technical condition and carrying out technical inspections on time. Ongoing assessment of the technical condition enables the diagnosis of damage and indicates actions necessary to remove them (Sitek, Syta, 2011).

Periodic and additional tests are carried out by vehicle inspection stations at the request of the owner or upon a referral by a starost or a road traffic control authority (Sitek, Syta, 2011).

The system of periodic technical inspections as well as the number of defects is very important in terms of road traffic safety and the number of road incidents (Palubicki, Czapiewski, 2017).

In our country we have two divisions of vehicle inspection stations, basic stations which are authorised to test vehicles with maximum permissible weight up to 3.5 tonnes and Regional Vehicle Control Stations which are authorised to carry out full-scope technical inspections. Moreover, they are authorized to carry out tests of conformity of historic vehicles with technical conditions and placing the substitution identification features. At the end of 2021 in Poland there were 5443 active vehicle inspection stations, of which 2980 are basic vehicle inspection stations and the remaining 2463 are district stations with full scope of authorisations in the field of technical inspections and other activities related to vehicles admitted to road traffic. Periodic inspection of each vehicle starts with identification and comparison of the actual state of affairs with data contained in the registration certificate or a corresponding document, and by assessing the registration plates and the condition of the identification features (Figure 1).

Next, the braking system is assessed in terms of its efficiency and braking force for the service brake and for the auxiliary (parking) brake. We assess the completeness of the braking system, the degree of wear of the brake discs and brake pads and the correctness of repairs made to the system by visual inspection of a component without dismantling it.

Figure 1. Picture of the vehicle identification with the data contained in the registration certificate.
Source: authors' materials.

Figure 2. Picture of a vehicle placed on a roller device.
Source: authors' materials.

The steering and running gear system is assessed in terms of the correctness of the geometric alignment of road wheels, condition of steering gear, swivel and articulated joints. In addition, in the vehicle running gear, the following checks of wheels and tyres are carried out. The spring and damping elements of the suspension are assessed, as well as the completeness of the system that makes up the suspension.

Using an organoleptic method, the vehicle lighting system is checked for efficiency, completeness and conformity with the necessary equipment for the given type and correctness of installation. The vehicle's visibility from the driver's seat, the condition of the vehicle windows, the light transmission if tinted film is used for the windscreen and driver and passenger side windows are also assessed. The condition of indirect vision devices (mirrors, cameras), vehicle equipment, seats and seat belts of the vehicle, seats and safety belts, and electronic systems are checked (Gawlik, 2012).

The condition of the vehicle chassis and bodywork and the elements attached to it are evaluated. The vehicle is organoleptically assessed for erosive corrosion, which is a quite serious and common problem in the Polish climatic zone. Signs of such corrosion are most often deformations and cracks in elements of the body and chassis (Figure 3).

Figure 3. A photograph showing a vehicle chassis structural element in an advanced state of degree of erosive corrosion.
Source: authors' materials.

During the activities related to the periodical technical inspection of a vehicle the elements and all systems of the vehicle are evaluated. In this case, the four-stage graded scale of assessment of the vehicle condition is used. The first level is the absence of remarks-positive result (Gębiś, 2020).

The second level is minor defects (UD) – defects do not affect road safety and environmental protection – positive result.

The third criterion is identified significant defects (UI) defects affect safety and environmental protection – negative.

In this case an entry is made in the Central Vehicle Register with a conditional permission to conditional admission to traffic for 14 days, in order to submit the vehicle to necessary repairs and re-testing. The owner or user of such a vehicle has 14 days to rectify the defects identified in order to obtain a positive result (without comments) on the defects found.

It should be noted that the current legislation does not force the inspector to pay attention to the technical condition of other items already inspected, which during these 14 days may have been damaged e.g. by a previously detected defect that could lead to a negative test result, e.g. a destroyed tyre (jammed edge) due to an incorrectly adjusted or damaged wheel alignment.

The fourth group on the four-stage assessment scale is hazard defects (CVT). These defects directly endanger the safety and orderliness of road traffic (RSI). In this case, the vehicle registration certificate or the corresponding document. This document will be handed over to the authority that issued it. A relevant entry is made in the register of the Central Vehicle Register. The vehicle user is informed that the vehicle has to be repaired or withdrawn from service, and the vehicle is banned from use, as it constitutes a danger to both the vehicle operator and other road users of road traffic (Kubiak, 2012).

2. Leading legal sources relating to the subject of the article

The supreme legal act reacting to the system of technical inspections of vehicles operated on roads is the act "The Road Traffic Law" of 20 June 1997 as amended (Act, 1997). Article 81 stipulates that: "The owner of a motor vehicle, agricultural tractor, slow-moving vehicle which is part of a tourist train, a moped or a trailer is obliged to present it for a technical inspection" (Law, 1997).

Another piece of legislation is the Announcement of the Minister of Infrastructure and Construction of 27 October 2016 on the announcement of the consolidated text of the Regulation of the Minister of Infrastructure on technical conditions of vehicles and the scope of their necessary equipment (Dz.U. 2016 pos. 2022) (Regulation, 2016). The quoted document sets out the administrative technical conditions and equipment to be met by a vehicle travelling on public roads.

Regulation of the Minister of Transport and Construction of 10 February 2006 on detailed requirements for stations carrying out technical inspections of vehicles (Journal of Laws 2006 No. 40 item 275). The regulation defines the following conditions of premises and the accompanying infrastructure both inside and outside the facility, as well as control and measurement equipment in the vehicle control station respectively to the tested vehicles (Regulation, 2006).

On the scope and method of carrying out technical inspections and specimens of documents used during these tests applies the Announcement of the Minister of Infrastructure and Development of 21 April 2015 on the announcement of uniform text of the Regulation of the Minister of Transport, Construction and Maritime (Journal of Laws 2015, item 776) (Announcement, 2015). This regulation contains a detailed procedure for carrying out periodic and additional technical inspections. The regulation defines the scope of periodic technical inspection and the scope of additional technical inspection.

3. Objective and scope

The aim of the study will be to perform an analysis of data from two vehicle inspection stations and answer the following questions:

Does the age of the vehicle affect the result of the periodic technical inspection?

Is there a relationship between the make of the tested vehicle and the result of theof technical inspection?

What is the most frequent reason for issuing a negative opinion by a vehicle inspection station?

From the available research tools for the qualitative and quantitative analysis, the following were selected. Statistica programme was chosen for the qualitative and quantitative analysis, and the data from the vehicle inspection stations were imported from PATRONAT programme. The database was prepared in the EXCEL programme.

4. Description of the test method

The District Vehicle Inspection Stations at which the technical condition of all vehicles admitted to road traffic was tested are located in the administrative district of Nowy Sącz. The control and measurement equipment of the stations under analysis includes the following devices and instruments:

- lfting device: whole vehicle, vehicle axles;
- equipment for checking the operation of the brakes: roller device, plate device (overrun device), retarder;
- vehicle wheel alignment measuring device;
- instrument to assess whether the vehicle's road wheels are correctly aligned;
- instrument for measuring and adjusting air pressure in vehicle tyres;
- vehicle headlamp aiming and brightness measuring device;
- sound level meter;
- smoke meter;
- vehicle-trailer electric junction tester;
- instrument for applying a controlled load to the control of the overrun brake control of the trailer;
- vehicle wheel jerk inducer;
- composite exhaust gas analyser for spark-ignition engines;
- instrument to measure wheel and axle alignment;
- suspension damping test equipment for vehicles with maximum permissible weight up to 3.5 t;
- diagnostic information reader for OBDII/EOBD;
- instrument for measuring the light transmission coefficient of the vehicle glazing of light;
- electronic gas detector for checking gas leaks.

Empirical data were collected at two vehicle inspection stations of the Nowy Sącz district as an archive of the PATRONAT programme of the Motor Transport Institute. The data concern vehicles tested at the stations in the period from 1 January 2021 to 31 December 2021.

From the data that can be imported from the PATRONAT program, the following were selected for analysis:

- vehicle make;
- vehicle type;
- test result;
- date of first registration at home or abroad;
- test result;
- defects found.

A database was prepared in the form of an Excel sheet on the basis of the mentioned variables for further continuation in Statistica. At the stage of data preparation, the correctness of entries was checked, transformations and variables were selected and preliminary analyses were carried out. Records were standardised, as the diagnosticians entered some records in an inconsistent manner.

On the basis of data contained in the PATRONAT program database concerning the date of first vehicle registration and the date of last inspection were created on the basis of variables were created. Station. Variable data were selected for analysis, which can be divided into three groups:

- vehicle-related variables: make; vehicle type; date of first registration in date of first registration in the country; date of first registration abroad; year of construction and age of the vehicle at the time of the survey;
- test-related variables: date of test, type of test, result of test;
- variables relating to defects detected during tests which are classified in accordance with Annex 1 of the Regulation of the Minister of Transport, Construction and Maritime Economy in the scope and manner of technical inspections of vehicles and specimens of documents used during these tests. These variables were divided into:
  - 0. Vehicle identification,
  - 1. Braking system,
  - 2. Steering,
  - 3. Visibility,
  - 4. Lights and electrical equipment,
  - 5. Wheel axles, tyres and suspension,
  - 6. Chassis and chassis attachments,
  - 7. Other equipment,
  - 8. Nuisance,
  - 9. Additional conditions,
  - 10. Other conditions.

4.1. General data

Based on information from the Central Register of Vehicles and Drivers (CEPiK) in Poland in 2021 there were 2463 District Vehicle Inspection Stations and 2980 Basic Vehicle Inspection Stations registered (www.cepik.gov.pl/statystyki, accessed: 16.04.2022) (Figure 4).

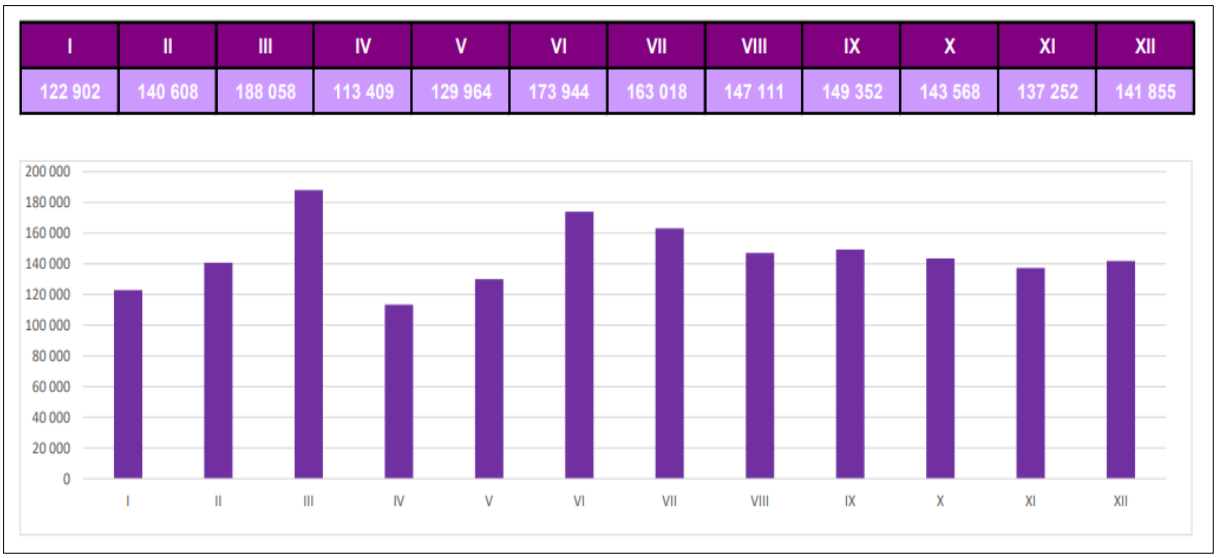

Figure 4. Graph showing vehicles registered in each month of 2021.
Source: compiled on the basis of www.cepik.gov.pl/statystyki (accessed: 16.04.2022).

On the basis of the data presented, it may be noted that March and holiday months, the highest number of vehicles was registered.

It may be noted that the highest number of cars in 2021 was registered in the Masovia Province, followed by the Greater Poland, Silesia, Lesser Poland, Lower Silesia (Figure 5).

The next piece of information which can be found in CEPiK is the number of technical inspections performed in 2021 by type of test and its result. Data for the whole of Poland are presented in Table 1.

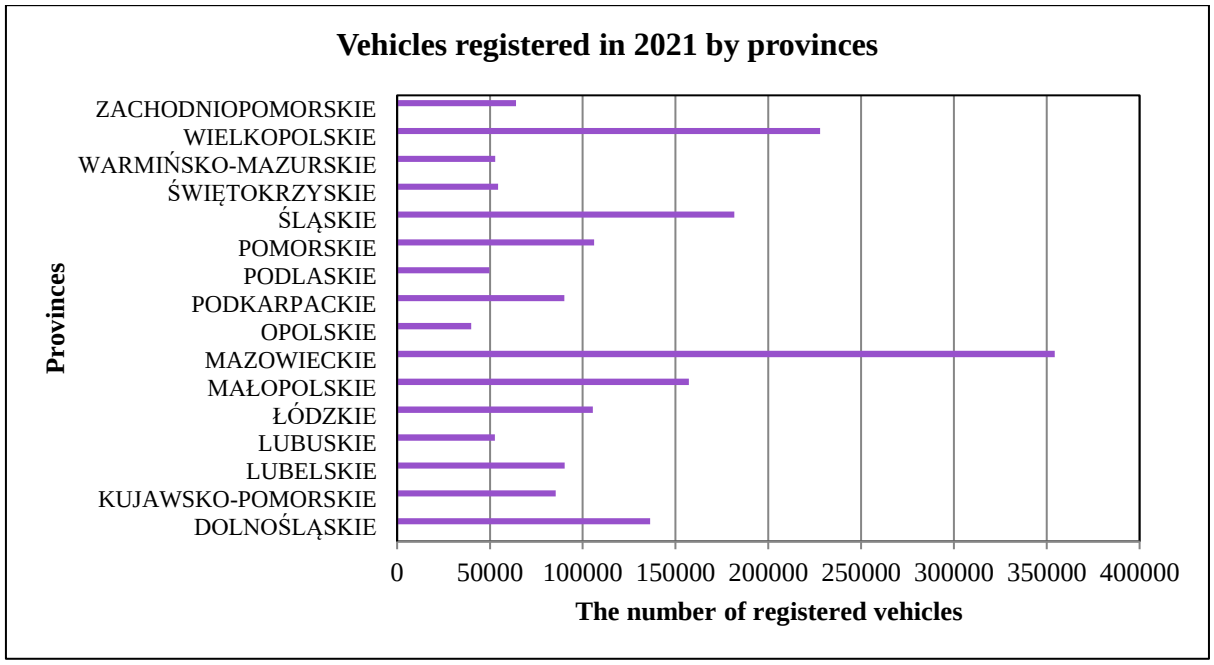

Figure 5. Graph showing vehicles registered in each province.
Source: own elaboration based on: www.cepik.gov.pl/statystyki (accessed: 16.04.2022).

Table 1
Statistical data on technical inspections by type of inspection and its result performed in 2021 in the entire Poland

Kind of inspection	Test result	Number of conducted tests
Periodic	negative	437 080
Periodic	positive	18 208 873
Additional	negative	3 384
Additional	positive	513 868
Compliance with technical conditions	positive	7 715
Compliance with technical conditions	negative	0
Technical inspection by rechecking the defects	negative	1 439
Technical inspection by rechecking the defects	positive	296 390
Odometer reading after replacement	negative	24
Odometer reading after replacement	positive	47 542

Source: own elaboration based on: www.cepik.gov.pl/statystyki (accessed: 16.04.2022).

On the basis of the data in the table, it can be stated that, on average 2.23% of the tested vehicles received a negative result of the periodic technical inspection in Poland. It may be noted that among the examined vehicles, as regards compliance with technical conditions, all of them were positive.

For comparison, a similar summary was prepared for the two analysed stations of Nowy Sącz district and compared with the national data (Table 2).

Table 2
Statistical data on technical inspections by type of inspection and result

Kind of inspection	Test result	Number of tests carried out in Poland	Number of test carried out in district vehicle inspection centre 1	Number of test carried out in district vehicle inspection centre 2
Periodic	negative	437 080	101	297
Periodic	positive	18 208 873	3317	7632
Additional	negative	3 384	1	21
Additional	positive	513 868	147	228
Compliance with technical conditions	positive	7 715	0	0
Compliance with technical conditions	negative	0	0	5
Technical inspection by rechecking the defects	negative	1 439	4	14
Technical inspection by rechecking the defects	positive	296 390	105	295
Odometer reading after replacement	negative	24	0	0
Odometer reading after replacement	positive	47 542	5	17

Source: own study based on data from the diagnostic stations analysed.

On the basis of the table it has been calculated that on average in Poland 93.3% of periodic examinations were positive, which is slightly more than the analysed stations. In district vehicle inspection centre 1 the average of positive results of periodic examination was 89.7% and in district vehicle inspection centre 2 the average of positive results of periodic examination was 90.1% (Figure 6).

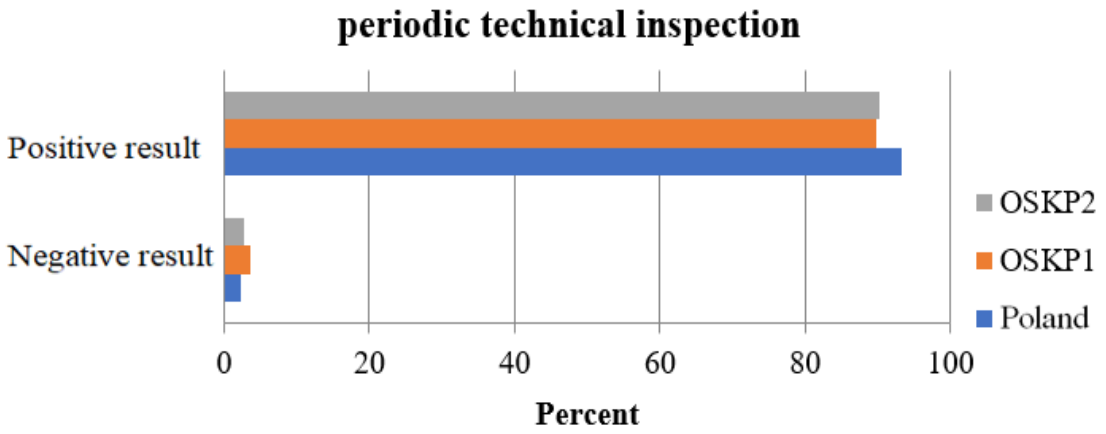

Figure 6. Bar chart showing periodic evaluation in the stations under analysis and in Poland.
Source: own study based on data from the diagnostic stations analysed and CEPiK.

4.2. Research findings

The analysis sought answers to the following questions:

– Does the age of the vehicle affect the result of the periodic technical inspection?
– Is there a correlation between the make of the tested vehicle and the result of the technical inspection?
– What is the most frequent reason for a negative opinion issued by a vehicle inspection station?

Figure 7 shows the relationship between the age of the vehicle and result of the technical condition test for district vehicle inspection centre 1 station. Among the analysed cars were dominated by vehicles from 10 to 15 years and from 15 to 20 years.

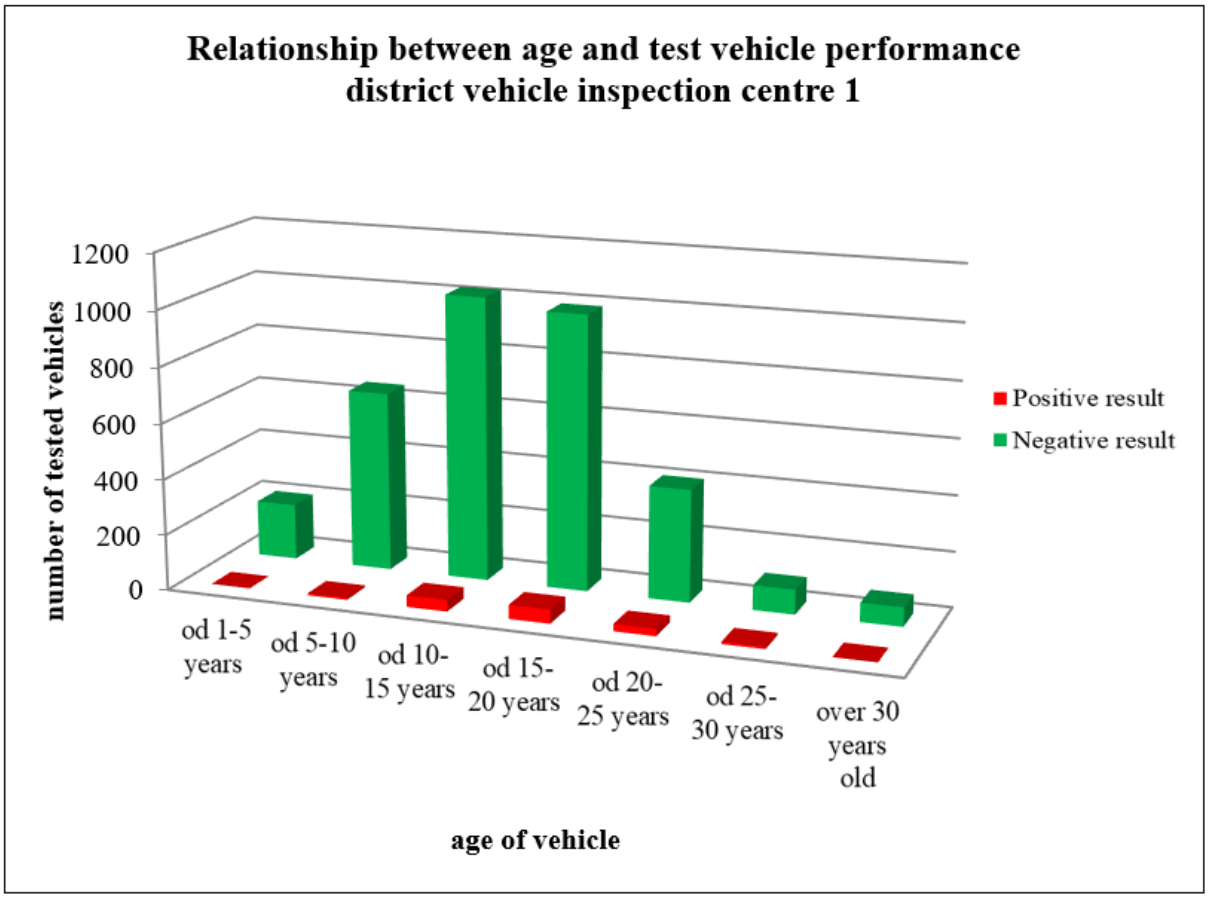

Figure 7. Column diagram showing the relationship between the age of a vehicle and its test result for district vehicle inspection centre 1.
Source: own study based on data from the diagnostic stations analysed.

The average age of all the analysed vehicles at the station was 14.9 years and the standard deviation was 6.4 years. The mean age for vehicles with a positive result was 14.7 and the standard deviation was 6.2 years. From the characteristics data, it can be seen that older cars had more negative results than younger cars.

Figure 8 shows the relationship between the age of the vehicle and the result of the technical condition test for district vehicle inspection centre 2. The cars analysed were also dominated by those between 10 and 15 years old and those between 15 and 20 years old.

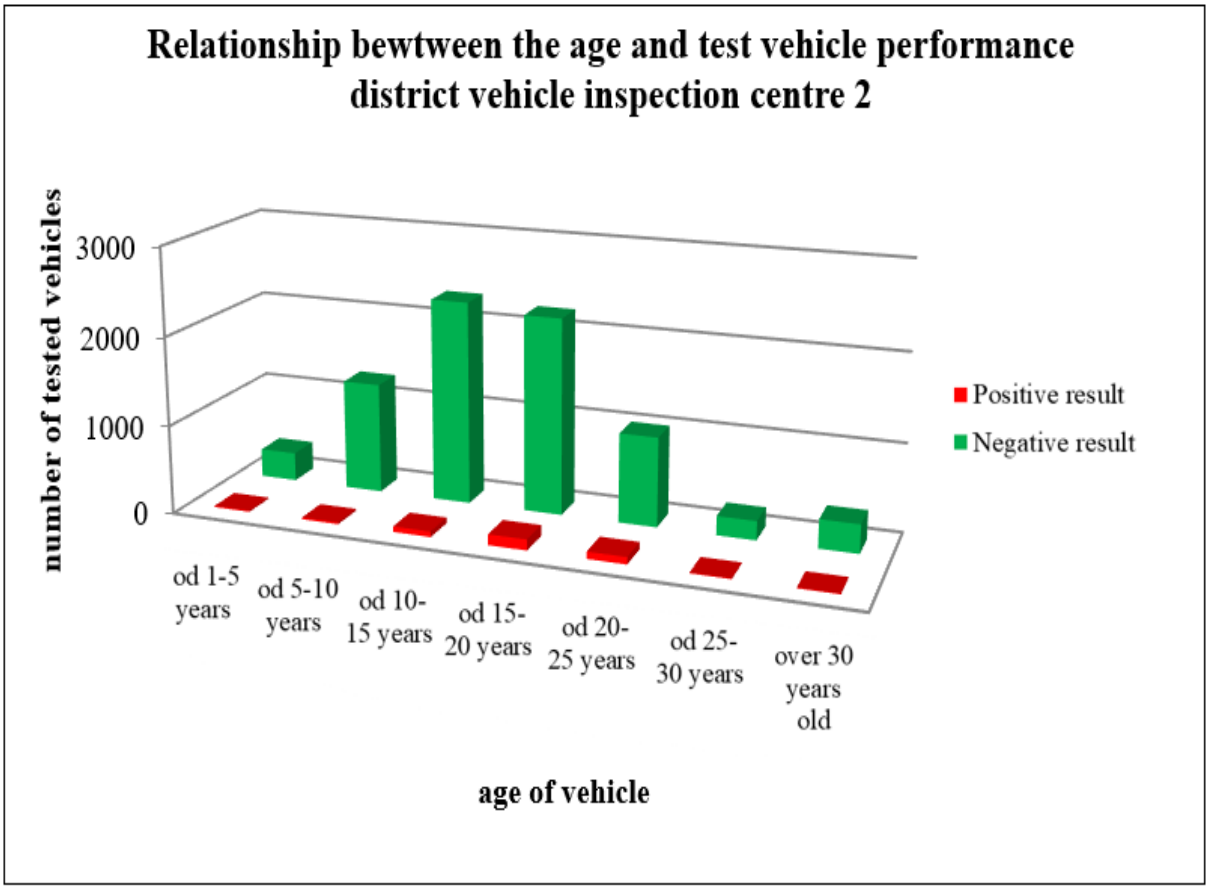

Figure 8. Column diagram showing the relationship between the age of a vehicle and its test result for district vehicle inspection centre 2.
Source: own study based on data from the diagnostic stations analysed.

The average age of all vehicles analysed at district vehicle inspection centre 2 was 16.1 years and the standard deviation was 7.4 years. The average age for vehicles with a positive result was 15.7 years, and the standard deviation was of 7.2 years. The characteristics data show that older vehicles had more negative results than younger ones. Comparing the two stations studied, the first was located in an urban area and had fewer vehicles undergoing periodical tests and also the average age of vehicles in operation is lower than in the second surveyed group. The second station was located in a large rural commune and had tested a lot of older vehicles, hence the average age of the tested vehicles was higher.

On the basis of Appendix No. 1 to the Ordinance on technical tests and specimen technical inspections and specimen documents (Notice, 2015), a table was prepared in accordance with the order indicated in the Ordinance. Table 3 shows defects detected in periodic vehicle inspections at the two analysed stations and the number and percentage of tests with negative results are given.

Table 3

Types of faults and their share in the total number of vehicles tested at OSKP1 and OSKP2 stations made in 2021

Type of failure	District vehicle inspection centre 1		District vehicle inspection centre 2	
	Number of cases at the station	Percentage share of vehicles with negative result	Number of cases at the station	Percentage share of vehicles with negative result
0. Vehicle identification	287	29.9	362	14.8
1. Braking system	90	**72.4**	1288	**72.4**
2. Steering	80	**57.5**	824	**51.9**
3. Visibility	56	**41.0**	575	**50.8**
4. Lights and electrical equipment	203	**34.3**	1073	**47.5**
5. Wheel axles, tyres and suspension	103	31.3	485	41.4
6. Chassis and elemnts attached to chassis	40	24.6	198	18.9
7. Other equipment	35	20.1	573	17.2
8. Nuisance	3	1.5	11	3.7
9. Additinal conditions	10	5.2	2	0.7
10.Other conditions	25	14.2	47	6.7

Source: own study based on data from the diagnostic stations analysed.

When analysing the percentage share of vehicles with various defects in relation to those vehicles that failed, the most numerous was the group of types of faults affecting road safety, which was ca. 80% of all systems at district vehicle inspection centre 1 and 86% of all systems at district vehicle inspection centre 2.

According to the Pareto principle we can conclude that the most numerous group are the systems: 1, 2, 3, 4, 5, 6 according to the numbering in the Decree (Notice, 2015). In both analysed stations the defects of the braking system were in the first place, followed by steering system and then visibility.

Very worrying is the result of defects of the braking and steering systems which on average have every second car with a negative result. Such vehicles pose a danger and are a serious threat in road traffic.

The next part of the article examines what are the most popular car brands at one and the other station and whether the location of the station was significant for such analysis.

Table 4 presents the most popular car brands from data obtained from district vehicle inspection centre 1.

Table 4
The most popular car brands from data obtained from district vehicle inspection centre 1

Lp.	Vhicle make	Number of the most frequently researched makes	Percentage share of the most frequently researched makes
1.	VOLKSWAGEN	367	18.0
2.	RENAULT	257	12.6
3.	AUDI	237	11.6
4.	OPEL	230	11.3
5.	FORD	211	10.4
6.	TOYOTA	171	8.4
7.	FIAT	157	7.7
8.	MERCEDES-BENZ	146	7.2
9.	PEUGEOT	136	6.7
10.	SKODA	126	6.2

Source: own study based on data from the diagnostic stations analysed.

Table 5
The most popular car brands from data obtained from district vehicle inspection centre 2

Lp.	Vehicle make	Number of the most frequently resesarched make	Percentage share of the most frequently researched makes
1.	VOLKSWAGEN	1150	23.2
2.	OPEL	637	12.8
3.	AUDI	598	12.0
4.	FORD	536	10.8
5.	TOYOTA	408	8.2
6.	RENAULT	365	7.4
7.	SUZUKI	360	7.3
8.	FIAT	334	6.7
9.	PEUGEOT	303	6.1
10.	SKODA	274	5.5

Source: own study based on data from the diagnostic stations analysed.

The most frequently tested vehicle makes at district vehicle inspection centre 1 were: VOLKSWAGEN, RENAULT and AUDI and they represented 23% of all tested. They accounted for 23% of all vehicles tested at these stations in a given year of analysis. The ten most popular car brands accounted for almost 60% of all tested vehicles, which is a large percentage of the analysed group.

Table 5 presents the most popular car brands from data obtained from district vehicle inspection centre 2.

The most frequently tested vehicle makes at the district vehicle inspection centre 2 were: VOLKSWAGEN, OPEL and AUDI and they accounted for 28% of all vehicles tested at those stations in a given year of the analysis. The ten most popular car make at this station of cars at this station also accounted for nearly 60% of all surveyed vehicles.

Table 6
Presents data on the failure rate of the most popular vehicle brands at district vehicle inspection centre 1

Lp.	Vehicle make	Number of the most frequently resesarched make	Percentage share of the most frequently researched makes
1.	VOLKSWAGEN	1150	23.2
2.	OPEL	637	12.8
3.	AUDI	598	12.0
4.	FORD	536	10.8
5.	TOYOTA	408	8.2
6.	RENAULT	365	7.4
7.	SUZUKI	360	7.3
8.	FIAT	334	6.7
9.	PEUGEOT	303	6.1
10.	SKODA	274	5.5

Source: own study based on data from the diagnostic stations analysed.

Table 7
Failure rate data for the most popular vehicle brands from district vehicle inspection centre 2 data

Lp.	Vehicle make	Percentage test positive result	Percentage test negative result
1.	TOYOTA	97.5	2.5
2.	FIAT	97.3	2.7
3.	SKODA	97.1	2.9
4.	FORD	96.8	3.2
5.	PEUGEOT	96.7	3.3
6.	AUDI	96.5	3.5
7.	VOLKSWAGEN	96.3	3.7
8.	SUZUKI	96.1	3.9
9.	OPEL	95.4	4.6
10.	RENAULT	94.0	6.0

Source: own study based on data from the diagnostic stations analysed.

It can be noted that at the first station, which is located in an urban municipality, there was MERCEDES-BENZ, while in the second municipality, due to its mountainous location there was a large SUZUKI brand and MERCEDES-BENZ appeared on a further place in the analysis. It can be confirmed that the terrain also has a bearing with what kind of buyers their makes have. The last part of the analysis of the surveyed communities concerned the failure rate of the most popular make in the two surveyed vehicle inspection stations.

Among the ten most popular vehicle brands tested at a given station TOYOTA, AUDI and SKODA turned out to be the least defective, and their share among the cars with defects was on the level of 2-3%. The failure rate of the remaining seven brands ranged from 3-6%.

Among the ten most popular vehicle brands tested at a given station, TOYOTA, FIAT and SKODA turned out to be the least defective, and their share among the cars with defects was on the level of 2-3%. The failure rate of the remaining seven brands ranged from 3-6%, which also means a low failure rate. It may be noted that in both stations the least defective brand was TOYOTA and SKODA.

5. Conclusions

The obtained results from the data analysis under each of the assumed objectives give some conclusions that can be applied by the centres supervising the vehicle inspection stations. On the basis of the data obtained from diagnostic stations, it is possible to read the technical condition of vehicles of a given make in consecutive years of operation. Another important result of the survey is the age range of vehicles most frequently subjected to tests, as well as an indication that the defectiveness of the tested vehicles increases with time. The defectiveness of vehicles of a given brand is the feature which may be most expected by the automotive world.

As diagnostic stations detect defects that affect the result of a technical inspection, the knowledge that can be gained can, to a large extent, be used to improve road safety in road traffic, but also to improve the quality of tested vehicles (Wicher, 2012). The diagnostician performing the test of the vehicle makes visual and organoleptic examination, that is, on the basis of their own senses and knowledge can give an opinion whether the tested car is properly used and operated in accordance with the manufacturer's recommendations. This correctness or incorrectness is not loudly pronounced in the world of motorization but, as it turns out, it has a big influence on the results of technical tests of vehicles.

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Design solutions for rail vehicles contributing to the improvement of the natural environment

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Abstract: The article presents activities aimed at protecting the natural environment by reducing the emission of harmful substances contained in exhaust gases from diesel engines, as well as the economics of operating diesel traction vehicles on the example of the Polish transport company F.H.U. ORION Kolej dribbles, rail freight. Two design solutions limiting the harmful impact of the vehicle on the environment were described, made by ORION Railroad on a diesel locomotive of the SM 42 series. In the first solution, the LNG gas supply system was installed on the existing a8C22 combustion engine, in addition to the traditional diesel fuel, in a dual fuel mode. The draggy project described in the article is a comprehensive modernization of the SM42 locomotive in the 6Dm version, consisting in the replacement of the entire generating set, control system, driver's cabin equipment and engine compartments.

Key words: padel, modernization, diesel locomotive.

1. Introduction

We meet at the present stage of human civilization development with the threat of climate change resulting from the so-called the greenhouse effect. The greenhouse effect causes that the gaseous shell of the Earth, richer in CO, acts as a one-way filter and allows it to pass through part of the visible spectrum to the Earth and stops infrared radiation across it surface of the earth. Long waves of thermal radiation are absorbed, as a result of which the temperature of the Earth's surface and air above the well increases. This phenomenon is commonly called the greenhouse effect (Gronowicz, 2005).

To some extent, land transport powered by internal combustion engines contributes to environmental pollution. Among the branches of land transport, rail transport causes the least damage, especially on electrified lines, but some railway lines and shunting works are carried out by diesel traction.

The degree of environmental pollution with technical land transport means powered by an internal combustion engine depends on:

- physicochemical properties of used fuels, lubricating oils, cooling fluids and others;
- structure and number of means of transport in individual categories, determined by engine capacity, vehicle purpose, production date, condition technical;
- characteristics of the share of vehicles in particular types of traffic.

The operation of internal combustion engines in locomotives is the main cause of environmental pollution with the emitted toxic compounds. They are four-stroke diesel engines, although they can still be found in two-stroke diesel engines in non-modernized locomotives of post-Soviet origin.

The composition of exhaust gases emitted to the environment by internal combustion engines is carbon monoxide, oxygen, water vapor, carbon dioxide, hydrogen and toxic compounds, which include carbon monoxide, nitrogen oxides, hydrocarbons, aldehydes, sulfur dioxide, solid particles. In diesel engines, we can expect high emissions of toxic compounds. The advantages of these solutions, however, are high overall efficiency and lower fuel consumption by about 20% compared to systems with split chambers.

Standards and recommendations concerning pollution of internal combustion engines in diesel locomotives.

Permissible limits for the emission of toxic compounds in the exhaust gas of internal combustion engines (for stages III and IV) used, inter alia, in diesel locomotives were published in Directive 2004/26 / EC of the European Parliament – see tables 1 and 2.

Table 1
Stage IIIA

Category	Net Power	Date	CO	NO_x+HC	PM
	kW		g/kWh		
H	130 ≤ P ≤ 560	2006.01	3.5	4.0	0.2
I	75 ≤ P ≤ 130	2007.01	5.0	4.0	0.3
J	37 ≤ P ≤ 75	2008.01	5.0	4.7	0.4
K	19 ≤ P ≤ 37	2007.01	5.0	7.5	0.6

Source: own study.

Table 2
Stage IIIB

Category	Net Power	Date	CO	HC	NO_x	PM
	kW			g/kWh		
H	130 ≤ P ≤ 560	2011.01	3.5	0.19	2.0	0.025
I	75 ≤ P ≤ 130	2012.01	5.0	0.19	3.3	0.025
J	56 ≤ P ≤ 75	2012.01	5.0	0.19	3.3	0.025
K	37 ≤ P ≤ 56	2013.01	5.0	4.7 (NO_x+HC)		0.025

Source: own study.

The values of the individual stages given in the table above are in line with the American Tier 3-4 standards. In the next stage, stage IV is planned, in which limits for PM emissions are introduced at the level of 0.02-0.025 g/kWh. Some engines will also require the use of NO reduction systems to meet Stage IV requirements.

2. ORION Kolej solutions as a way to improve ecology in gutter transport

The article presents activities aimed at protecting the natural environment by reducing the emission of harmful substances contained in exhaust gases from diesel engines, as well as economy. Operation of diesel traction vehicles on the example of the modernization of the transport company F.H.U. "ORION Kolej operating in the rail freight industry.

Two design solutions have been described in order to reduce the harmful impact of the vehicle on the natural environment. which was made by the company ORION Kolej on the diesel locomotive SM 42. The SM42 locomotive, marked scrii PKP, type 6D, was produced in the years 1960-1990 of the twentieth century, and is still in use today. The

vehicle is equipped with a generator set with an a8C22 fuel engine that does not meet the applicable exhaust emission standards. The SM 42 locomotive is the most numerous series of diesel locomotives operated in Poland by railway carriers and railway siding operators from industrial plants.

2.1. The SM42 locomotive in the ON + LNG dual-fuel system (diesel oil + natural gas)

In the first solution described in the article, the LNG gas supply system of the existing a8C22 engine was installed, in addition to the traditional diesel fuel supply.

Thanks to this solution, the operation of the locomotive allows for the simultaneous combustion of diesel fuel and LNG heat. Depending on the share of gan LNG in the fuel mixture, economic savings are achieved, consisting in lower consumption of diesel oil, which is much more expensive than LNG gas, and lower impact of harmful substances generated during diesel fuel combustion. The solution consisting in mounting the LNG gas supply system on the existing a8C22 engine is a relatively cheap, economical and technically simple project, which does not cause major problems during the assembly and operation of the vehicle. Fuel savings and environmental impact measurements as exemplified by vehicle endurance tests. The data is presented in the table.

The company "ORION Kolej" in cooperation with the Latvian partner DiGiaS and the Austrian company SAG equipped the SM42 locomotive with a dual-fuel system for the ON-gas LNG combustion engine – see Figure 1.

Figure 1. SM 42 locomotive in a dual-fuel system – Garodiesel.
Source: authors' materials.

In 2019, a concept for the development of the locomotives was presented combustion engines of a dual-fuel supply system based on the LNG gas supply technology in DiGas combustion engines. A partner with a production potential was sought to undertake such a project on refurbished locomotives operated in Poland (Piotr Damenko, Marek Babel-Dual-fuel systems for combustion engines, gasoline locomotives TTS 11-12 / 2019).

The ORION Kolej company, with an established position on the locomotive repair market and experience in the repair of internal combustion engines, as well as a fleet of its own vehicles, decided to start this project, taking care of protection and the environment. Install system components on the gas supply of the SM 42 series locomotive, Therefore, we decided to take a risk and install elements of the gaseous fuel supply system in the SM 42 diesel locomotive.

The locomotive will be operated in its own fleet of vehicles, taking advantage of its undoubted advantages: savings in fuel consumption and care for the natural environment. The effect of a two-year period of joint work "ORION Rail". DiGas Latvia and SAG Austria is the first locomotive in Poland, described in the article, that uses LNG to power an internal combustion engine.

Of the European Union Horizon 2020 in the field of research and innovation under the co-financing agreement No. 784620.

The DiGas company, together with the employees of "ORION Kolej", conducted fuel consumption and exhaust emissions tests on the SM 42 diesel locomotive No. 729 on July 27, 2021.

Stationary tests were carried out through the load on the motor, the ter resistor in the various positions of the drive switch. Tests of the locomotive showed a significant reduction in fuel consumption – diesel oil, by replacing it with gaseous fuel. The harmful substances contained in it are significantly reduced exhaust gases, mainly nitrogen oxides, solid particles (soot), sulfur dioxide. The exhaust emission tests were performed by an independent laboratory for the analysis and control of environmental pollution using a portable emission measurement system (PEMS). Determination of the actual emission of toxic exhaust gas components in g / kWh (based on NO. PMI SO2 measurement values for individual PNJ controller stations) was carried out in accordance with the PN-EN ISO 8178 standard for the locomotive powered solely by diesel, tables 3 and 4.

- The amount of CO2 emissions was calculated on the basis of the measured values of fuel consumption (ON) for individual PNJs with the use of Big-Methane. The reduction in CO2 emissions is directly related to the degree of replacement of LNG diesel fuel supplied by the dual fuel system.
- Calculated from: Guide to Determining Air Pollutant Emissions NER L.A.3.c, European Environment Agency. Level I railways for maneuvering locomotives 5.

Analyzing the above results, after using the dual-fuel system on the SM42 locomotive, one can expect a reduction in the emission of harmful substances in the exhaust gases by an average of about 70%. The list is presented in Figure 2.

The internal combustion engine in a locomotive in a dual-fuel system, apart from diesel fuel, burns natural gas LNG. Due to the fact that gas fuel is much cheaper than diesel fuel and depending on how much we use. We can count on the savings and measurable economic benefits associated with this project on LNG gas. It can be said that the so-called. As a result of the strength tests of the SM42 locomotive, the coefficients of replacing diesel oil with LNG natural gas at individual controller stations (PNJ) were obtained as shown below – Figure 3.

Table 3
A8C22 engine diesel fuel supply; list of harmful emissions subsidies

DIESEL FUEL SUPPLY (ON)					
PNJ	Power, kW	NOx, g/kWh	PM, g/kWh	SO_2, g/kWh	*CO_2, kg/h
Idle	10	97.6	2.26	1.81	29.36
1	84	14.3	0.255	0.557	82.74
2	102	14.3	0.247	0.671	101.42
3	119	14.8	0.279	0.774	109.43
4	136	16.5	0.363	0.961	120.11
5	180	13	0.422	0.692	160.14
6	231	11	0.55	0.533	200.18
7	246	9.6	0.651	0.413	210.85
8	318	8.69	0.935	0.307	272.24
9	421	7.07	0.678	0.281	354.98
10	490	7.71	0.911	0.334	435.05
11	538	6.69	1.04	0.348	480.42
Totality, g/h		1840	177	73	-

Source: own study.

Table 4
Powering the a8C22 engine in a dual-fuel system with ON-LNG diesel oil for natural gas – a list of emissions of harmful substances

POWER SUPPLY IN ON-LNG TWO-FUEL SYSTEM					
PNJ	Power, kW	NOx, g/kWh	PM, g/kWh	SO_2, g/kWh	*CO_2, kg/h
Idle	10	8.42	1.06	1.03	16.73
1	84	1.22	0.078	0.27	39.71
2	102	2.59	0.1	0.23	35.50
3	119	4.66	0.106	0.23	32.83
4	136	4.92	0.13	0.26	32.43
5	180	3.70	0.163	0.17	40.04
6	231	3.77	0.198	0.11	40.04
7	246	2.78	0.282	0.08	40.06
8	318	5.57	0.25	0.06	54.45
9	421	1.98	0.215	0.05	67.45
10	490	2.45	0.242	0.06	78.31
11	538	3.19	0.265	0.07	96.08
Totality, g/h		582	52	18	-

Source: own study.

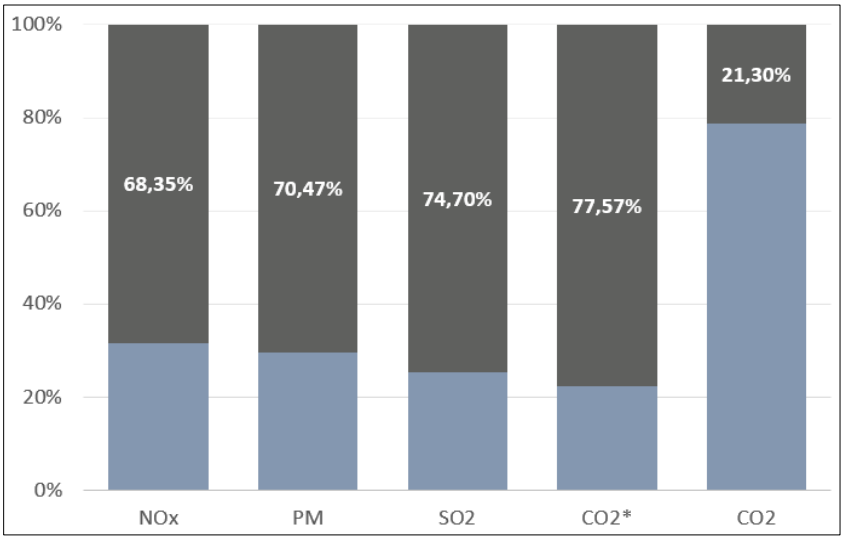

Figure 2. Comparison of the reduction of emissions of harmful substances in exhaust gases. Calculations with the use of Big-Metar. Economic analysis of fuel consumption costs – diesel oil in a dual-fuel system.
Source: own study.

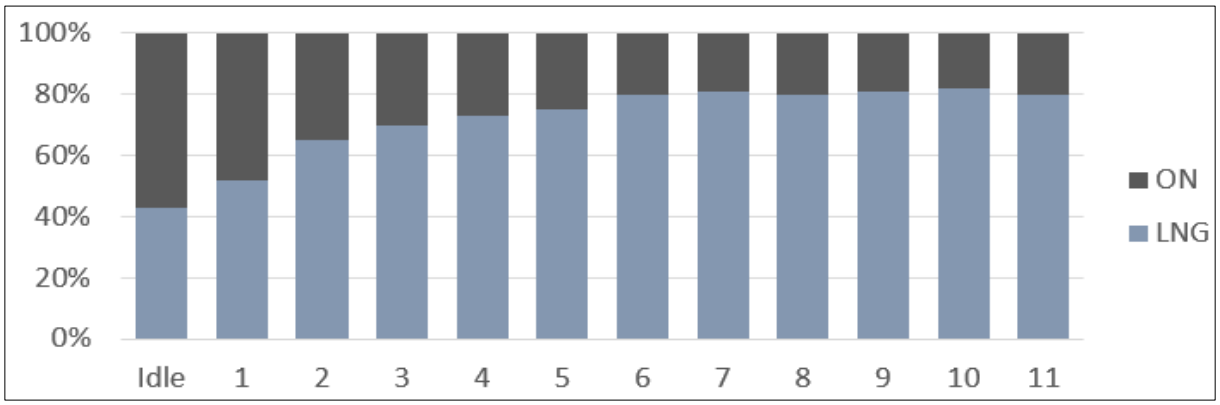

Figure 3. The size of diesel oil replacement with LNG in the SM42 locomotive depending on the power of the driver's station.
Source: own study.

Table 5 shows the results of fuel consumption – diesel oil during operation, the locomotive engine only on diesel oil compared to the system diesel fuel dual fuel plus LNG natural gas. Analyzing the obtained data (Table 6), the tests show that in economic terms – the price of used diesel fuel was EUR 60, when powered only with diesel oil compared to the consumption of EUR 14.10 for diesel, adding EUR 28.81 for LNG gas, we have a total cost of about EUR 43 when operating in a dual-fuel system – hourly vehicle operation according to the load phases of the locomotive in accordance with the adopted standard PN-EN ISO 8178 Type F.

After appropriate calculations, it can be assumed that by calculating the costs of used fuel oil, we will achieve savings of € 73 277 when maneuvering and transporting the vehicle, i.e. only € 30 305 for shunting works for the annual operation of the locomotive in the ON + LNG dual fuel system. The cost comparison was made as of the day of the study, i.e. for the average wholesale net fuel prices of August 2021 with a 12-hour working day of the SM42 locomotive.

The main advantage of this solution is a significant improvement in the quality of exhaust gases, economy and fuel consumption – which is achieved with low design costs related only to the installation of the injection unit system on the engine, sensors and controller and a natural gas tank under the support of the locomotive.

Table 5
Comparison of diesel fuel consumption during operation in a dual-fuel system

DIESEL CONSUMPTION (ON)		
PNJ	**ON, l/h**	**Dual fuel system, l/h**
Idle	11	6.27
1	31	14.88
2	38	13.3
3	41	12.3
4	45	12.15
5	60	15
6	75	15
7	79	15.01
8	102	20.4
9	133	25.27
10	163	29.34
11	180	36
* Average	63.45	15.01
LNG	-	82.34

Source: own study.

The main advantage of this solution is a significant improvement in the quality of exhaust gases, savings in fuel consumption – which is achieved with low design costs related only to the installation of the injection system on the engine, sensors and controller, and a natural gas tank under the locomotive's presbytery.

2.2. Modernization of the SM42 locomotive to 6Dm version with a modern CAT C27 engine

The second project implemented by the ORION Kolej company related to the economy of operation and improvement of the natural environment is the comprehensive modernization of the SM42 locomotive. The scope of the modernization of the vehicle in the 6Dm version concerns the equipment of the locomotive with a modern combustion engine from the American manufacturer CATERPILLAR, meeting the STAGE IIIA exhaust emission standards, connected with the asynchronous main generator, replacement of the control system, equipment of the driver's cabin and engine compartments (Figure 4 and 5).

Figure 4. The modernized 6Dm-01 locomotive.
Source: authors' materials.

Figure 5. Modernized SM42 (6Dm) locomotive during type approval tests.
Source: authors' materials.

Scope of the vehicle modernization the entire mechanical part of the locomotive has been modernized.

The elements used, subjected to major repairs, are a completely rebuilt support of the ILN (ILNa) locomotive, bogies and traction motors, which were subjected to pressure and vacuum impregnation. A new one was made the structure of the driver's cabin and machinery spaces containing the power generator and auxiliary devices. The power generator consists of a CAT C-27 combustion engine, main generator and auxiliary generator. The locomotive has a microprocessor control, anti-skid system, panel braking system, diesel gear. Electric locomotive alternating current – direct current.

Built-in traffic safety devices include the following systems:

- Active standby system;
- Automatic train braking system SHP with Radio-Stop system;
- Fire detection and extinguishing system;
- Radio communication with the GMS-B system;
- TTV monitoring system.

The locomotive is also equipped with a GPS vehicle location system along with a system for monitoring fuel consumption, internal combustion engine operating parameters, vehicle load, diagnostic and security systems, vehicle implemented by a microprocessor controller, electronic tachograph.

The locomotive has air-conditioning in the driver's cabin, sanitary facilities which include a fridge, electric heating plate, washbasin, spacious wardrobe, diagnostic monitor, parking spring brake.

Driver's cab

The structure of the driver's cabin is made of steel profiles, mounted on the locomotive stand by means of four metal-rubber elements. This solution eliminates vibrations from driving and the internal combustion engine. The entrance to the cabin is from the platforms and is located on both sides of the vehicle. The width of the cabin has been increased. Modern lift and slide windows with glued-in panes are built into the side walls. The windshields are equipped with a heating system. In the recesses of the walls and ceiling of the cabin, thermal and acoustic insulation in the form of non-flammable mineral wool is installed. All internal walls, ceiling and both countertops are lined with aesthetic elements (panels) made of non-flammable polyester resins.

There are two ergonomic driver's consoles in the cabin, which allow driving in a given direction, and after folding the seat, the operator from a standing position, which is required during maneuvers – see Figures 6 and 7.

Palpits equipped are equipped with a diagnostic panel, driving and braking actuators, brake system pressure gauges, radio, buttons and devices necessary to operate the locomotive. When designing the desktop, the rule was to place only the necessary devices on the desktop, and their location was in accordance with the principles of ergonomics.

In the driver's cabin there is also a panel of the low voltage electrical cabinet, in which switches for the operation of the combustion engine, parking brake, fire alarm control panel and fuel consumption control terminal are installed. Driving in a locomotive may be performed by one person. AND Generator. The power generator installed on the locomotive consists of a Caterpillar C27 diesel engine, the main EMIT GTds 400 M4C-3 asynchronous generator and an auxiliary generator 3x400 V.

The whole is connected by a clutch to the coolant cooler and mounted on the frame, and by means of metal-rubber supports on the locomotive stand – Figure 8. The CAT C27 combustion engine is a four-stroke, turbo-charged engine with charge air cooling with electronically controlled fuel injection by unit injectors. The engine meets the STAGE IIIA exhaust emission standards, and its fuel consumption is 198 g / kWh – see Figure 9.

The main generator is an alternating current machine, with two bearings, flanged with the flywheel housing of the internal combustion engine. An auxiliary generator with a toothed drive is mounted on the generator belt.

Figure 6. The interior of the cabin of the marine locomotive 6Dm ORION Kolej.
Source: authors' materials.

Figure 7. The console of the 6Dm 01 locomotive.
Source: authors' materials.

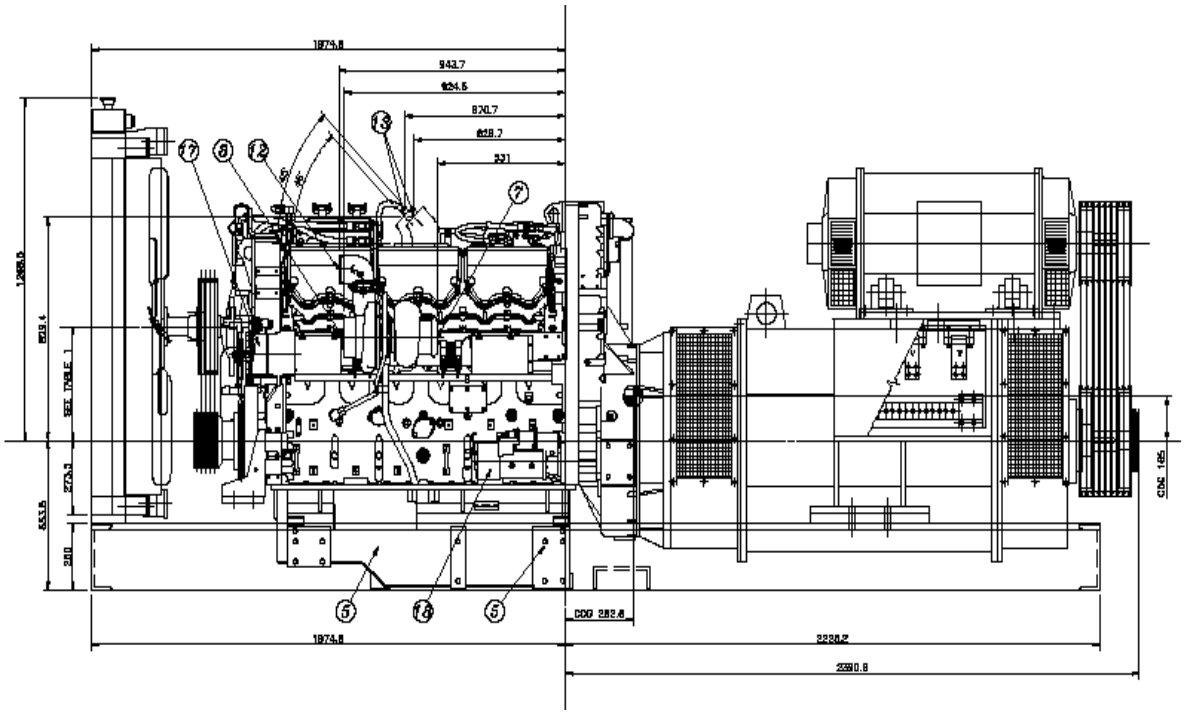

Figure 8. Diagram of the generator of the modernized 6Dm locomotive.
Source: authors' materials.

Locomotive control

The locomotive is controlled by a microprocessor controller which regulates the excitation of the main generator, controls the operation of the air compressor, cooperates with the electronic ECM controller of the internal combustion engine, automatically activates the traction motor bypass system after exceeding the set driving parameters, performs automatic control and elimination of wheel slip, performs the work of safety systems work of the locomotive and internal combustion engine.

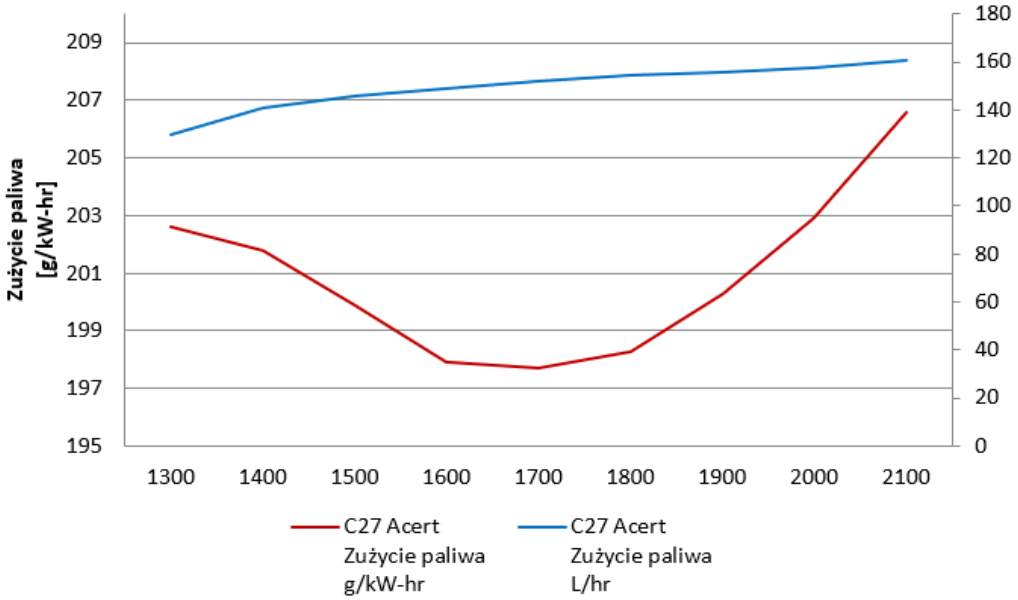

Figure 9. Graph of fuel consumption of CAT C27 combustion engine.
Source: authors' materials.

3. Conclusions

The ORION methods presented in this article. A turn to improve ecology the economics of the operation of diesel locomotives shows that a small modernization through the use of an LNG gas-powered system and a deep change of the SM 42 locomotive to a 6Dm locomotive, significantly improves the ecological and economic efficiency of rail transport. These solutions show the path that can be followed, the aim of which is to eliminate old, fuel-consuming and non-ecological railway traction vehicles.

Modernization of the vehicle in the 6Dm variant is associated not only with the replacement of the generator set improving fuel and oil consumption and reducing the emission of pollutants into the environment, but also with the change of the external shape of the vehicle, which improves the safety of maneuvering by – improving visibility, ergonomics of the wavelet by eliminating bastards, social equipment driver's cabins, on-board diagnostics.

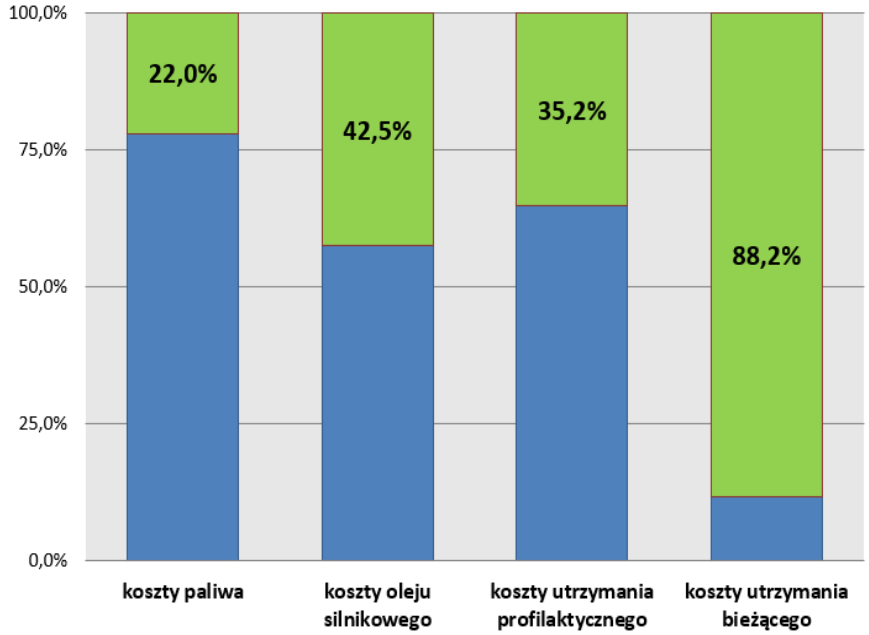

Figure 10. Savings of selected parameters of the 6Dm locomotive after modernization. Source: authors' materials.

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Development trends in modern logistical tools

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Abstract: The article is an attempt to rationalise and put together common characteristics of modern tools, developed and created to rate the need for constant management of logistic processes. The three most visible are: artificial intelligences used to perform repetitive and mathematically advanced tasks to reduce the workload on human employees, centralization of data processing to reduce the amount of mistakes in the process and cloud computing, which reduces costs connected with owning and securing own servers for companies. Article focuses on certain logistical tools widespread throughout modern enterprises: ERP, MES, office management and transport (or traffic) management systems that are essentially required for a company to be innovative and efficient enough to keep up with the competition.

Key words: management, IT, enterprise, logistics.

1. Introduction

Logistics can be conceptually conceived as a technique or set of tools used to optimize material, financial and informational flow. It allows better organization of production, distribution of goods and services and process management inside enterprises on a higher level as well. Modern tools used to manage enterprises are based on artificial intelligence, cloud data processing and are created to manage most data available autonomically, without human interaction. Logistical tools serve economical growth, ease management tasks and allow making optimal decisions based on available data. Question of common characteristics between different systems used to manage enterprises was posed as a research problem: what is common between ERP, MES, office management and transportation systems? The research was based on tools available on the market for any company reagrding their funcionalities.

2. Manufacturing Execution Systems

Manufacturing Execution Systems (MES) are also called Production Realization Systems. They are built around IT systems connected with systems of automation, which monitor production processes, collect data about their state and quality of production. Collected data is processed and delivered in real time to the user. It allows immediate response to any undesired outcomes (https://queris.pl/, accessed: 16.04.2022). MES class systems allow users to manage processes such as:

1. Queueing processes – taking into account the priorities and properties of individual production batches. The system manages the work and supervises its course in order to detect any irregularities.
2. Supervising current tasks – in order to ensure the agreed production plans.
3. Automatic data collection and documentation – the system collects data on processes, materials and activities performed by personnel or machines.

4. Performance analysis – by constantly measuring efficiency and comparing the results with historical data, it includes the assessment of resources devoted to each process, their duration and keeping agreed plans and costs.
5. Quality control – control of the condition of finished and semi-finished products and assessment of compliance with the standards. In addition, it determines the quality level of the processes carried out and In the event of detecting irregularities system itself proposes corrective actions.
6. Maintenance works – the system has all the information on the operation of production devices (it alerts about faults and helps in diagnosing the causes). (https://mecalux.pl/, accessed: 16.04.2022).

The advantages of MES systems are their accuracy in monitoring the costs incurred. They include information on workforce, materials, defective products, downtime and tools, all in real time. The prophylaxis offered by these systems allows to extend the life and total working time of the machine. The process takes place without user's participation and works during periods of downtime. Information on the reduction of the amount of defective products and waste is sent on an ongoing basis and in a very short time, which allows for a quick response, repair of errors or defects and restoration of the machine to work, while reducing the amount of waste. MES makes it possible to update the stock on an ongoing basis, in real time, so as to limit the use of space that can be better managed at a later time (https://mindbox.pl, accessed: 17.04.2022). Each technology also has disadvantages that one should be aware of. Some of them are: problems with budget planning (software implementation may require additional financial outlays), there is also a risk related to the implementation of the changes (communication with the team affected by this system must be clear and consistent), in addition, there may be problems with the project management (changes and modifications in relation to the original version of the project entail additional costs and extend the duration of the implementation) (https://mindbox.pl, accessed: 17.04.2022). Project suppliers and contractors also play an important role, any error in this part will result in extended system implementation time and will entail additional financial obligations and costs.

3. Manufacturing Execution Systems – examples

Queris MES system – this system helps to control the efficiency of processes, queue them and carry out production in the shortest possible time.

System features consist of:

- automatic registration of production and testing the actual working time of machines;
- downtime detection (even on a minor scale) and automatic notification about them;
- visualization of production and the spectrum of machines with information about the causes of downtime;
- managing production orders and planning the sequence of their execution;
- an extensive analysis module with automatic report generation;
- quality control support by collecting information on product deviations;
- monitoring of products, flows and consumption of production media;
- data exchange with other systems, electronic document flow (https://queris.pl/, accessed: 17.04.2022).

The architecture of this system allows for integration with other tools operating in the enterprise. It also enables all departments in the company to fully use the obtained information.

MES UNIS PRO system – is a system addressed to small, medium and large enterprises that want to monitor the progress of production works on an ongoing basis, taking into account their machine park. The UNIS PRO system allows them to support the following areas of activity: Technical Preparation of Production (TPP), Production Planning and Startup (APS), Work Control and Registration (CPR), Production Execution (MES), Machine Efficiency (OEE), Quality Control (QMS), Maintenance (TPM). An additional convenience in this system is the ability to track the real costs incurred on a given order on an ongoing basis in relation to the costs assumed by the constructor or technologist during implementation (https://autoid.pl/, accessed: 16.04.2022).

SAP MES system – SAP production management system aggregates data from various sources, integrates with other SAP systems and generates one production record. SAP MES is also used to automate production processes as well as to optimize production management in the enterprise as a whole. It ensures: product competitiveness, minimization of production costs, increased productivity and profits of the organization, making competent decisions, production of high-quality products with a minimized risk of defects. The SAP MES system clearly solves the issues of analysis, coordination and production improvement (https://leverx.com/, accessed: 15.04.2022).

MES system from AVEVA – this system presents the values that can be realistically improved in the company, some of which are: quality increase, extended machine uptime, cost reduction, increased productivity and an average increase in OEE (an indicator measuring the effectiveness of the use of machines and devices). Depending on the size of the enterprise, this system may be used on various levels (https://astor.com.pl/, accessed: 12.04.2022).

Small and medium-sized enterprises can count on: machine monitoring, OEE, identification of production bottlenecks, reporting and order management. Large companies will benefit from: order and operation management, ERP integration, materials management, quality assurance, traceability and traceability. On the other hand, global companies will find a configuration with this system on the following levels: integration with ERP, standardization and scalability, dissemination and implementation of best practices and digitization of processes (production and support).

4. Enterprise Resource Planning systems

Enterprise Resources Planning systems are a software that enables comprehensive enterprise management. Resource planning, which includes ERP systems, allows one to control and manage the most important resources and processes on many levels in the company. They include: accounting and finance, sales, document circulation, warehouse, HR and payroll, reports and analyzes, production, budgeting and planning. During the decision-making process ERP system users have access to one database, which enables information to be adjusted to their own needs, simulation and data analysis. The main goal of the system is to integrate the existing areas of the company's operations. The great advantage of this system is that it allows one to integrate and automate business processes by sharing common data throughout the enterprise and generating real-time information (Latała, 2018). Another advantage of this system is that it supports the company in planning,

production and distribution. The high flexibility of ERP systems allows them to be adapted to the specifics of most enterprises due to the fact that the modules can function independently (Golarz, 2017). Logistics activity areas in which ERP systems can be used include:

- production – determining production costs, managing product changes, forecasting the production volume, determining the critical level for the inventory and 24-hour control of the production process;
- integration of the logistics chain – a feature that will probably set the future directions of ERP systems, causing them to go beyond the enterprise;
- customer service – creating a database of customers and information about them, processing orders, electronic transfer of documents;
- finance – accounting, flow control of accounting documentation, settlement of activities, preparation of financial reports in accordance with the expectations of individual groups of recipients (Chwesiuk, 2011).

The ERP system, in addition to the financial benefits it brings, allows one to improve the company's operations on many levels. However, there are factors that influence the effective implementation of the system in the company's operations:

1. An important element that should be taken into account is the system supplier. It is also important to check the readiness of your system to introduce the necessary modifications before implementing ERP. The key is to get acquainted with the service provider's experience and to check the qualifications of programmers and consultants.
2. The basic features that should distinguish an ERP system suitable for enterprise logistics are: openness, user-friendliness, innovation, stability and the ability to work in real time.
3. The ERP package should be created using the latest methodology, technique and technology. It is also important to know which database the system works with. A well-designed, reliable, and efficient database must be at the heart of a good system (Golarz, 2017).

Other factors for success when implementing an ERP system are:

1. Precise purpose of implementation – at the level of project definition it is necessary to clearly define the purpose of implementation (PRINCE2 methodology calls it the business case) which is the driving force behind the project and when it is no longer applicable, the project must be terminated.
2. Implementation schedule – it is a way to avoid unpredictable costs and allows you to define works that can be carried out.
3. Appropriate qualifications of the implementation team – the appropriate selection of the team is a key element on the path to the success of the project.
4. Decentralization of powers and responsibilities – a situation in which the decision-making person is unable to make a decision on the implemented system causes delays in the entire project.
5. Correct prioritization of tasks for members of implementation teams – it is important to skillfully define task priorities. For example, specialists burdened with participation in many projects will not be able to perform their tasks properly.
6. Clearly defined principles of customer-supplier cooperation – it is a good practice to create a document setting out the principles of cooperation.

7. Correctly selected ICT infrastructure – improperly selected server or network parameters make it impossible to work in the implemented system.
8. Attention to end-user training – the more time is devoted to training, the easier the post-implementation stage will be.
9. Efficient project management – the use of the existing and proven methodologies for project management and system implementation is an important factor for success (Golarz, 2017).

5. Examples of ERP systems

TetaERP (https://teta.unit4.com/, accessed: 17.04.2022) system – a system used to plan the company's resources as well as to control financial and accounting processes. It supports such departments as:

1. Financial Planning – Powered by Unit4 Financial Planning & Analysis software, it provides faster ways to manage performance, planning, budgeting, forecasting, financial consolidation, reporting, and visualization and analytics. It complements the financial module in the TetaERP system.
2. Logistics – the ERP system improves the processes of delivery, purchase, storage, inventory management, and distribution until it is delivered to the recipient. It allows you to efficiently register invoices, gives you access to the supplier schedule to control order fulfillment, and allows you to control the status of orders and their compliance with the terms of delivery.
3. Production – this department handles production orders and documents, service and maintenance, supports and facilitates the production planning process, quality control and allows you to plan detailed parameters of the finished product.

The Comarch ERP (https://www.comarch.pl/, accessed: 31.03.2022) system works on many levels. It helps to simultaneously manage several key areas in the company, such as sales – trade, finance and accounting, production, warehouse, payroll and human resources. The basic feature of Comarch ERP systems is the possibility of their configuration, expansion with additional modules and solutions for specific industries.

1. Comarch ERP XT – a company management program that integrates and automates processes related to running a business. Stationary and internet sales combined with invoicing, accounting and warehouse. All data is automatically saved in the Comarch cloud, and one can also access them via the mobile application.
2. Comarch ERP Optima – a program designed for small and medium-sized enterprises, thanks to the wide range of modules it supports, it is the optimal ERP system for company management. It supports i.a. (accounting, trade and warehouse, payroll and human resources, bank, e-commerce, software for accounting offices, reporting and analysis, robotization and artificial intelligence, financial services).
3. Comarch ERP XL – is a functionally developed ERP class system characterized by a modular structure. The optimal configuration and number of modules is selected based on the analysis of the company's needs and functionality. In addition to the server version, the system is also available in the SaaS (Software as a Service) model, in which Comarch ERP XL is offered via remote Internet access.

4. Comarch ERP Enterprise – this system works well in international companies with an extensive structure. It supports: process transformation, business diversification and opening to foreign markets.
5. Comarch ERP Altum – the advantage of this system are the mechanisms that enable the automation of routine activities and the tools to make decisions based on analyzes and forecasts.

There are many ERP systems on the market that support various areas and industries. The functions of the ERP system play an important role, which is the integration of processes taking place in the enterprise (https://optimes.syneo.pl/, accessed: 02.04.2022). However, such a system should be introduced taking into account factors that will allow for its efficient implementation and subsequent operation.

6. Office management systems

Not only production of goods needs to be controlled and supervised. The development of the computing power of computers and the need to use the Internet to perform office tasks have led to a situation in which it is possible to measure the quality and productivity of office workers. This type of work is very difficult to standardize because there are a number of activities that are not directly measurable in office work, but modern office management systems can measure, among others:

- time of commencement and completion of work;
- time of activity at work (measured most often based on the activity of the cursor on the computer screen);
- time until the call is answered from the start of the call, if it is also synchronized with the telecommunications system;
- time of opening the tab in the browser;
- number and time of response to e-mails;
- length and frequency of calls.

These are elements that aim to indicate the quality and efficiency of work in the system, and therefore they are the control elements of the office work process. Additional elements, beyond the measurement of working time and various activities in office management systems, may include:

- knowledge base on procedures, activities and problem solving;
- invoicing;
- CRM, i.e. a database and customer relationship management system;
- work organizing calendars.

Examples of office work management systems shall be three CRM systems of various sizes, offered by various manufacturers: Bitrix24, Oracle CX and Synergius CRM. The Synergius CRM (https://synergiuscrm.pl/, accessed: 20.04.2022) system advertises its product as a multi-channel customer relationship management tool:

- allows one to manage and improve the work of sales staff and monitor the so-called sales opportunities;
- enables building a knowledge base about contractors;
- provides tools for planning and coordinating work;
- it can be integrated with an ERP system;
- allows you to create reports for traders and company management;

- organizes communication;
- has a mobile application;
- organizes documentation: product catalog, offers, orders, invoicing and payments.

Thus, it is a typical example of an office service system, serving to improve the contact of the sales department with customers. It will be well suited to typical service companies that sell goods that they do not produce themselves.

The Oracle CX (https://www.oracle.com/, accessed: 20.04.2022) system (CX stands for Customer eXperience, which means that the system not only serves customers, but creates experiences for them. A similar trend can be observed when creating web applications – no longer independent UIs (user interfaces) are created, but UI itself is part of the UX (user experience) which is designed by designers and offers a very similar set of tools to Synergius CRM, however it is sold in three packages, targeting different industries:

- oracle CX for telecommunications, which deals with the needs related to running a call center or selling telecommunications services;
- oracle CX for the financial services sector, where the tools are optimized for banks or investment funds, and therefore put more emphasis on finance and contact with financial institutions;
- oracle CX for the retail and consumer goods sector, which is actually a CRM system optimized for customer relations and goods handling.

Bitrix, Inc. creating the Bitrix24 (https://www.bitrix24.pl/, accessed: 21.04.2022) system, which is a universal tool, not optimized for a specific type of activity, but enabling office service and contacts between colleagues. The most important elements of the Bitrix24 system include:

- knowledge bases where colleagues exchange experiences that can later be used for the so-called onboarding new employees;
- the ability to use a data storage disk in the cloud;
- project and process management: creating Gantt charts, kanban cards, task and project templates and automation of some activities;
- automatic HR support, including tracking of working time and absences;
- on-line conferences and a communicator built into the application;
- built-in website creator, which provides the ability to create websites, eg online stores, which can significantly help novice entrepreneurs.

One of the most important advantages of Bitrix24 is its price: it is free to a limited extent, but the paid versions allows one to have more. The free version is not so limited that it is impossible to use it. This encourages entrepreneurs to check who system works and – once they have transferred most of the tasks related to company management to the system – it is easier for them to convince themselves to buy a paid subscription than to implement a new system.

7. Transport systems

Historically, the first task of logistics was only the transport of goods, and many of the tools used in this area later moved to the logistics management of people, teams, production and machine park. Modern transport systems rely almost entirely on artificial intelligences for the following tasks:

- planning routes for delivery vehicles;
- organization of transport (determining shipments and vehicle loading volumes);
- forecasting fuel consumption and related costs;
- assigning drivers to routes;
- satellite data analysis and traffic measurement to better match delivery times;
- delivery tracking.

All these tasks are performed in order to take the responsibility for the quality of the transport service and the delivered goods from the driver. One of the best examples in this area is InPost, which has created an optimized courier service system using the parcel locker (Paczkomat) network. All the procedures that the consumer has to follow are minimized: all one really needs to do is pay for the parcel and put it in the parcel locker. Then, the handling system assigns a shipment number to the ID of the place where it is found and immediately selects a box at its destination, where the shipment is to be found. Everything is organized by a central system that sets the right routes for all drivers, calculates the load independently and determines each shipment to be loaded.

8. Centralization of system tasks

Due to the need for proper data processing by algorithms, there is a need to centralize the system's tasks, i.e. to create one place where data is analyzed and processed in accordance with the needs, which is most often the management server. There is, of course, the possibility of creating autonomous systems that process the collected information independently and even integrating systems from different software producers. Such a solution, however, means the possibility of communication errors at the level of information processing, which may result in erroneous or suboptimal results. An additional disadvantage of distributed systems is the need for the end user to use different interfaces and self--interpretation of the results that could be collected within one software for easier analysis.

Centralizing tasks related to handling large amounts of information can be dangerous due to the risk of making a mistake: if an algorithm or the entire program contains even minor errors, they can be multiplied.

9. Automation of data collection and processing

Even low-power computers can extremely efficiently process huge data sets without the need to design complex user interfaces that are necessary for people to manipulate data – hence the need to automate data processing. It is cheaper and more efficient, and generates fewer errors than for users of the program manipulating the data themselves.

Challenges related to the automation of data collection are becoming more and more important in the logistics service systems of enterprises. You can see with every technological innovation that people and machines are designed for different jobs and cannot replace each other, but can complement each other better and better. Data input into systems is more and more often done automatically, e.g. by detecting text on invoices and printouts or by fully automating the transfer of documents, thanks to which there is no need to waste employees' time on repetitive and unproductive activities, such as rewriting texts into a computer system. In addition, sensors and control systems are installed in production companies, which allow for constant monitoring of the most important measures of the company's work.

Of course, all these things do not work in all companies, but there is an increasing pressure from large enterprises to introduce innovative solutions, thanks to which technological costs are reduced for smaller companies that want to catch up in the giants' innovation race.

10. Optimization of system maintenance costs

IT systems are maintained on servers where they collect and process data in accordance with imposed algorithms. There are also programs that help to handle tasks in the company, installed on different workstations, but they do not deserve to be called systems due to the following characteristics:

- collect data from only one workstation;
- do not communicate with each other;
- they are used to perform a narrow range of activities.

However, if the systems are to be effective, they must allow communication with various workstations (individual computers, production cells, sensors, etc.). This is due to the fact that the management system, in order to make optimal decisions, must have access to the widest possible set of data in order to compile it properly.

The costs of operating the system can be divided into several categories:

- maintenance costs:
  - service costs related to maintaining the system performance at the appropriate level, repairing possible failures
  - costs of utilities (cooling devices, electricity),
  - costs of data collection related to the need to enter data into the system by employees or sensors and meters,
  - security costs related to the security of collected data, server control and continuous monitoring of network traffic,
- purchase costs:
  - the cost of designing or adapting the system to the company's needs,
  - the cost of implementing the system (employee training, data migration),
  - the cost of purchasing a server or renting space on an external server,
- update costs:
  - costs of purchasing parts that are necessary for the proper operation of the system: sensors, meters, but also server equipment, if it is located in the company using the system,
  - costs of implementing changes – updates introduced by the manufacturer.

The subscription model for buying service systems for different parts of the enterprise is becoming very popular: new companies cannot afford the high costs associated with the purchase of the system, therefore there are different plans available, where some options are blocked in the cheapest ones, encouraging the purchase of more expensive plans. An additional advantage for the manufacturer is the constant income associated with the purchase of a subscription: a lower monthly fee is more convenient than a large one-time payment: it increases the turnover and financial liquidity of the software producer, and on the other hand reduces the purchase costs for the company. The manufacturer can thus control access to various system options and monitor its performance. Such a situation

reduces the demand for systems dedicated to one company only: software producers do not create new systems, but only update ready-made systems and adjust modules that can be included in the system to the customer's needs. This limits to some extent the innovativeness of solutions introduced in the systems and causes that new modules must be backwards compatible with the previous ones.

11. Conclusions

There are many tools available on the market to control the company's operations, almost all of which exhibit the examined features, i.e. the vast majority are built and created according to the current trends. IT systems for supporting enterprises have many common features and perform many tasks that could not be dealt with by employees on their own. The main directions of development of these tools include centralization of tasks in systems, automation of data collection and processing, and optimization of system maintenance costs.

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Section III

New challenges, technologies and solutions innovations in production engineering

Noise reduction at the car body parts assembly line

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Abstract: The structure of the car body assembly hall is a function of the technological process while maintaining compliance with technical conditions and construction law regulations, which include they include protection against noise and vibrations. Targeting research and implementation works is the need to reduce the acoustic emission of overhead conveyors installed over robotic lines, ensuring standard working conditions in the assembly process supervision zones. Acoustic measurements were made, the sound level distribution in the assembly hall was determined using the acoustic field modeling method and a design of soundproofing protections was developed. After completing the assembly works of sound-absorbing and insulating structures, measurements of the noise level were carried out by the Environmental Research Laboratory of the Labor Protection Center, which showed that the sound level was reduced to the normative level. When developing the structure of criteria for the implementation of the technological process in an industrial hall, acoustic requirements should be taken into account, which are equivalent conditions for starting production. Subsequent introduction of insulating structures and acoustic development of noise emission sources is problematic and usually does not bring about positive results.

Key words: acoustic parameters, modeling of the acoustic field.

1. Introduction

The functional structure of the assembly hall results from the requirements of the technological process, design and installation solutions, organization of internal transport, auxiliary processes carried out with the participation of robots and the construction concept of the facility. In the analyzed case, the process of adapting the production hall to the implementation of assembly works took place, which was not taken into account in the design phase of the facility. This change in technology determined the incorrect shape of the interior of the building's hall due to the acoustic climate. An industrial hall as a construction object, in accordance with the technical conditions, should comply with specific provisions of the Construction Law, which, together with separate acts and regulations, provide, among others, protection against noise and vibration.

The geometric classification of the structure of the facility determines the design solutions influencing the acoustic conditions in the hall and determines the use of specific acoustic protection. The shape of the hall affects the parameters of the acoustic field inside. In halls with a projection similar to a square, the energy of waves reflected from individual walls has practically the same distribution, while in long halls the influence of energy of waves reflected from longer walls may be of greater importance. In addition, the geometry of the ceiling and the shape of the roof have a negative impact on the acoustic field in the hall, which may result in local concentrations of acoustic energy with levels higher by several decibels (Funkhouser et al., 2004).

In the analyzed object there is a spatial vibroacoustic system in which the propagation of sound is determined simultaneously by vibroacoustic processes of technological transport means as well as the structure of the considered interior (Rindel, 2002). It is necessary to analyze the acoustic parameters describing the near wave field – the Fresnel zone, in which there are interference phenomena with different phases, and the far field as the Fraunhoffer zone, in which the phase difference between the components does not play a role (Engel, Piechowicz, Stryczniewicz, 2003).

Statistical and deterministic methods are used to assess the acoustic field distribution. When using the statistical method, it is assumed that the acoustic field inside the object is homogeneous, i.e. that the state of equilibrium is established in all places of the examined area. Using this method, the most accurate results are obtained when the average sound absorption coefficient has the lowest values (Engel, Stryczniewicz, Kosała, 2003). Practical analyzes of the acoustic field distribution in an industrial hall combine the statistical method with empirical results of the acoustic pressure distribution at measuring points. The level of diffuse sound at a given observation point can be determined from the dependence 1, (Engel, Piechowicz, Stryczniewicz, 2003):

$$L_R = 10\log\left[10^{0.1L_p} - \left(\sum_{i=1}^{n} 10^{0.1L_{Ni}} \frac{1}{\Omega_i r_i^2}\right)\right] \text{ [dB]}$$

where:

L_R – the scattered sound level at a given observation point [dB].

L_p – the sound level at the point of observation [dB];

L_{Ni} – sound power level of the i-th source [dB];

$L_N = 10\log\left(\sum_{i=1}^{n} 10^{0.1L_{Ni}}\right)$ – total sound power level of all sources [dB]

Ω_i – solid angle of radiation of the i-th source [rad];

r_i – distance from the i-th source [m].

The distribution of the sound level depends on the shape, size, configuration of absorbing materials on the walls and the degree of filling in the room. In industrial conditions, making measurements on a dense mesh is very burdensome. A practical way is to approximate the distribution of measurement results with, for example, polynomials (Engel, Piechowicz, Stryczniewicz, 2003).

2. Measurements of acoustic parameters

The basis for measuring the acoustic parameters of machines and the noise level at workplaces are the PN–EN ISO 3382–1, PN-81/N-01306 and PN-84/N-01307 standards specifying the requirements for noise measurement methods in places where people stay and for indoor and outdoor workplaces.

The quantities measured at the designated measuring points in the assembly hall are:

- sound level A;
- maximum A-weighted sound level;
- peak C sound level.

For the assessment of noise levels, assembly lines are designated also the level of exposure to noise, which should not exceed the value of 85dB for 8 hours of a working day. The maximum A-sound level at workstations should not exceed 115dB, while the peak C-sound level should not exceed 135dB. The noise exposure level related to an 8-hour working day in LEX [dB] is determined from the relationship:

$$L_{EX,8h} = L_{Aeq,T} + 10\log\left(\frac{T}{28800}\right) \text{ [dB]}$$

where:

T – noise exposure time [s], for t<8h=28800[s].

For 8 hours of a working day, the noise exposure level is the same as the A-weighted sound level. For the design of sound-absorbing and insulating structures in the hall, the number of measuring points and the number of microphone positions required are provided in accordance with the requirements of ISO3744 and ISO3746. Measurements were made with the use of standardized measuring instruments compliant with the applicable standards. A frequency analysis of time courses of acoustic pressure was carried out with the use of a set of apparatus:

- B&K 4133 microphone with dimensions of ½ "(dynamic range 31-160dB for 4Hz-40kHz);
- N IV-SJ measuring recorder (dynamic range 66dB);
- B&K BK 2133 analyzer for a fixed bandwidth from the octave level to 1 / 24th octave, equipped with digital filters enabling real-time analysis of signals with frequencies up to 22.4kHz.

The distribution of the acoustic field was determined assuming that the acoustic field inside the hall is partially diffused. The diffuse part of the acoustic field was determined based on statistical relationships. In the vicinity of the sound sources, the acoustic field was described as determined. In addition, corrections were made to take into account the specific shape of the assembly hall.

3. The concept of reducing the noise level of the hall for assembling non-standard car body elements

The assembly hall for non-standard car body elements is equipped with two assembly lines for filling the surface of the passenger car's roof. Car bodies are transported from the paint shop on the hangers of overhead conveyors, then they are directed to the lifts leading the bodies to the Skid conveyor lines, where the filling of the car roof surface is installed. The assembly of the roof filling is performed by gluing the guide frame together with the driving elements for sliding the roof windows or specialized fabric and the rear filling as an embossed element of the car body sheet. The operation of sticking the roof

guides to the car body is performed by robots after the dispenser has applied the adhesive. In the area of the roof gluing stations, there are monitoring and quality control stations for the process being carried out.

The use of sound-absorbing structures of the dominant noise emission sources may not introduce excessive maintenance and repair difficulties. It is necessary to ensure easy opening elements made of acoustic panels. In the case of the drive station of overhead conveyors, it is necessary to provide ventilation, using air ducts that function as sound absorption silencers. Due to the need for a quick repair intervention of the overhead conveyor chain in the event of its failure, it is not possible to use soundproofing structures directly along the conveyor track.

There is also a problem of proper assessment of the acoustic power of the dominant noise sources in the analyzed hall conditions due to the phenomenon of wave reflection from the hall walls and equipment facilities. In close proximity to the walls, the sound power levels of the reflected waves and the source may be equivalent. Consequently, the sound pressure at the measuring point consists of the pressure generated by the wave directly emitted by the source and the pressure generated by the reflected wave. Correct measurement should be made between the near field and the reverberation field, which is characterized by a decrease in the sound level of 6 dB for each doubling of the distance from the source. The measurements carried out in the conditions of the described structure of the factory hall at workplaces are therefore a kind of simplification in relation to the assessment of the acoustic power level of sound sources.

By analyzing the results of measurements of acoustic parameters at designated points in the assembly hall, the results of modeling the statistical distribution of the acoustic field and technical conditions, the following intervention concept was adopted to ensure the required sound level below 80dB in designated areas of the A-H hall:

1. The noise emitted along the tracks of the overhead conveyors has the character of a long-range cylindrical wave. There is emission in low octave bands with multi-point spatial distribution of noise sources. The analysis of acoustic measurements showed the need to use flat horizontal absorbers, which are a type of acoustic screens installed under the WeMa gratings on the floor of the hall's platforms in the area of assembly lines.
2. The zone of the conveyor drive station with a high level of noise emission was distinguished, mainly in the range of low octave bands, which indicates the necessity to use a closed sound-absorbing casing. The construction of the conveyor drive station from panels with a high relative acoustic insulation R_z coefficient will reduce the emission towards the side enclosure of the hall, where the waves are repeatedly reflected with the orientation towards the assembly lines zone.
3. Due to the high reflection coefficient of β waves from the surface of the hall's side walls, as evidenced by the results of the noise level, double-sded side vertical curtains made of acoustic foil should be installed above of the transport platform assembly lines.
4. Also due to the low noise absorption coefficient α by the side walls of the hall and the highly reverberant nature of the fencing adjacent to the longer side of the hall (made of T50 sheet formats), shielding of these zones should be installed.

5. The stages of silencing assembly lines together with side curtains should be treated as a whole due to the compact nature of multi-point noise sources coming from overhead conveyors and the close vicinity of production lines.

Providing a lower sound level in relation to the standard requirements, with a value below 80dB in the designated zones of the A-H hall, will enable the introduction of further supplements to the development of the free area of the facility. The floor plan of the assembly hall with the marked measurement points is shown in Figure 1, while the results of acoustic measurements are given in Table 1.

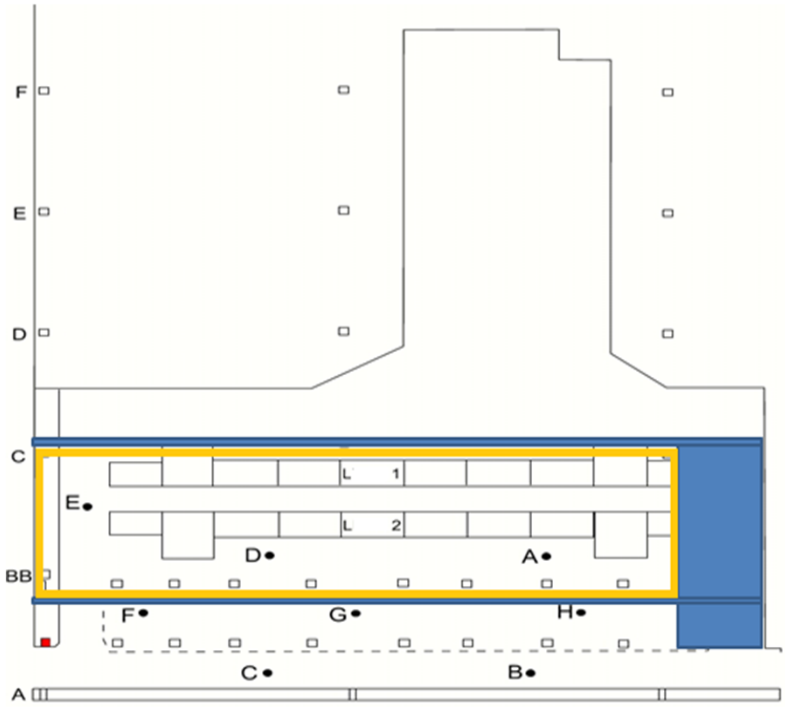

Figure 1. Floor plan of the assembly hall with marked noise measurement points and zones acoustic adaptations:

– installation of the conveyor drive station and the zone of foil screens PVC Enitra acoustic acoustic (level 6.8 m), blue color,
– acoustic panels ACOUSTIC SF in the grate zone WeMa have the hall landing floor (5.5m level) yellow color.

Source: authors' materials.

Table 1

List of noise measurement results at measuring points in the assembly hall before making the acoustic adaptation

Punkt pomiaru	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
L_{Aeq}	86.5	86.5	85.5	86.8	84.0	85.8	86.9	86.2
L_{Amax}	87.7	86.8	86.0	86.9	84.9	86.3	86.7	86.4
L_c	88.0	91.7	90.6	88.2	87.4	88.8	91.1	92.0

Source: own study.

When selecting the soundproofing and insulating structures of diffuse noise sources, the assessment of the degree of sound absorption by the hall interior was taken into account, assuming that the reverberant acoustic field is diffused, i.e. it is homogeneous and steady. Due to the influence of the hall "acoustic background" on the measurement results, the K1 correction was introduced. The applied criterion refers to the value of the difference Lp between the measured sound pressure levels with the assembly line program turned on and off K1 correction value:

$$K_1 = -10\log\left(1 - 10 - 0{,}1_{L_P}\right)[dB]$$
$$L_p = L'_p - L''_p \; L_p > 10dB \; wtedy \; K_1 = 0$$

where:

L'p – equivalent sound level averaged over the measurement area w assembly line operation time,

L''p – Equivalent background noise level averaged over the surface with the lines and the conveyor drive turned off

The K_2 correction was determined from the acoustic absorption of the hall and the measuring area:

$$K_2 = 10 \log [1+4 \; S/A] \; [dB]$$

where:

S – area of measurement [m^2]

A – acoustic absorption of the hall [m^2] A = α Sv

α – average sound absorption coefficient

S_v – total area bounding the measurement zone [m^2].

The average sound absorption coefficient α was determined on the basis of estimating the sound absorption coefficient by the structures of the hall equipment.

4. Acoustic design of sound-absorbing and insulating structures in the assembly hall

The development of the acoustic design of the closed drive station of the suspended chain conveyor was preceded by acoustic measurements in the "close zone" of the sound source at a distance of 1.5 m from the reducer. The spectral noise distribution in the drive station zone, broken down into octave bands, is shown in Figure 2.

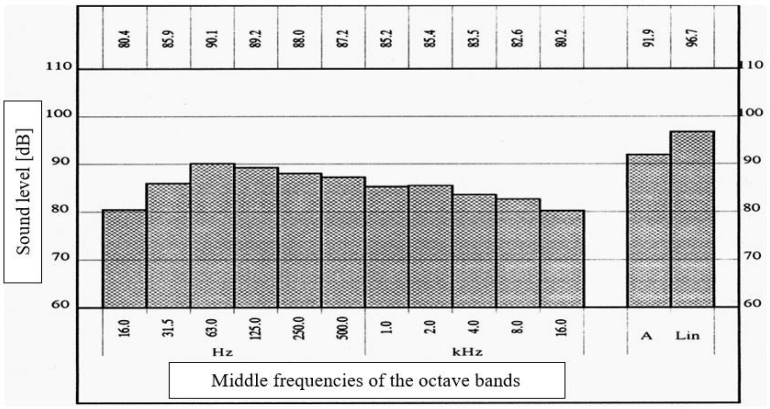

Figure 2. Noise spectral analysis in the drive station zone 1.5 m from the reducer.
Source: own study.

By introducing the reference level as the average value of the acoustic pressure according to PN-84 / N-01332, the required distribution of the average acoustic pressure in the L_{m1} octave bands was obtained, corresponding to the noise levels of 91.9dB (A). The reference level value for the Lm2 sound pressure was adopted for the frequency corresponding to the A sound level value of 75 [dB].

Acoustic insulation of the housing: $D_{ob} = L_{m1} - L_{m2} + 5 \ \ [dB]$

Acoustic insulation of the housing walls:

$$R_{swo} = D_{ob} - 10\log\frac{S_{ob}}{S_{źr}} \ \ [dB]$$

Acoustic insulation of the walls of the soundproofed housing: $R_{swp} = D_{ob} + 10\log\frac{S_{ob}}{A_{ob}} \ \ [dB]$

The results of calculating the acoustic insulation to be provided by the walls of the soundproofed housing are presented in Table 2.

Table 2

Computation results of relative acoustic insulating power R_{SW} for absorbent-reflective panel in housing

f[Hz] / [dB]	63	125	250	500	1000	2000	4000	8000
L_{m1}	91.2	90.4	88.5	87.4	85.8	85.9	83.8	82.5
R_{swo}	9.2	14.8	24.9	26.1	28.1	25.3	26.4	26.8
R_{swp}	12.5	18.9	32.2	42.1	46.0	49.0	47.7	43.4
ΔR_{sw}	3.3	4.1	7.3	16.0	17.9	23.7	21.3	16.6

Source: own study.

The selection of acoustic panels for the drive station housing was made on the basis of set of panels validated in the acoustic chambers of the Department of Vibroacoustics of the AGH University of Science and Technology (Cieślikowski, 1993). The selection of the appropriate acoustic insulation of the panel means the necessity to obtain positive values of ΔRsw for each octave band. An absorption-reflective panel AR-40 40 mm thick was selected, the structure of which is: perforated sheet (27.5% full area) from the noise source side, then mineral wool ρ=120kg/m^3, absorbent, Keller plate, solid sheet from the inside. The distribution of the specific acoustic insulation of the selected panel is shown in Figure 3.

For the difficult to attenuate frequency levels of 63Hz, there is a slight surplus of the acoustic insulation of the Rswp panel in relation to the required Rswo insulation. In the remaining bands, the values of ΔRsw clearly increase, which proves the appropriate selection of the insulating structure.

The introduction of a surplus of acoustic insulation of the housing by an additional 5dB is fully justified due to the necessity to make a channel covered with an absorption damper for the track of the suspended chain conveyor. A graphic record of the sound level distribution in the area of the housing channel for the rail guides of the overhead conveyor chain is shown in Figure 4.

f,[Hz]	R,dB
100	18.5
125	18.9
160	29.5
200	28.2
250	32.2
315	35.8
400	38.2
500	42.1
630	44.3
800	44.7
1k	46.0
1.25k	48.2
1.6k	48.3
2k	49.0
2.5k	49.8
3.15k	49.5
R_w	43

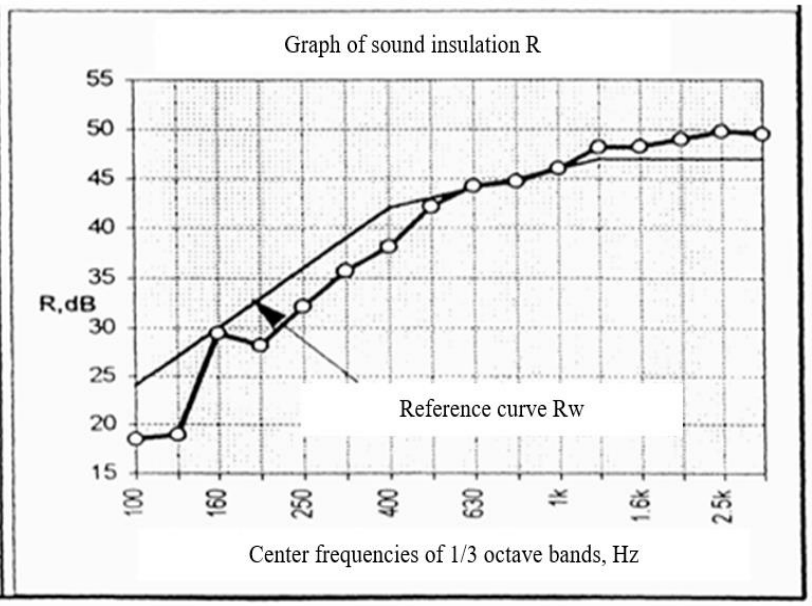

Figure 3. Catalogue card for the attestation of panel insulating structure R_W =43 dB.
Source: *Opracowanie dokumentacji zabezpieczeń dźwiękochłonnych pras na Wydziale Tłoczni Zakładu nr-2 FIAT AUTO POLAND S.A. w Tychach*, B. Cieślikowski, 1993, Kraków: EUROPROJEKT.

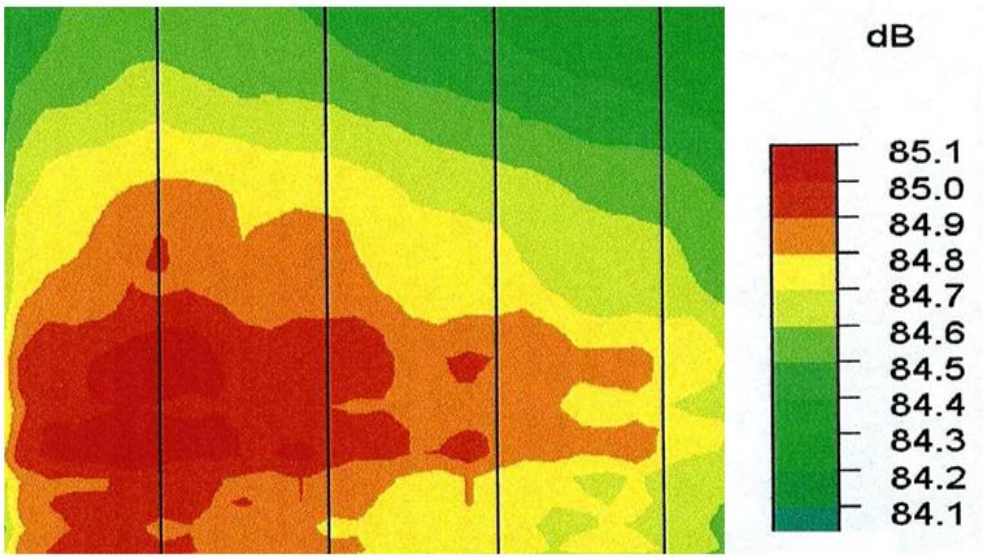

Figure 4. The sound level distribution in the area of the housing channel for chain rail guides overhead conveyor.
Source: own study.

After the assembly of the soundproofing and insulating casing of the drive station was completed, acoustic measurements were made at the designated points A-H of the assembly hall – Table 3. A variable distribution of the acoustic field was obtained with values exceeding the required noise level of 80dB. The measurement results are presented in Table 3. Relatively small surplus acoustic levels are planned to be reduced by introducing screening with AMF ACOUSTIC-SF boards for platforms below WeMa gratings and introducing vertical curtains made of PVC Enitra acoustic foil with a thickness of 5 mm on both sides of the tracks of the suspended conveyor – Figure 5.

Table 3

List of noise measurement results at measuring points in the assembly hall after the construction of soundproofing and insulating structures for the conveyor drive station

Punkt pomiaru	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
L_{Aeq}	81.2	81.0	80.6	80.3	81.6	83.8	81.4	81.4
L_{Amax}	81.4	80.6	81.0	80.7	82.5	84.4	81.7	81.5
L_C	82.9	82.6	82.7	82.2	82.4	82.7	83.0	81.3

Source: own study.

A graphic representation of the measurements of noise levels at measurement points after the construction of the soundproofing and insulating structure of the conveyor drive station and after installing the landing screens and acoustic foil curtains is shown in Figure 6. The effects of the acoustic design were verified by the final measurements made by the employees of the Environmental Research Laboratory of the Labor Protection Center – Table 4.

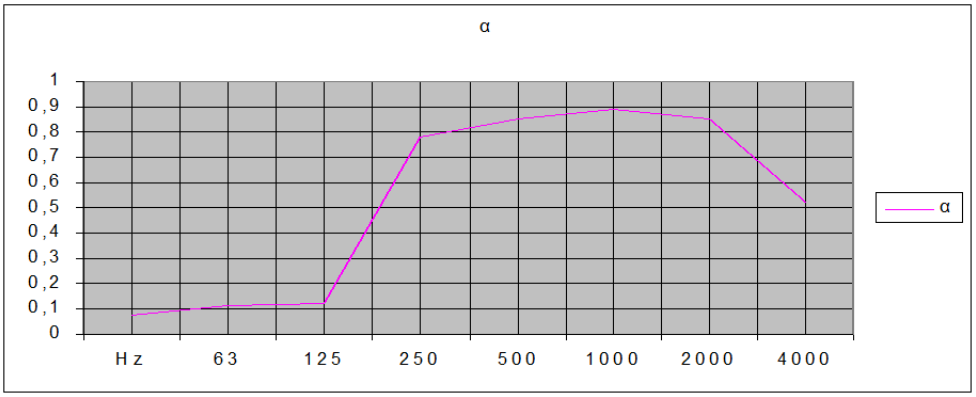

Figure 5. Distribution of the sound absorption coefficient α of AMF ACOUSTIC SF – manufacturer's catalog.

Source: own study.

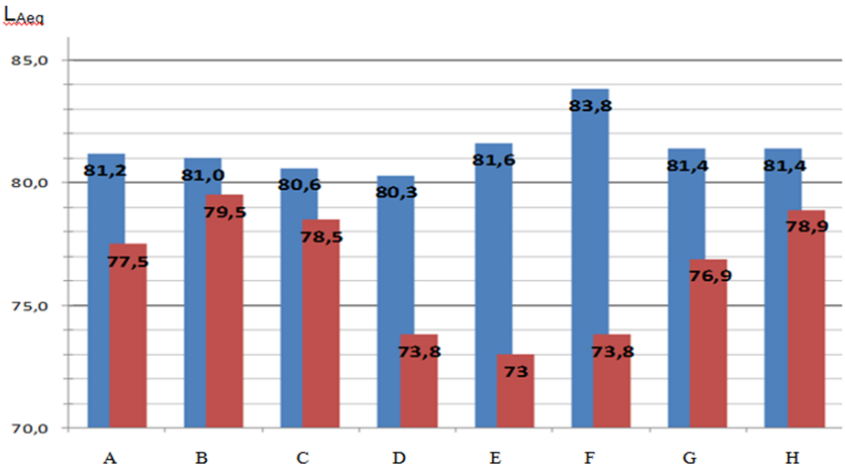

Figure 6. Graphical representation of noise levels at measurement points: after completion of the soundproofing and insulating structure of the conveyor drive station (blue), after installing landing screens and acoustic foil curtains (red).

Source: own study.

Table 4

List of noise measurement results at measurement points in the assembly hall after the completion of the installation of sound-absorbing and insulating elements (Measurements made by the Environmental Research Laboratory of the Labor Protection Center)

Punkt pomiaru	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
L_{Aeq}	77.5	79.5	78.5	73.8	73.0	73.8	76.9	78.9
L_{Amax}	77.7	80.8	80.5	77.1	74.2	75.7	80.7	80.4
L_c	81.0	81.7	80.6	79.2	77.4	78.8	81.1	81.0

Source: own study.

5. Conclusions

- The stages of soundproofing industrial facilities should be treated as a whole due to the compact nature of multi-point noise sources and the close vicinity of production lines.
- In industrial conditions, making measurements on a dense mesh is very burdensome. A practical way is to approximate the distribution of measurement results with, for example, polynomials.
- When developing the structure of criteria for the implementation of the technological process in an industrial hall, acoustic requirements should be taken into account, which are equivalent conditions for starting production. Subsequent introduction of insulating structures and acoustic development of noise emission sources is problematic and usually does not bring about positive results.
- Improvement of the acoustic climate in the assembly hall for non-standard car body elements was demonstrated after the designed sound-absorbing structures were installed, ensuring standard working conditions for employees.

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Numerical analysis of the cylinder head casting

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Abstract: The application of numerical simulations in the foundry engineering allows to predict and analyze pouring and solidification processes of the casting, as well as to locate potential defects in the cast. The publication describes the research on the use of CAD and CAE tools in order to properly design the process of producing an aluminum (AlSi6Cu4 alloy) cylinder head in the gravity die casting technology. Empirical formulas used in the foundry were used to calculate elements of the gating and feeding systems and the pouring time. In order to optimize the head manufacturing process, several simulations were carried out with the use of the MAGMASOFT5 program, allowing the technology to be refined so that the casting would be of the best quality. As a result of the research, the proper method of supplying the metal into the cavity of the metal mold was determined. The result of using appropriate risers was also examined. Application properly selected risers and chills allowed to eliminate casting defects. The obtained test results allow for the proper selection of the casting technology and implement the above automotive element for the production.

Key words: simulation, modeling, gravity casting, die casting, cylinder head.

1. Introduction

The foundry engineering is a branch of industry that currently produces components for almost all areas of the economy. The recipients of castings are primarily the automotive industry, but also machinery, construction, railways, energy and many others. Market analysis shows that this trend will continue, which prompts the foundry industry to seek better and better technological solutions, and thus a better quality of finished products.

Therefore, simulation programs are of great importance now, as they enable technologists to optimize the casting production process before implementing them into production. This allows to eliminate the disadvantages of cast components and significantly reduces the costs incurred by foundries. Using numerical simulations in the foundry allows predictions and analysis processes of pouring and solidifying the casting (Menne at al., 2007). The simulation programs also enable the precise localization of the defect in the casting and the verification of the correctness of the selected gating and feeding systems. Using simulation software is therefore an indispensable element of the foundry industry's functioning nowadays. The growing trend of using numerical simulations by foundries around the world, as well as easier access to efficient computer systems, obliges the development of this technology (Kapturkiewicz et al., 2000).

Cylinder head is one of elementary parts of piston engine. In two-stroke engines, cylinder head is respond only for close a cylinder deck. In modern four-stroke engines, cylinder head has a few more functions. For example inside it, are located intake/exhaust ports, valves with cam follower and camshaft. Directly in cylinder head, are located spark plugs and (or) fuel injectors. Furthermore, to outsides walls are mounting intake and exhaust manifolds.

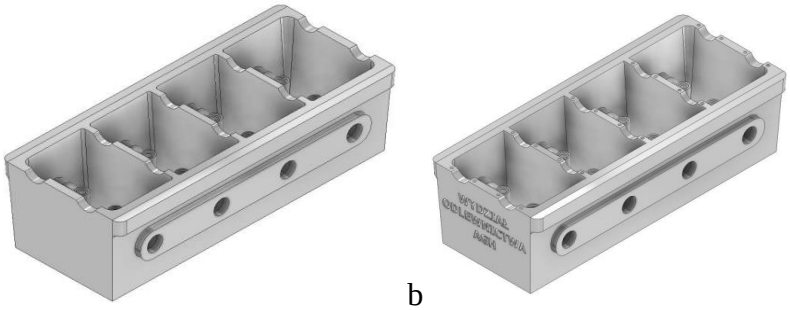
The cylinder head is subject to extremely high thermal stress due to direct contact with hot combustion gases. The greatest heat loads occur in the vicinity of the exhaust valves, exhaust ports and spark plug sockets. In addition, a cylinder head is an element that significantly affects the stiffness of the entire engine body, which directly translates into its durability and reliability (Luft, 2003). For this reason, there are several requirements that the material used for the head must meet. First, good thermal conductivity is required, allowing for heat dissipation from thermally loaded places.

Another important requirement is also high mechanical strength, low specific weight, corrosion resistance and good casting properties. The heads are made of aluminum alloys, which dissipate heat more effectively than cast iron. Moreover, aluminum alloys have a favourable density-to-mechanical strength correlation coefficient. Aluminum alloys can be gravity cast in metal molds, and this is the method most commonly used in the mass production of cylinder heads (Ivanova, 2002; Lesuer, Kipouros, 1995; Erik, 2011).

2. Preliminary methodics

Designing the 3D model

The first stage of preparing the technology was to design a model of the engine head. Three-dimensional models of the casting and the gating system were made using the CAD software – SolidWorks. This software enables the creation of three-dimensional solids and saving them in the STL format, which allows the import of a 3d object to the MAGMASoft5 simulation program. The project included the creation of a cylinder head for a four-stroke in-line spark-ignition engine. The adopted dimensions are based on the values of the main geometric indices of engines used in passenger cars, to meet the conditions of proper engine design. The 3D model is shown in Figure 1.



a b

Figure 1. 3D models made in CAD software: a) cylinder head, b) cylinder head after mechanical treatment.
Source: authors' materials.

3. The casting technology theoretical approach

Gravity die casting technology was chosen for casting the engine head – currently, it is the most commonly used method of producing cylinder heads. The gravity die casting method of aluminium alloys consists in pouring liquid alloy into a metal mold under the influence of gravitational pressure. Casting using this method allows for relatively simple and serial production of aluminium castings without the need to constantly create new molds (Chen et al., 2016). A very good surface smoothness, as well as excellent dimensional accuracy, characterizes castings made by this method.

An alloy was selected as the casting material aluminium: AlSi6Cu4. This alloy shows high strength properties, a relatively low thermal expansion coefficient as well as high thermal conductivity and good flowing power. It is also characterized by low shrinkage and high corrosion resistance (Ružbarský, 2019). Properties of AlSi6Cu4 alloy are presented in Table 1.

Table 1
Mechanical properties of AlSi6Cu4 alloy

Alloy	Method of casting	Mechanical properties			
		R_m [MPa]	$R_{0,2}$ [MPa]	A_5 [%]	Hardness [HB]
AlSi6Cu4	Sand casting	160	100	1	60
	Metal mold casting	170	110	1	70
	Die casting	220-300	150-220	2-4	70-100

Source: own study.

4. The technological calculation to perform numerical simulation

In order to design an appropriate gating system, calculations were made regarding the pouring time and the selection of sections of the elements of the casting system. The formulas used in foundry were used for the calculations (Tabor, Rączka, 1998).

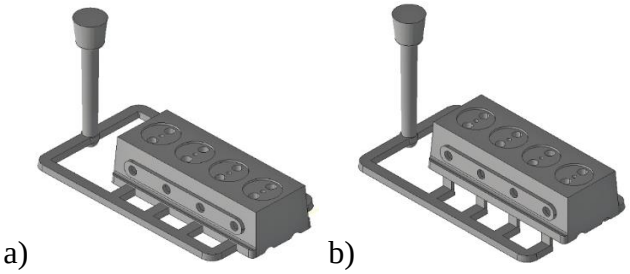
Table 2
The results of calculations gating system

The name of the parameter	Unit	The result of the calculation	The value used in calculations
The weight of the cast	kg	5.96	5.96
The weight of the cast with gating system	kg	8.34	8.34
Pouring time	s	6.35	6.35
Velocity metal in the form	cm/s	1.57	1.57
The sum of the minimum cross-sections gates	cm^2	6.57	6.57
Gates section	cm^2	0.82	0.9
Runner section	cm^2	7.9	8
Sprue section	cm^2	6.57	8
Pouring basin capacity	cm^3	486	639

Source: own study.

5. Versions of the gating systems

Based on the calculations, two versions of the gating system were designed. In the first case, the metal is supplied from sideway of the casting, while in the second version, the metal is supplied from below. The metal supply from the side allows for directional solidification and a relatively smooth metal flow. On the other hand, the supply from the bottom ensures smooth filling, better gas removal from the mold cavity and, which is important when casting aluminum alloy – it reduces oxide inclusions. However, this method of supplying metal requires designing larger risers, the temperature distribution in the casting is spotty (Tabor at al., 1998). Both of these types of metal feeding into the mold cavity are suitable for aluminum alloys, therefore it was decided to compare these versions using the simulation in MAGMASoft5 software. The metal gating system from the sideways of the mold is shown in Figure 2a, and from the bottom – in Figure 2b.



a) b)

Figure 2. Schematic diagram of the gating system: a) side supply of metal; b) feeding the metal from below.
Source: own study.

6. The casting process simulation analysis using MAGMASoft5

The MAGMASoft program was used to simulate the casting phenomena. This software enables computer simulation of the processes accompanying the production of castings. Using simulation programs allows to improve the manufacturing process, eliminate errors during production and avoid unnecessary production costs.

The first stage of preparing a simulation in MAGMASoft was importing 3D models of castings and gating systems. Each of the objects imported to MAGMASoft5 required assigning an appropriate material in order to assign physical parameters corresponding to a relevant element of the gating system. After the next step – meshing, parameters such as material definition, heat transfer coefficient, boundary conditions, number of heating and production cycles as well as filling and solidification parameters have been defined. Adopted conditions to carried out simulations are summarised in Table 3.

Table 3
Selected boundary conditions to perform simulation

The name of parameter	Value	Unit
Selected alloy	AlSi6Cu4	-
Selected mould material	Steel	-
Selected core material	AlSi12Cu	-
Initial cast alloy temperature	700	°C
Initial permanent mold temperature	200	°C
Initial core temperature	150	°C
Number of cycles	6 heating and 2 production cycles	-
Pouring time	6,24	s

Source: own study.

7. Preliminary simulations

In the first stage, preliminary simulations were carried out without the gating system in order to verify the correctness of the geometrical location (orientation versus gravity direction) of the casting in the pouring mold. Simulation identifies areas where porosity is predicted. Porosity is the most important parameter that indicates the occurrence of defects in the casting in the form of voids formed when the metal solidifies. Therefore, it is extremely important to strive for the complete removal of porosity, especially from the responsible places in the castings. The results of the conducted preliminary simulations are presented in Figure 3.

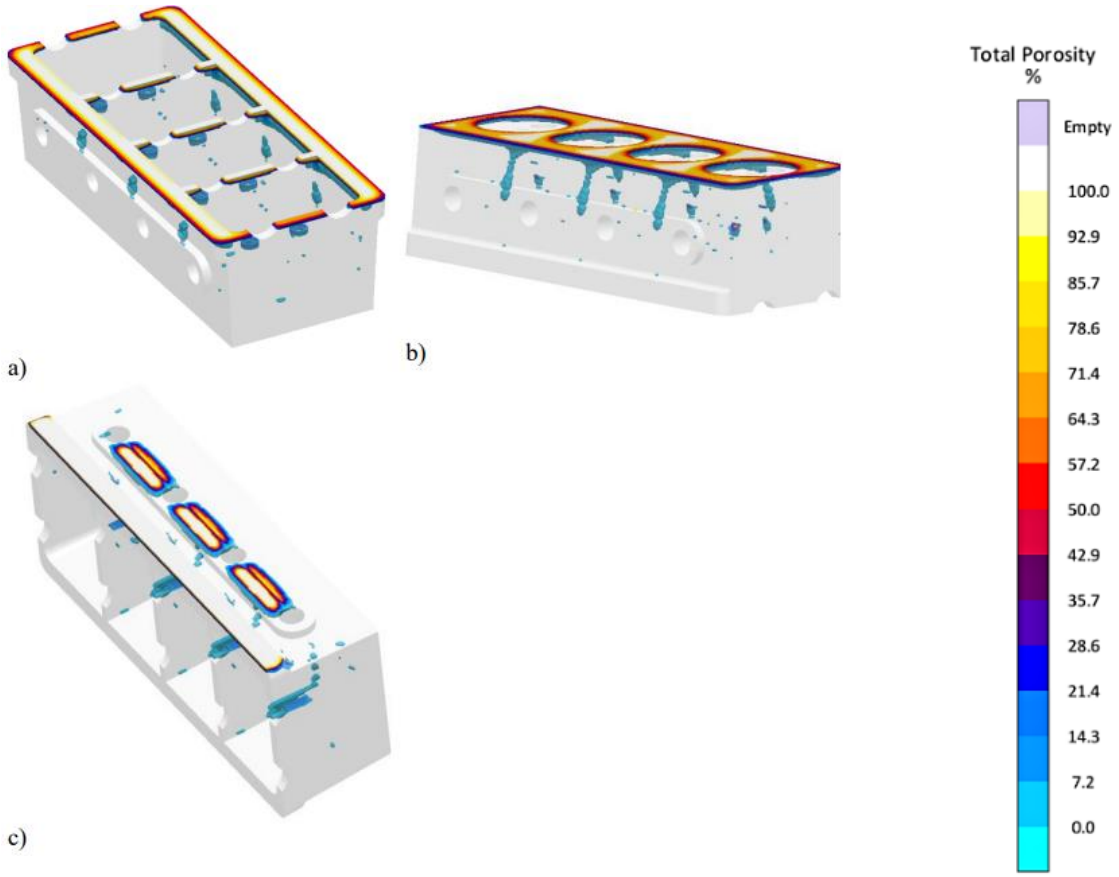


Figure 3. Cast porosity: a) first version; b) second version; c) third version.
Source: own study.

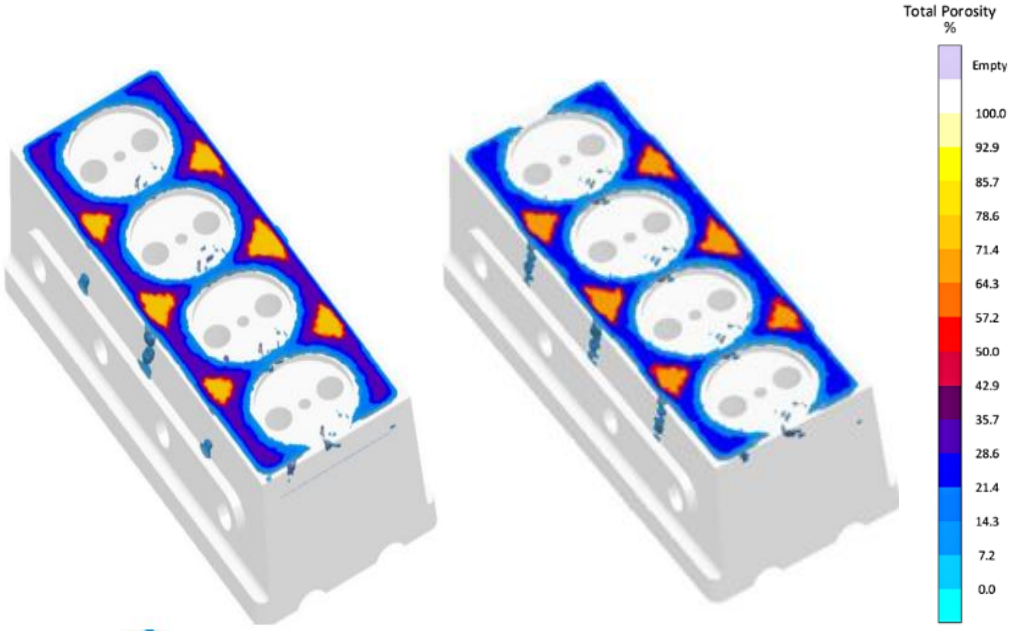


Figure 4. Cast porosity: (a) side feeding; b) feeding from below.
Source: own study.

The second version was selected for further research because of the easier possibility of designing the gating and feeding systems. As shown in Figure 3, the porosity, in this case, accumulates mainly in the upper face of the casting, which can be reduced in this case more easily by using feeders – risers on the upper face of the casting.

In the next stage of the research, simulations were carried out with two versions of the gating system in order to select the appropriate method of bringing the metal to the mold. For the analysis, the results of porosity were used in both cases (Figure 4), and the flow velocities were compared (Figure 5).

The porosity in both cases is at a similar level. In the first version, with sideways gates, slightly higher porosity values are found on the upper face of the casting.

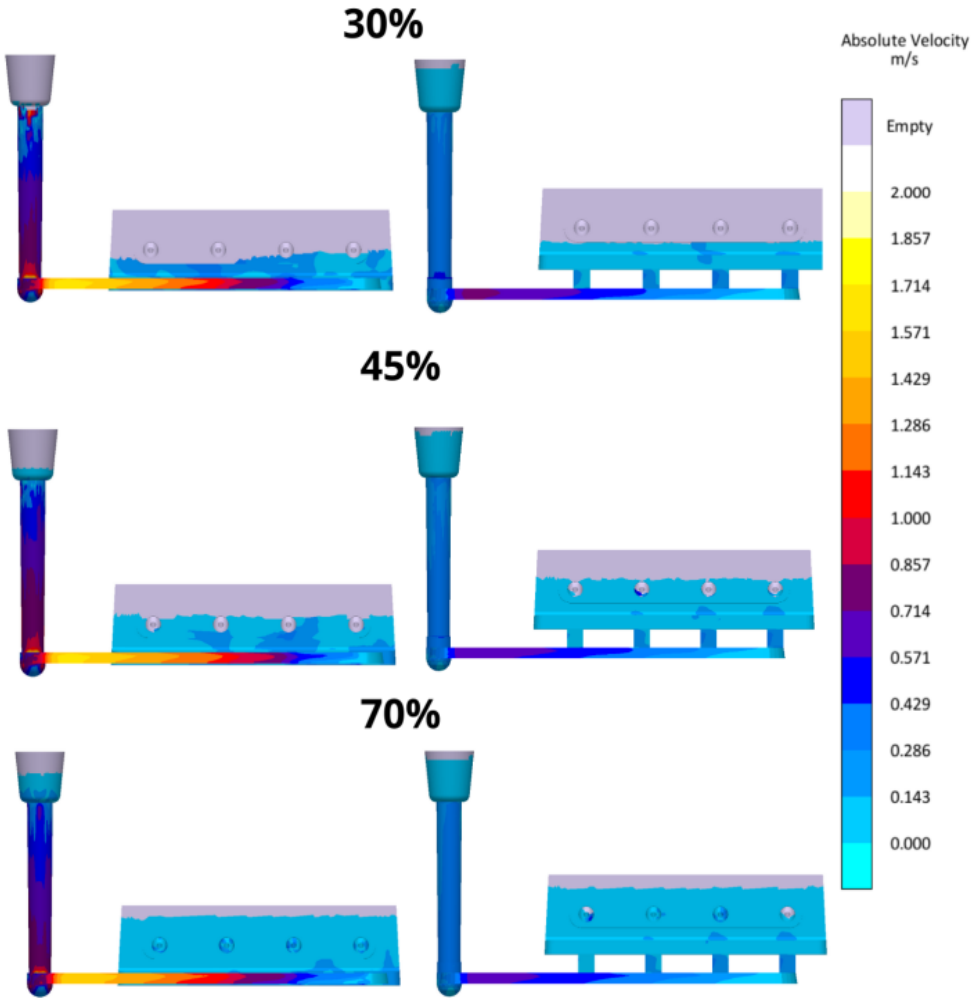


Figure 5. Comparison of the metal flow velocity in the two versions of the gating system, on the left side – inlet from the side, on the right – from the bottom.
Source: own study.

The value of the flow velocity in the case of side pouring is noticeably higher, as shown in Figure 5. In the bottom pouring version, the flow is less turbulent, indicating that undesirable casting defects are likely to be less likely to occur. Based on the above values of flow velocity, porosity and theoretical knowledge, it was decided to select a version with bottom pouring for further simulation.

On the upper face of the casting, significant porosity is visible, with a value of up to about 80%. In order to remove it, feeders have been designed on the upper surface of the casting. A simulation was carried out, the effect of which is shown in Figure 6. Feeder caused the porosity at the upper face of the casting was almost completely eliminated (except for microporosity). The principle of operation of risers is that during solidification, the metal flows from them to the casting, supplying it at the moment when metal deficiencies due to shrinkage appear in the casting. Thereby, the contraction cavity (casting porosity) is located the instead of the casting – in the riser (Perzyk et al., 2004).

The module analysis ("Feedmod") also shows that the risers are working properly. The Feedmod is defined as the ratio of the component volume to the surface area heat dissipation. In accordance with the requirement of directional solidification, the feeders are designed so that the individual parts of the casting itself have modules increasing towards the riser. The parameter of the obtained module is presented in Figure 7.

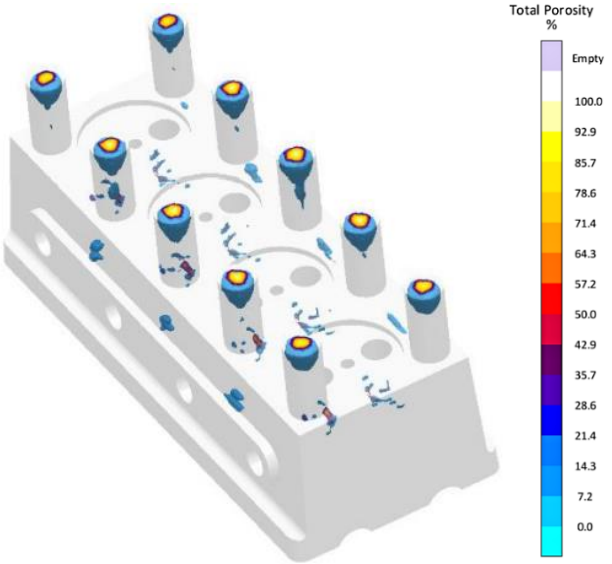


Figure 6. The distribution of porosity in the casting – the effect of risers.
Source: own study.

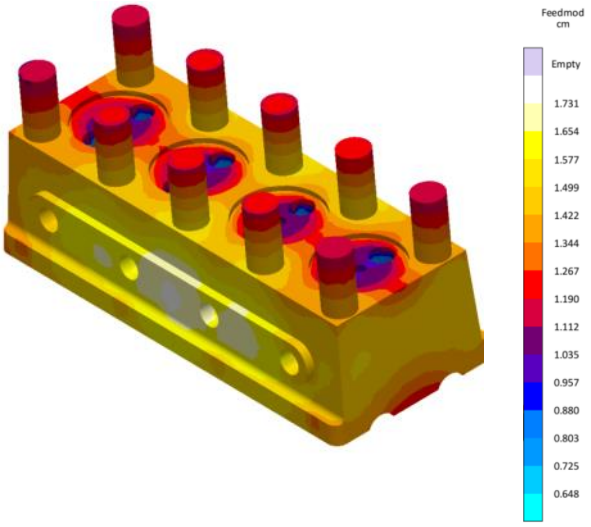


Figure 7. Cast module – effect of risers.
Source: own study.

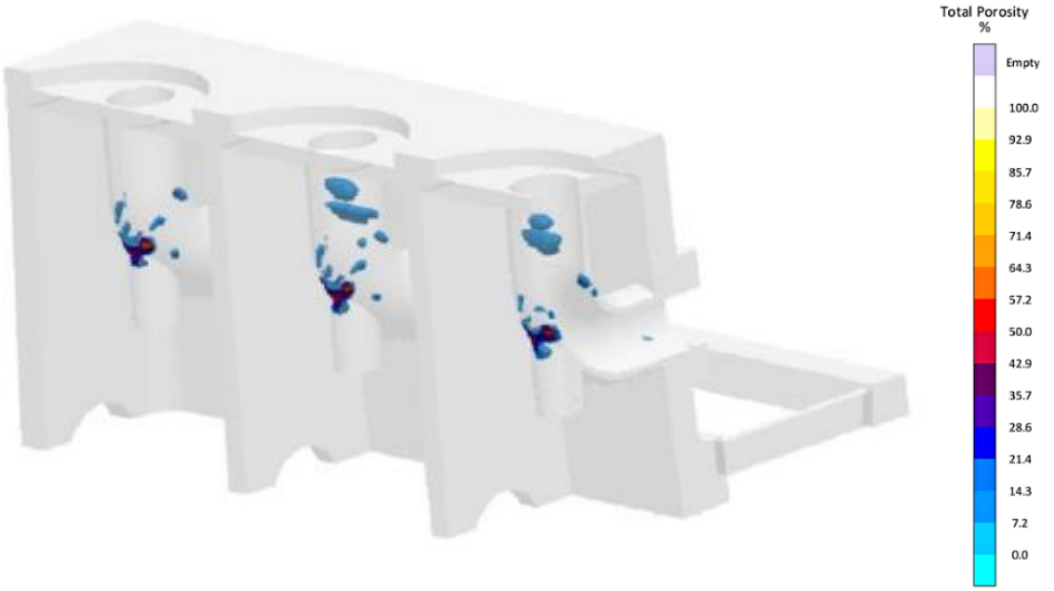


Figure 8. Porosity in the place of inlet channels with valve seats – detail view.
Source: own study.

The porosity still remains at the point where the intake ports connect to the valve seats, as shown in detail in Figure 8. Removal of the porosity from there is essential as it is the most thermally stressed component and plays an essential role in the operation of the cylinder head.

In order to eliminate the defect in this place, it was installed chills in the form of plates on the inside between the cast and the core. Chills work by lowering the temperature of the casting part because of high specific heat and high thermal conductivity, which improves solidification directivity. External chills (used in this case) can be made of various types of materials, but it is important that the chills material has a higher specific heat than the casting material (Perzyk et al., 2004).

The alloy used in this study shows a high specific heat of about 870 J / (kg * K), which prompted the choice of graphite with a higher specific heat value as the chills material in accordance with the values of Table 4. The model of the chill used is shown in figure 9. The results of the simulation with the use of chills are shown in Figure 10.

Table 4
Specific heat and heat conductibility of exemplary materials

Material	**Density**	**Specific heat**	**Heat Conductibility**
	kg / dm^3	**J / kg·K**	**W / (m·K)**
Lamellar iron	7.20	720	39
Ductile iron	7.10	515	29
Vermicular iron	7.10	620	35
Steel	7.80	520	25
Graphite	2.1	1510	60
Silico Carbide	-	963	-

Source: own study.

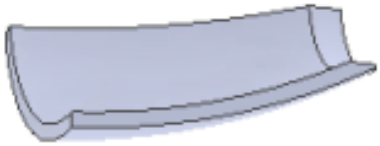


Figure 9. Chills used to eliminate porosity.
Source: own study.

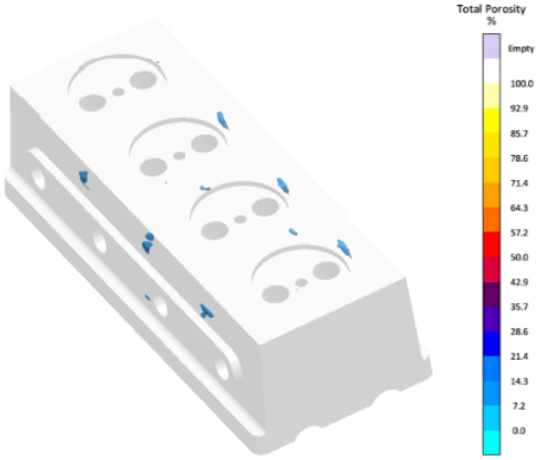


Figure 10. Porosity after using chills.
Source: own study.

The chills have completely eliminated the porosity of the intake ports connection, thanks to which a qualitative cast was obtained in this responsible element. A detailed view of the place from which the porosity has been eliminated is shown in Figure 11. In fact, because of the great difficulty of casting within this component, valve seats are often seated into the head after casting or during casting. They are usually made of alloy steel with a content of up to 30% Cr, 2% Cu, 0.3-0.4% Si and Mn (Luft, 2003).

Figure 11. Porosity after using chills – detailed view.
Source: own study.

Single points of porosity also occur at the junction of the sidewall of the casting and the camshaft support – it is also necessary to eliminate them Remaining porosity at the junction of the casting side wall and the camshaft support. In order to eliminate this disadvantage, "T" chills were used as shown in Figure 13 .

In order to correctly select the size of coolers so that they function properly, appropriate calculations were carried out. For the calculations, the modulus values obtained from the simulation results (Figure 12) and casting formulas were used (Henderieck, 2007).

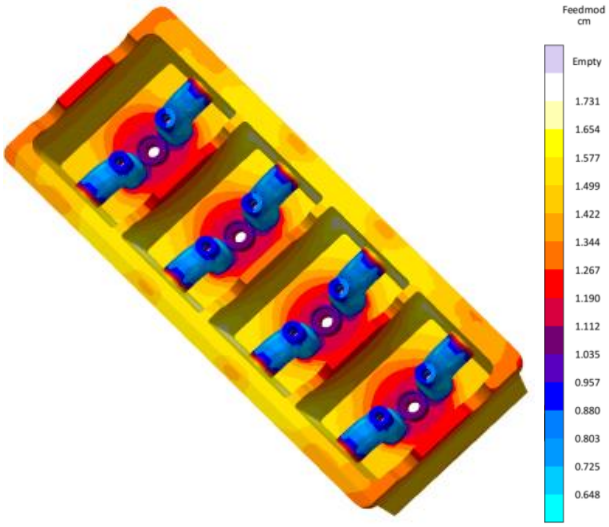


Figure 12. Cast modulus distribution used to calculate the volume of chills.
Source: own study.

$$V_{chill} = \frac{\varsigma_{metal} \cdot V_{0c} * (M_{oc} - M_{req})(L_{metal} + C_{metal} \cdot (T_P - T_L))}{M_{chill} \cdot \varsigma_{chill} \cdot T_{chill} \cdot C_{chill}}$$

Symbols:

V_{chill} – volume of chill [cm^3],
V_{0c} – volume of casting, concerned in the chill area [cm^3],
ς_{chill} – density of chill metal [g/ cm^3],
ς_{metal} – density of casting metal [g/ cm^3],
M_{0c} – original module of the concerned casting location [cm],
M_{req} – required modulus of the concerned casting location [cm],
T_P – pouring temperature [°C],
T_L – liquidus temperature of casting metal [°C],
T_S – solidus temperature of casting metal [°C],
T_{chill} – maximum allowed temperature of chill [°C],
C_{chill} – average specific heat of chill metal (20 to 400°C),
C_{metal} – average specific heat of liquid casting metal,
L_{metal} – melting heat of casting metal.

$$V_{chill} = \frac{2{,}7 \cdot 104 \cdot (1{,}596 - 1{,}431)\,(660 + 870 \cdot (700 - 610))}{1{,}596 \cdot 2{,}1 \cdot 200 \cdot 400}$$

The volume of a single chills was calculated: $\mathbf{V_{chill1}} = 10{,}21\ [\mathbf{cm^3}]$.

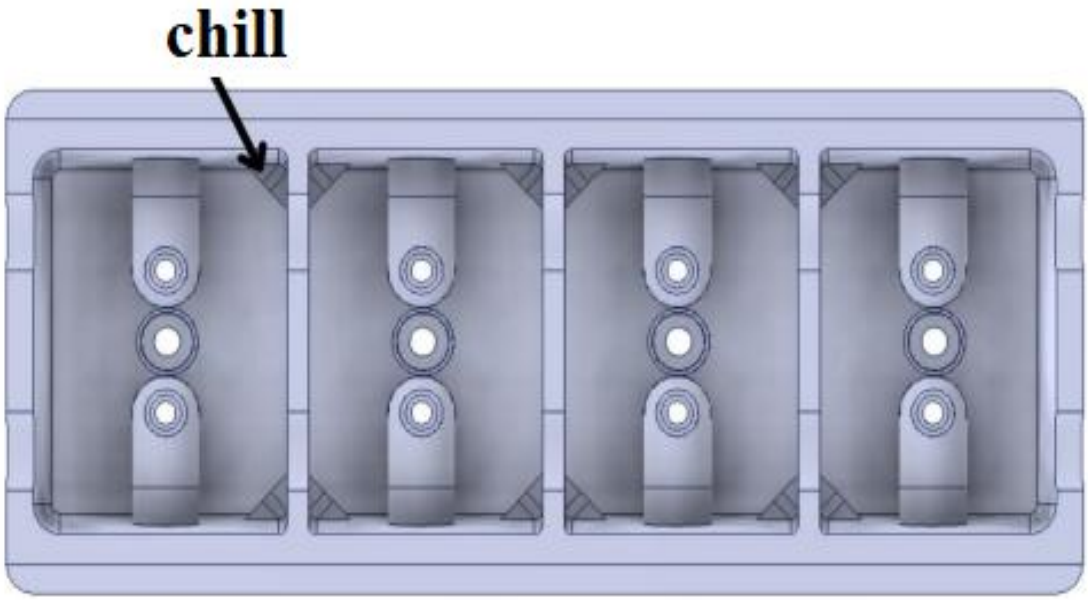


Figure 13. Applied chills – shape and arrangement.
Source: own study.

The simulation was carried out with the use of additional chills, the result of which is shown in Figure 13. As a result of the simulation, the porosity area decreased. The above technology allowed for a significant reduction of casting defects.

8. Conclusions

This research presents the complexity of the process of designing products, such as castings, on the example of producing a cylinder head. Obtaining a ready casting requires several projects and tests so that the product is of the best quality.

The simulation of the pouring process in simulation programs consists of many attempts to adjust the gating and feeding system to obtain a cast without defects. The assumption of the work was to optimize the engine head manufacturing process. Numerous simulations in the MAGMASoft5 program made it possible to establish a favourable technology for the above-mentioned casting.

The simulation results available in MAGMASoft5 are extremely helpful in selecting the appropriate casting filling and feeding design. The "Porosity" parameter, for example, allows you to locate and examine the amount of porosity present. The value of the module (Feedmod) helps in understanding the thermal conditions during casting, thanks to which it is possible to select the appropriate risers.

In this study, the proper method of bringing the metal into the cavity of the metal mold was determined, and the result of using the appropriate casting filling and feeding design was also examined. The use of risers and chills made it possible to obtain a cast that was almost free from defects.

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Plastic formation in the process of cutting the material due to drilling

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Abstract: The essence of the cutting process is the deformation zone in the form of chips directed in the cutting zone. In this zone, a material separating wedge is formed, which leads to plastic deformation of the processed material. The results of the metallographic tests carried out are presented in 10 tables and 13 drawings, which show the scope of the tool (drill) impact on the processed material. The research showed significant changes in the material during drilling. Changes in the texture of the material and damage to the front surfaces of the tool are visible.

Key words: plastic deformation, cutting process, material, drilling.

1. Introduction

Plastic deformation analysis in the cutting process by drilling can be carried out in various ways. The paper presents the results of research on plastic deformation and accompanying phenomena during drilling. It has been shown that when drilling holes in the cutting process, plastic deformations, elastic strains, and friction occur (Jurko, Zaborowski, 2013; Jurko, 2005; Kalpakin, 1991).

Analysis of plastic deformation in the cutting process can be implemented in different ways. The essence of the examination cutting process is aimed at cutting zone, which defines an important element of the plastically deformed material, whereupon the property, which we call root chips (Zaborowski, 2011; Zumgahr, 1981; Grzesik, 2022; Jemielniak, 2022).

Cutting zone is a collective name to see the effect of the cutting wedge element plastically deformed material object. For a detailed description of the cutting zone is necessary to define the following elements:

- Primary zone of plastic deformation – shear zone plane, preferably phenomena of emergence and shaping chips, as the effect of cutting force and its components: voltage deformation state, position angle shear plane, compression chips, the temperature field chips, shape chips, formation, and fracture chips, cutting force and cutting resistance.
- Secondary zone plastic deformation – preferably phenomena of friction and wear of cutting wedge as well as the generation of heat and temperature, position angle texture-contact length of the cutting wedge/frontal area, tension and friction-up edge, friction, formation and heat transfer and temperature, wear mechanisms.
- Tertiary zone of plastic deformation – preferably phenomena associated with the formation of the cut surface, its profile, morphology, and properties (surface integrity): interaction surface of the cut and the dorsal surface, breakdown voltage on the flank surface, wear mechanisms of the flank surface.

2. Cutting zone

Figure 1 shows the root chips obtained in axial turning steel 1.4301, according to 2. After treatment of the sample was studied root chips with REM application. The results obtained from the primary surface zone of plastic deformation, shown in Table 1 and 2.

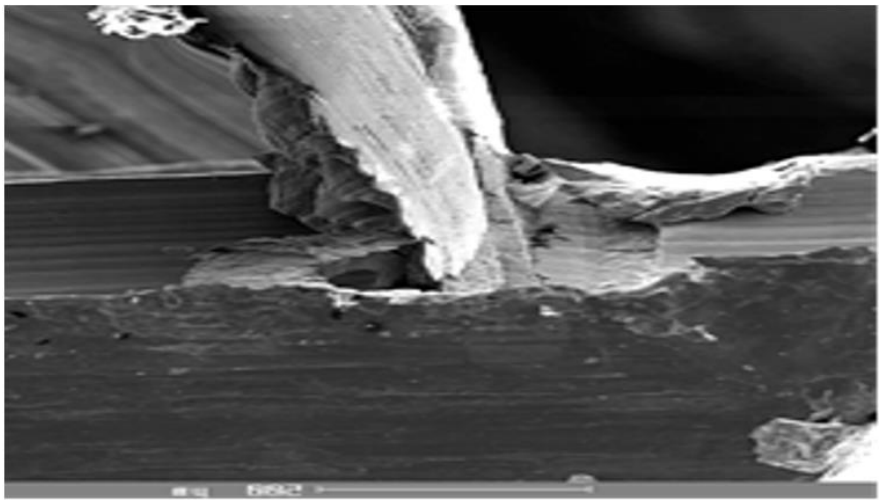


Figure 1. Root chips.
Source: own study.

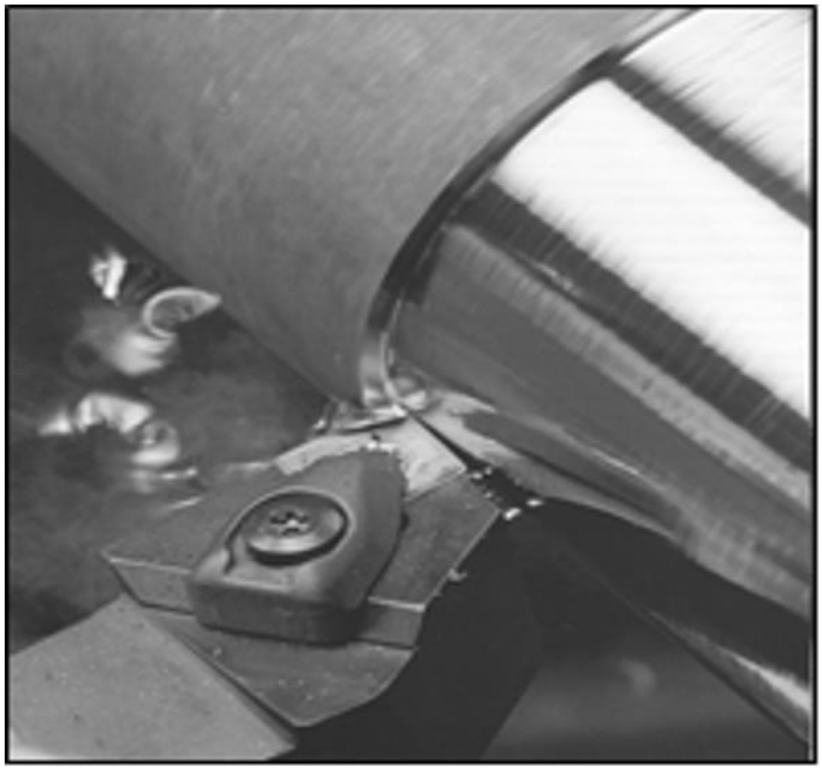
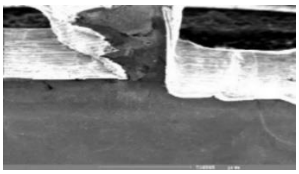
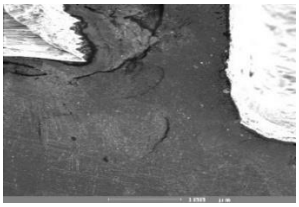
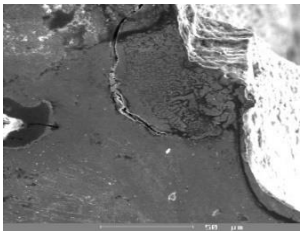
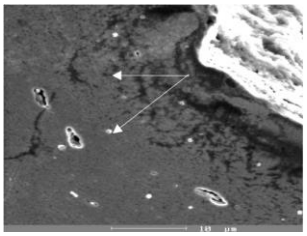
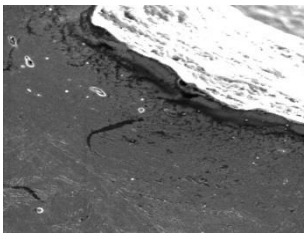
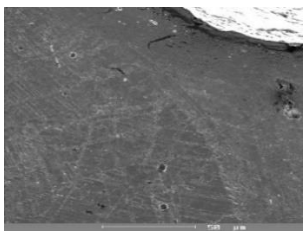
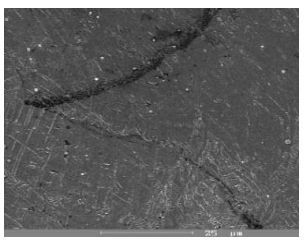
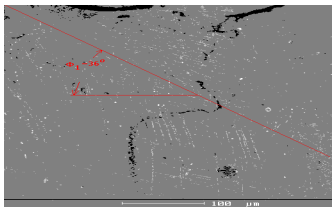
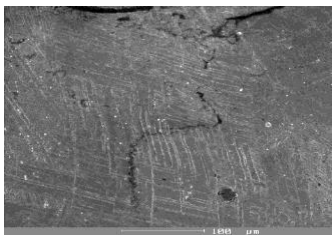
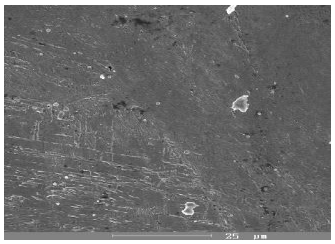
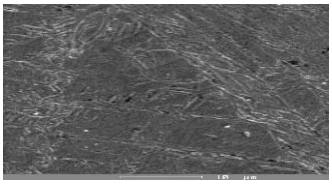
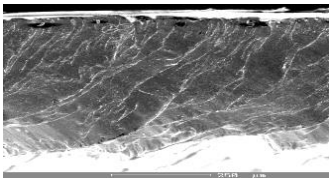
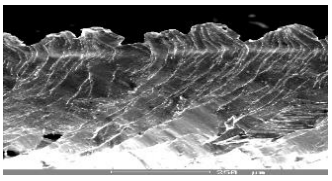
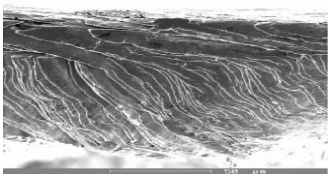
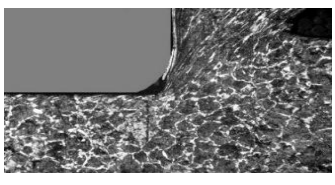


Figure 2. Cutting zone.
Source: own study.

The primary zone of plastic deformation is defined shear plane, which defines the beginning of creation, and simultaneously forming particles. Examples of cross-sections of chips in turning and drilling documented in Table 3 and 4.

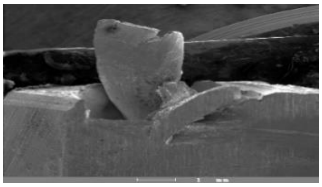
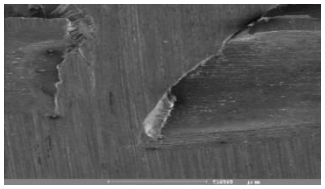
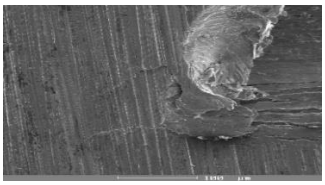
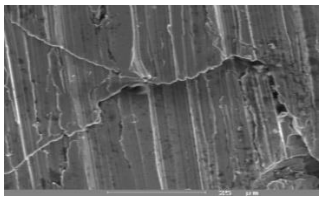
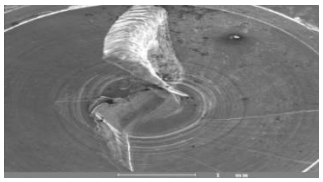
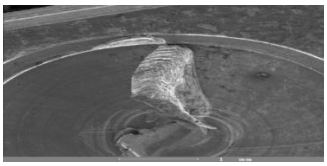
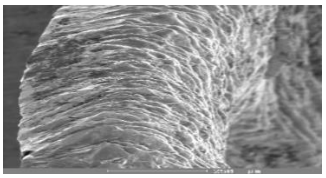
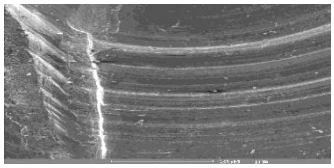
Table 1
The primary zone of plastic deformation in turning

Designation	Figure	Description
E1		Root chips, steel 1.4301 Axial turning
E2		Detail from figure E1 of Primary-zone of plastic deformation: • Plastically deformed material • Significant destruction before cutting wedge • Plastic deformation in shaping chips
E3		Detail from figure E2 • Significant destruction before cutting wedge • Destruction of elements of different sizes material • Cracks due to the operating pressure of the cutting tool material object
E4		Detail from figure • Significant destruction before cutting wedge • Destruction of elements of different sizes material • Cracks due to the operating pressure of the cutting tool material object
E5		Detail from figure E2 • Significant destruction before cutting wedge • Destruction of elements of different sizes material • Cracks due to the operating pressure of the cutting tool material object
E6		Detail from figure E2 • Significant destruction before cutting wedge • Destruction of elements of different sizes material • Cracks due to the operating pressure of the cutting tool material object
E7		Detail from figure E2 • Destruction of elements with a large volume of material which are separated by distinctive crack • Formation of slip lines and slip bands in the shear plane, with a gradual continuation of the core material object

E8		Detail from figure E2 • Destruction of elements with a large volume of material which are separated by distinctive crack • Definition-angle shear plane $\Phi_1 = 36^o$
E9		Detail from figure E2 • Destruction of elements with a large volume of material which are separated by distinctive crack • Slip lines and slip bands in the shear plane, with a gradual continuation of the core material object
E10		Detail from figure E6 • Destruction of elements with a large volume of material which are separated by distinctive crack • Slip lines and slip bands in the shear plane, with a gradual continuation of the core material object
E11		Detail from figure E9 • Slip lines and slip bands in the shear plane, with a gradual continuation of the core material object • Define the shear plane
E12		Texture chips • Forming particles • Stalled layer • Slip lines and slip bands
E13		Texture chips • Forming particles • Strong-stalled layer • Slip lines and slip bands
E14		Texture chips Specific-forming particles • Stalled layer • Slip lines and slip bands
E15		Root chips, steel 1.1182 Axial turning

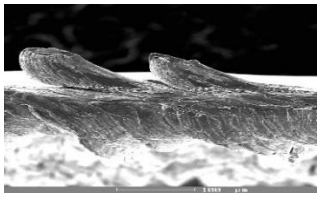
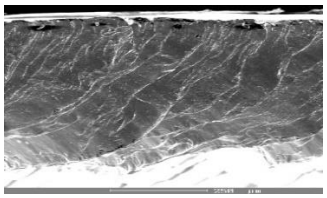
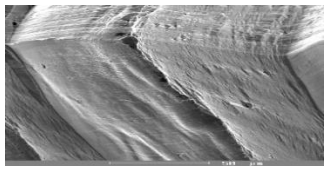
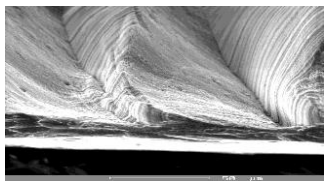
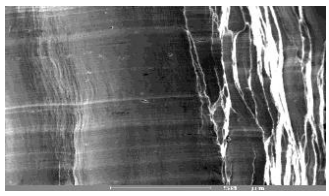
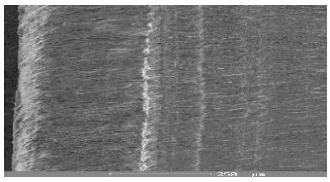
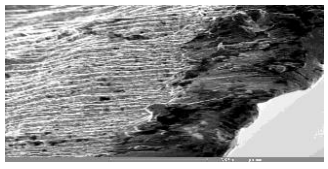
Source: own study.

Table 2
The primary zone of plastic deformation during drilling

Designation	Figure	Description
E16		Root chips, steel 1.4301 Drilling
E17		Detail from figure of E16 Primary-zone of plastic deformation • Plastically deformed material
E18		Detail from figure of E17 • Significant destruction before cutting wedge • Destruction of elements of different sizes material • Cracks due to the operating pressure of the cutting tool material object
E19		Detail from figure of E18 • Significant destruction before cutting wedge, before cutting edge • Destruction of elements of different sizes material • Germs (outbreaks), microcracks spread to cracks in the direction of the applied displacement of the cutting tool
E20		Root-chips for two helical cutting edges dril • Part of the material is pushing cross-cutting edge
E21		Detail from figure of E20 • Root chips from one cutting edge • Plastic deformation prior to cutting wedge • Formation and shaping chips
E22		Detail from figure of E21 • Plastic deformation element abstracted layers of material object
E23		Detail from figure of E20 Hardening-sectional surface of the • Slip lines and slip bands

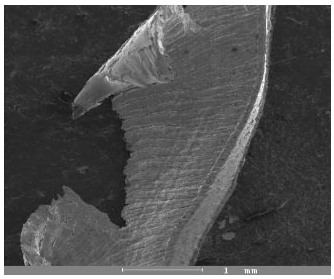
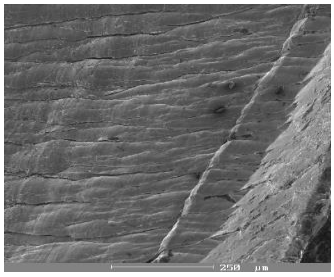
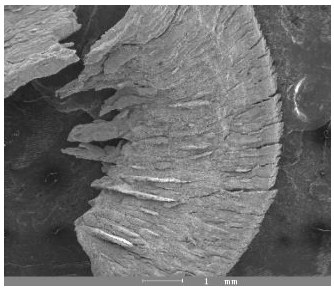
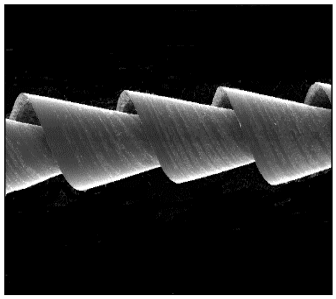
Source: own study.

Table 3
Creating and shaping chips in turning

Designation	Figure	Description
E24		Cross-section of particles in turning steel 1.4301 • Two-stage blades chips • Expression of adhesion between chipping and the front surface of the cutting tool Stalled-(white) layer • Slip lines and slip bands
E25		Cross-section of particles in turning steel 1.4301 • Two-stage blades chips • Expression of adhesion between chipping and the front surface of the cutting tool Stalled-(white) layer • Slip lines and slip bands
E26		Cross-section of particles in turning steel 1.1182 Texture-sectional chips Stalled-(white) layer • Slip lines and slip bands
E27		• Tearing element chip • Expression of adhesion between chipping and the front surface of the cutting tool • Slip lines and slip bands
E28		Cross chips in turning steel 1.4301 Lamellae-chip • Slip lines and slip bands • Twinning lamellae in chips • Stalled (white) layer
E29		Plastic deformation chips • Slip lines and slip bands • Twinning lamellae in chips • Changes in textural elements chips for steel 1.4301
E30		Plastic deformation chips after parting steel 1.4301 • Changes in textural elements defined cutting edge chip
E31		Plastic deformation chips • Slip lines and slip bands • Twinning in chips

Source: own study.

Table 4
Creating and shaping chips when drilling

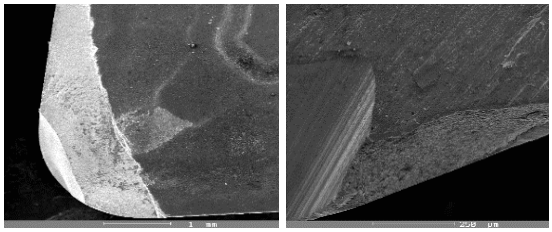
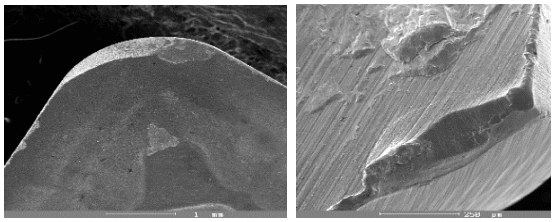
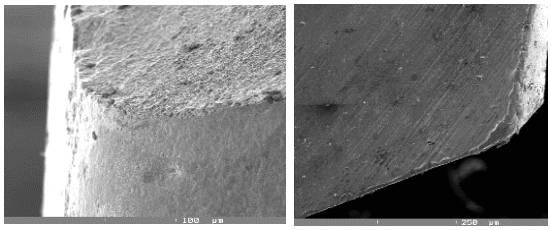
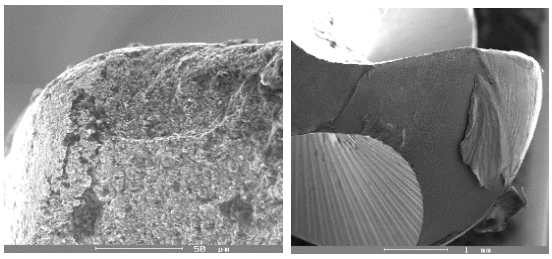
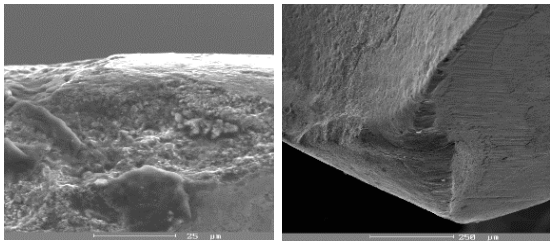
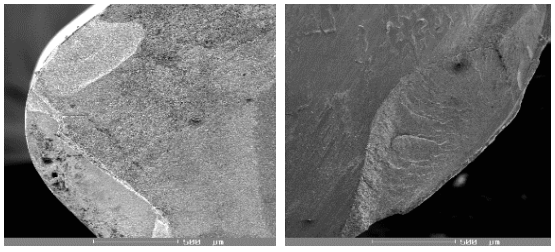
Designation	Figure	Description
E32		Plastic deformation chips after drilling 1.4301 • Changes in textural elements defined cutting edge chip
E33		Detail from figure E32 Plastic deformation chips after drilling 1.4301 • Changes in textural elements defined cutting edge chip • Slip lines and slip bands
E34		Plastic deformation chips after drilling Ti-alloys • Changes in textural elements defined cutting edge chip
E35		Plastic deformation chips after drilling Ti-alloys • Characteristic shape of chips when drilling in the shape of the helix • Slip lines and slip bands

Source: own study.

3. Zone Secondary deformation

Secondary zone plastic deformation is an important area in which the foundation drainage chips after the end face of the cutting tool experiencing various forms of damage to the front surface of the cutting tool when up edge formation. Table 5 lists the most common forms of damage to cutting tools in turning and drilling.

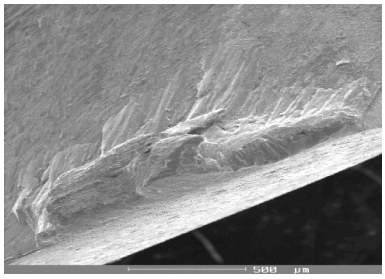
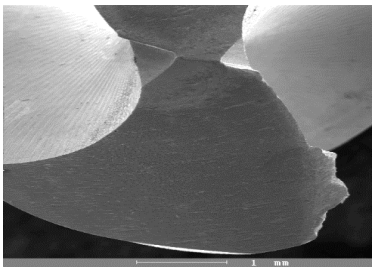
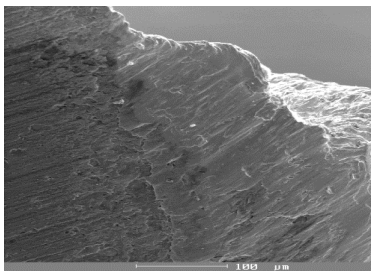
Table 5
Damage to the frontal area of the cutting tools in turning and drilling

Designation	Figure	Description
E37		Thermal destruction • Achieving temperature fields on the face • Fracture element fields
E38		Fracture element of cutting edge • Foetuses, crack propagation
E39		Plastic deformation at the tip • Change the shape of the cutting
E40		Plastic deformation at the tip • Elements of larger volumes-complete loss cutting
E41		Plastic deformation on the main cutting edge • Gradual loss cutting
E42		• Groove on the face • Destruction of the volume of material on the face

Source: own study.

One of the accompanying phenomena in the cutting process is a phenomenon up edge formation, table 6 Built up Edge (BUE) is formed under defined conditions, the cutting process and thus to the defined material. It is characteristic that BUE formed mainly on the face of the cutting tool. Based on the knowledge and experience of actual practice it is a phenomenon that is undesirable for the cutting process, even though it is partly its advantages.

Table 6
BUE on the face of the cutting tooling turning and drilling

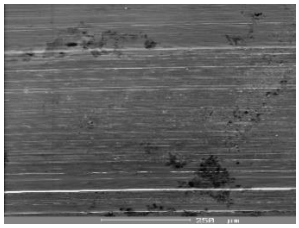
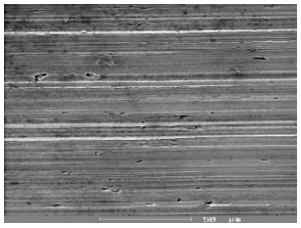
Designation	Figure	Description
E43		BUE the face of the helical drill • "Stuck" element plastically deformed material object 1.4301 • Composition-up edge of the stable and unstable parts of the
E44		BUE dorsal surface of helical drill • "Stuck" element plastically deformed material object 1.4301
E45		Detail figure of E44 Connectedness-up edge on the dorsal surface of the main • Adhesion surface after the cut

Source: own study.

4. Tertiary plastic deformation zone

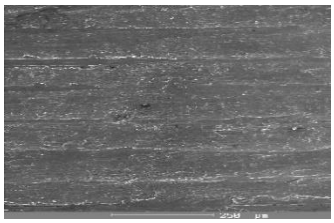
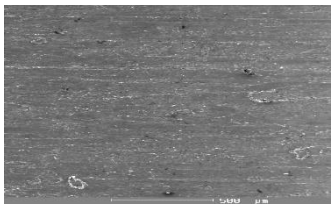
Tertiary zone of plastic deformation region is important for achieving the desired surface (Table 7 and 8), and the effect of cutting parameters on the damage of cutting tools on the dorsal surface, according to Table 9. The cutting process is characteristic of some materials (such as austenitic stainless steel) to strengthen the surface after the cut. Paved the cut is a manifestation of intense plastic deformation and for some materials can cause significant change mechanical properties, particularly strength and surface hardness. This is a very frequent cause of damage to cutting tools, mainly on their flank surface.

Table 7
Surface after the cut in turning

Designation	Figure	Description
E46		Surface after turning steel 1.1182 • Tool marks • Impurities on the surface
E47		Surface after turning steel 1.4301 • Tool marks

Source: own study.

Table 8
Surface after the cut in drilling

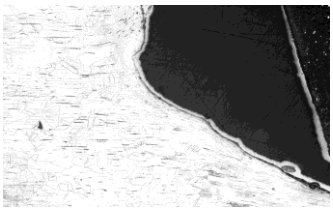
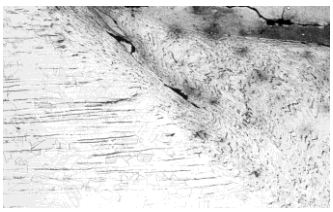
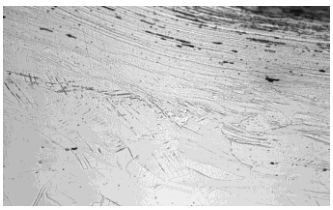
Designation	Figure	Description
E48		Surface after drilling steel 1.1182 • Tool marks • Impurities on the surface
E49		Surface after drilling steel 1.4301 • Tool marks

Source: own study.

Table 9 documents the plastic deformation below the surface when drilling steel 1.4301. Interestingly, the microhardness of the material is up to 50% higher compared to the hardness of the base material, figure 3. Chapter devoted to cutting damage of the tool is helpful in terms of damage defined elements of the twist drill. The content of this chapter is focused on three core damage: breakage, wear and BUE. The specification of these lesions is based on real experience. Generally, when examining damage axial tools can be based on such damage. Turning the cutting tools, but we must also take account of the different conditions of the cutting process. This argument must be taken into account especially when very problem-different materials.

Table 10 is the damage helical drill destruction (Table 11).

Table 9
Plastic deformation during drilling

Designation	Figure	Description
E50		Deformation at the tip surface after cutting in drilling • Steel 1.4301
E51		Plastic deformation along the depth of the hole-steel 1.4301
E52		Intense plastic deformation under the main cutting edge Limit of the deformed and undeformed material
E53		Intense plastic deformation below the top Limit of the deformed and undeformed material

Source: own study.

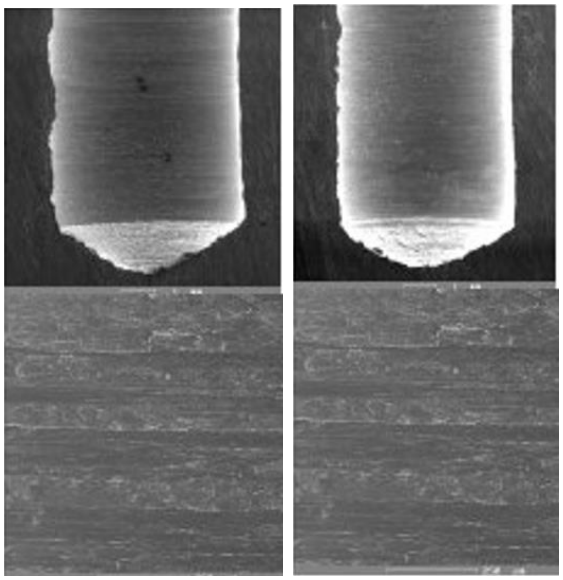
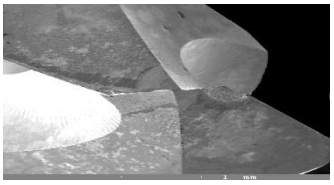
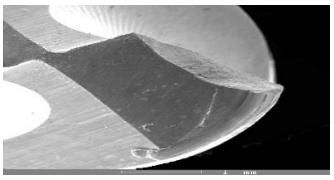
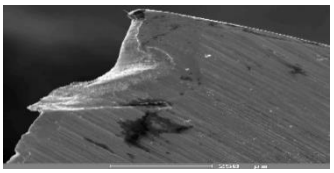
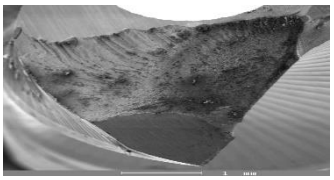
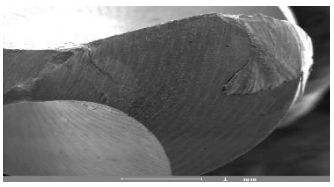
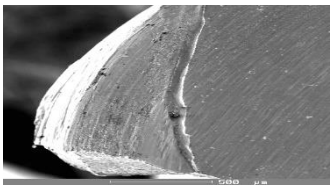
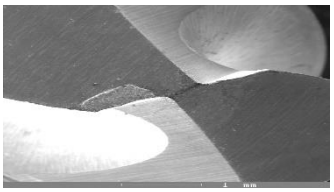
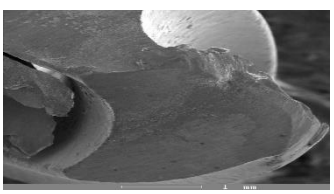
a  b 

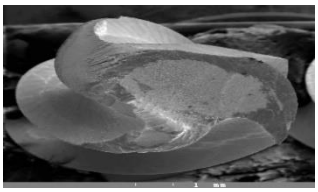
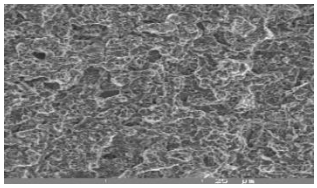
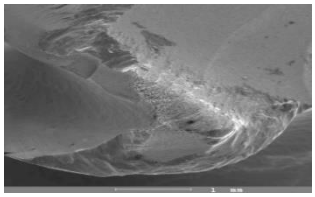
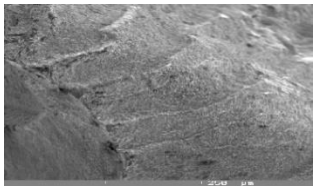
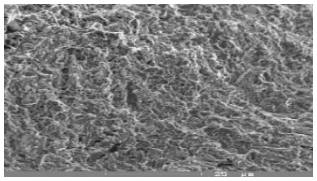
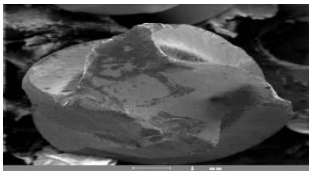
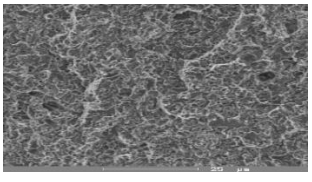
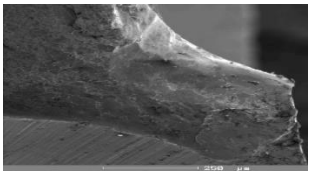
Figure 3. The morphology of the surface after the cut when drilling: a) HSS, b) HSCoTiN.
Source: own study.

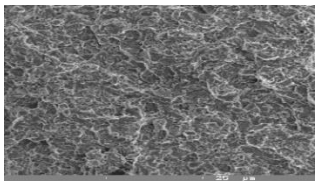
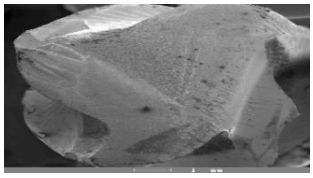
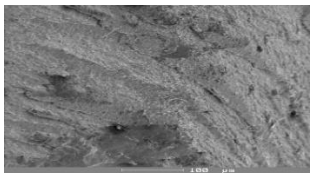
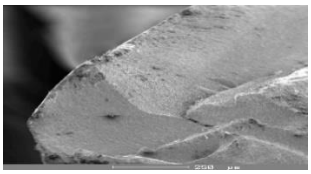
Table 10
Damage the cutting tools on the back surface

Designation	Figure	Description
T01		Influence in the area of cutting edges Jagged-cut edge
T02		Destruction of the cutting edge
T03		Fatigue
T04		Fracture on the flank surface
T05		Plastic deformation at the tip • Cracks in the transverse cutting edge
T06		Fatigue at the tip
T07		Fracture element in a transverse cutting edge
T08		BUE at the cutting edge • Sticking material on the face • Great Values section of the chips

Source: own study.

Table 11
Damage helical drill destruction

Designation	Figure	Description
T09		General view of the quarry tool
T10		Detail of the microstructure fracture with visible “black holes”
T11		Fold the cutting wedge. On the cutting element of the visible signs of ductile fracture with local zones of brittle fracture
T12		brittle fracture detail of figure T11
T13		Microstructure in local places uneven, with different elevation
T14		General view of the quarry tool – 30% ductile fracture, 70% brittle fracture
T15		The microstructure of the local brittle fracture – detail of figure T14
T16		Detail of the quarry tool

T17		local microstructure of the ductile fracture. Prevalent petalled shape structure elements
T18		General view of the quarry tool – 15% ductile fracture, 85% brittle fracture. At the core instrument (dominated by brittle fracture)
T19		Transition Area brittle – ductile fracture, prevalent cascade (multistage) quarry The intensity of
T20		Quarry area adjacent to the main cutting edge – dimples. In this area mainly dominated by brittle fracture, cleavage-intensive elements of the cutting material

Source: own study.

Quarry area at the main cutting edge. Comparing brittle fracture and ductile fracture is a fracture in tough to see the difference in the shape of elements in the microstructure – Figure T09.

In helical drill core and its surroundings dominated brittle fracture as shown T01. The microstructure of the fracture is shown in figure T10. Away from the core to the secondary cutting edge is characterized by a tenacious fold figure T03, taking in the local sites is also visible brittle fracture (figure T02). The microstructure of the fracture is shown in figure T13. Compared with figure T10 microstructure is more cascade. It is also a consequence of the change of refraction, which forms on the surface gradually local band. In these tough fracture zones are also visible zone of brittle fracture as shown T12. In figure T09 see grains and binder. Significantly there are places with rapture segments, which was the result of dynamic load at fracture. The proportion of these craters ("black holes") to the total area of fracture is 16-20%. The section can be cascaded to talk about the nature of fracture surfaces.

Figure 4. Fracture on the cut of the helical drill.
Source: own study.

At the end of this chapter lists some even accompanying phenomena that accompany drilling. These concomitants are often part of the real processes in practice. E.g., when drilling occurs breaking the drill Figure 4, part of which remains wedged in building materials, Figure 5.

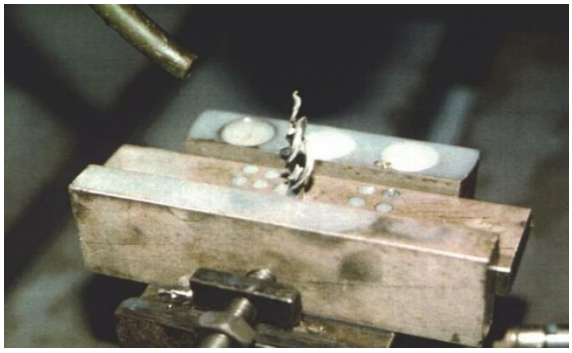
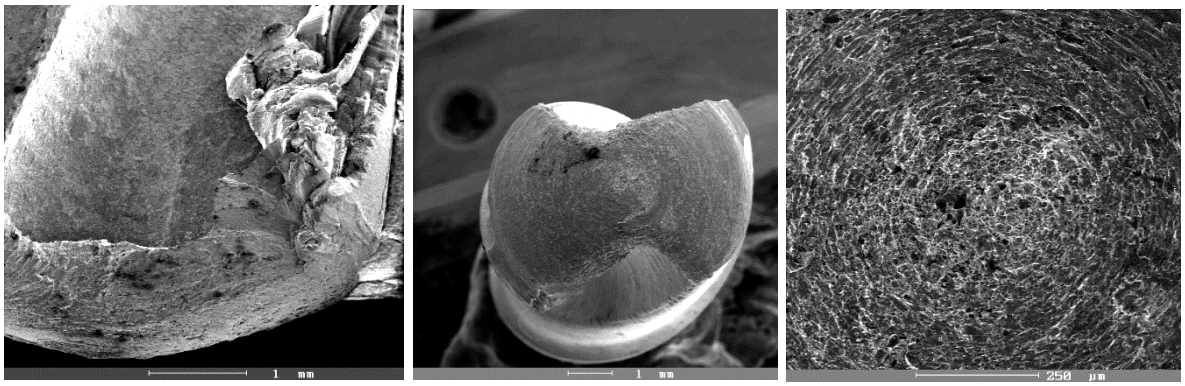


Figure 5. Breakage drill and wedge the object.
Source: own study.

Another example of the practice is called burning the bit during drilling, causing mainly incorrect choice of cut conditions, and wrongly chosen tool for building material, Figure 6.



a) b) c)

Figure 6. Burnt twist drill: a-overall view, b-eye view of the top, c-detail from the structure.
Source: own study.

The shape of the cutting section (wedge) along a transverse cutting edge is defined by an angle of 2κr whose size is recommended for various material objects. Compared with the shape of the cutting section (wedge) along the main cutting edge of the cutting wedge angle defined in sections each tool planes several times less than the angle 2κr. Length transverse cutting edge (ℓcs) is dependent structural adjustment, which takes place grinding of the flank surface (Figure 7). In terms of production holes, the best adaptation of a minimum length (ℓcs). When a transverse cutting edge leads to varying conditions of the cutting process. The basic variable parameter is the cutting speed, the size of which varies from zero (at the top of the helical drill) after the value. Place (or point) on the cut section (transverse cutting edge) helical drill called peak helical drill.

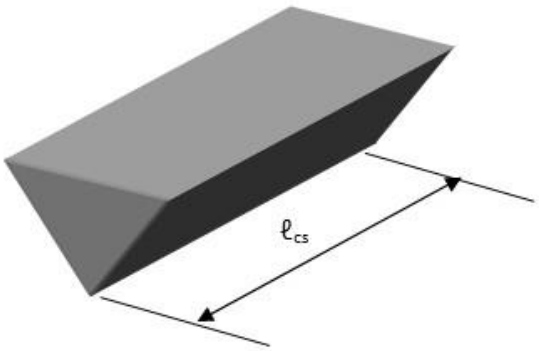


Figure 7. Model of cutting – transverse cutting edge.
Source: own study.

One of the biggest problems in drilling engineering design is modified transverse cutting edge, in order to minimize pressure on the material object. On the other hand, these adjustments are often damaged bit, especially for drill diameters up to 10 mm. The problem of drilling a transverse cutting edge document Figure 8.

View the wedge-shaped cutting of the helical drill in local areas of the cutting edge (AA, BB) and transverse cutting edge (CC). From Figure 9 shows variation of plastic deformation in different local zones on the cutting edge, due to changes in process conditions in cutting zone. Especially negative phenomenon is plastic deformation of the material object under a transverse cutting edge.

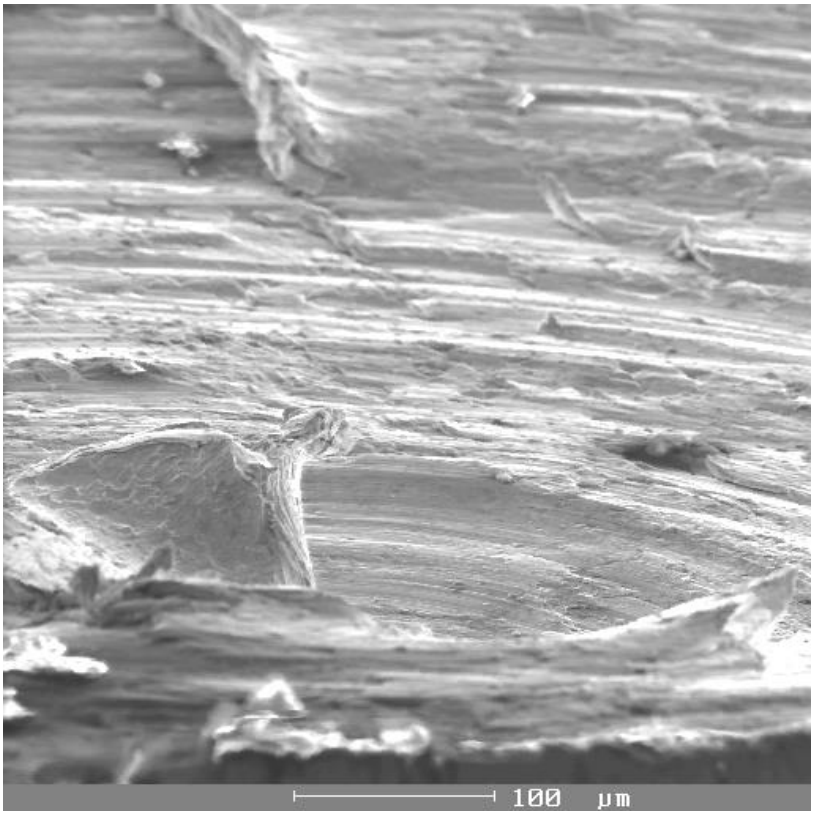


Figure 8. Plastic deformation in the transverse cutting edge.
Source: own study.

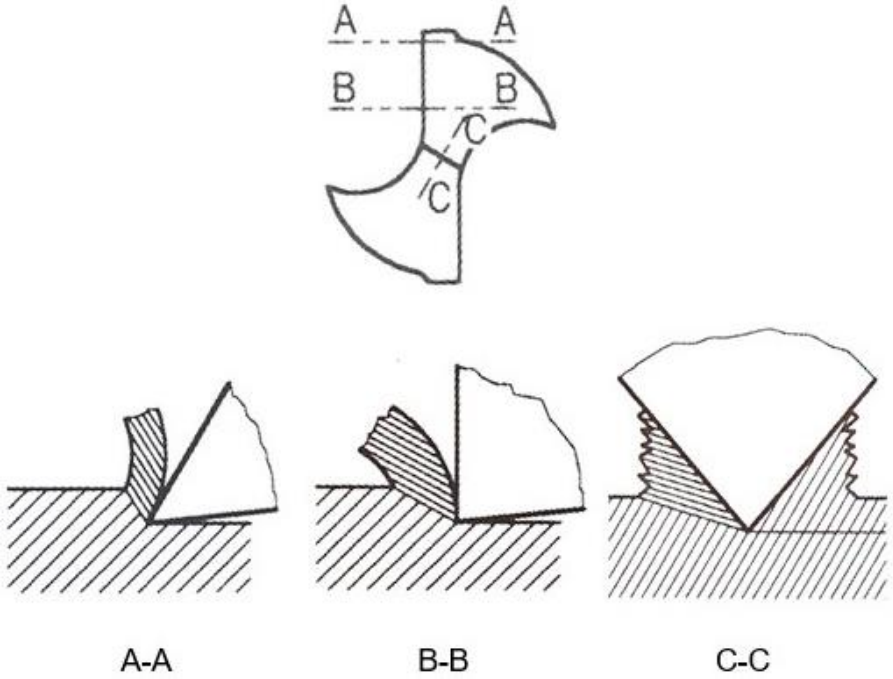


Figure 9. Plastic deformation under the cutting wedge.
Source: own study.

Solution the length of the transverse cutting edge is grinding of the dorsal surface. Damage to grinding of the dorsal surface is shown in Figure 10 in this area are visible traces after removing elements in the surface layer (abrasive wear mechanism). Damage to the coating abrasive wear mechanism begins on the main cutting edge and heads to grinding main dorsal surfaces. Abrasive wear mechanism of the surface layer is greatest at the top of the ramp helical drill. The abrasive wear mechanism due to thermodynamic effects and friction between elements of the cutting tool material and material object manifests irregular tracks (grooves) solid elements (carbide) material object on dorsal surfaces.

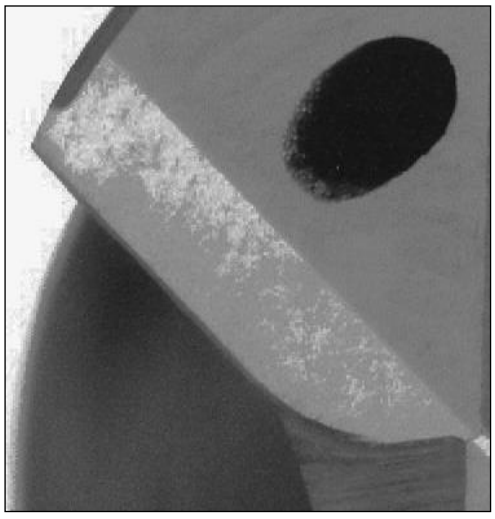


Figure 10. The abrasive mechanism the grinding flank surface of the helical drill.
Source: own study.

Damage to the coating on the face (Aγ) in figure 11 on this surface are visible traces after removing the surface layer of elements (abrasive wear mechanism) and sticking material (elemental particles).

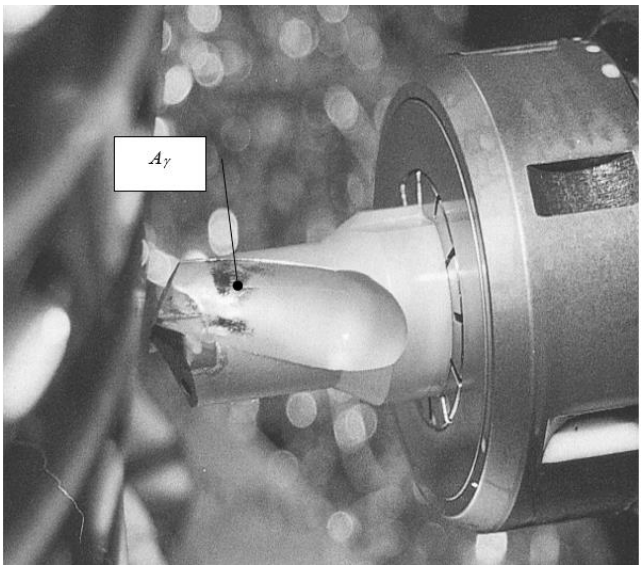


Figure 11. The abrasive mechanism at the face of helical drill.
Source: own study.

Damage to the coating abrasive wear mechanism begins on the main cutting edge and moving the front face. The abrasive wear mechanism due to thermodynamic effects and friction (Figure 12) between elements of the cutting tool material (on the face) and building materials (plastically deformed chip) is manifested by irregular tracks (grooves) solid elements (carbide) material object on the face. Plastically deformed chip has the characteristics defined in terms of the excavation area (chip temperature, hardness chips, chip shape).

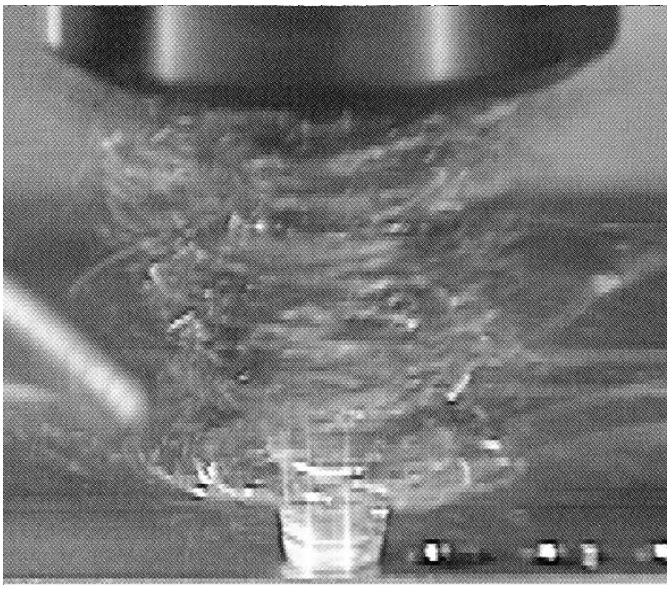


Figure 12. Thermodynamic effects in the cutting zone during drilling.
Source: own study.

In engineering practice in the production of holes leads to various forms of damage helical drill. Most negative form of damage to the cutting of the quarry, which causes complete decommissioning cutting tool (complete life), without any modifications.

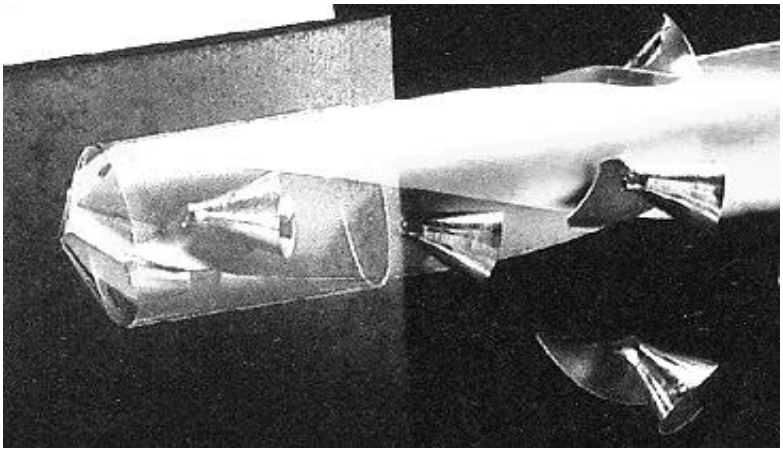


Figure 13. Shaping chips when drilling.
Source: own study.

When drilling is one of the major problems of the cutting process, properly and promptly pay plastically deformed material object elements (Figure 13) to damage the surface of the cut – drilled holes.

5. Conclusions

Machining of various materials causes at the point of contact of the tool with the material not only an increase in friction and plastic deformation, but also an increase in temperature, which leads to a change in the shape of the chip and wear of the cutting edge. In this case, the selection of cutting parameters and the correct shape of the tool used are important.

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Analysis of selected crankshaft casting technologies using simulation tools

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Abstract: The presented work concerns the use of engineering design tools and computer simulations at the design stage of the crankshaft manufacturing process in the gravity casting technology. The work includes numerical analysis of selected crankshaft casting technologies, selecting the best one, making a model in 3D printing technology, and then making the casting and testing it. The selected item is made of ductile iron. Numerical analyzes were performed using the MAGMASoft® simulation program and the optimization module available within it. In order to implement the selected technology, a printer working in FDM technology was used. The casting was made in the industrial conditions. In addition, tests were carried out on the actual cast of the crankshaft, which confirm the effectiveness of the technology used.

Key words: modelling, gravity casting, optimization, 3D printing, numerical simulation.

1. Introduction

Cast iron belongs to the group of materials showing a very interesting spectrum of material properties, which is used in such industrial sectors as automotive and transport. These materials are classified into three broad groups based on the morphology of the graphite particles in the material: cast iron with lamelar graphite, vermicular or ductile graphite. Graphite morphology is very important as it controls the mechanical and physical behavior of the material (Olofsson, Salomonsson, Svensson, 2015). In this paper, an attempt was made to design a crankshaft technology made of a material with spherical graphite, called the ductile (sometimes called nodular) cast iron. Ductile cast iron castings are very widely used due to: high strength, high ductility, excellent castability, good machinability and high corrosion resistance.

The crankshaft must be a very durable component. Many different forces act on it. Moreover, it is subject to various vibrations. Therefore, in modern cars, the crankshaft is usually made of nodular cast iron (Bayrakçeken, Tasgetiren, Aksoy, 2007; Bhaumik et al., 2002).

During the production of each casting element, care should be taken to obtain the required quality at the lowest possible cost. Thanks to specialized software, it is possible to simulate the processes of casting metal and solidification of the casting with high precision, which is an inseparable part of the quality of production. Computer simulation of casting processes is an effective tool to optimize the processes occurring during filling the mold cavity, solidification and cooling of the castings. In the production phase, it is possible to avoid defects such as shrinkage, porosity or microporosity. Modifications to the technology and adjustments to casting and molding parameters can help to prevent such defects. By optimizing the production process, it is possible to reduce the costs associated with the production of a given series of castings, while reducing the costs associated with finding and removing the causes of defects (Bhatt et al., 2014).

Numerical modeling in foundry is based on the use of experimental and semi--empirical physical and numerical models. Using simulation software, it is possible to obtain original solutions for complex processes after numerical anayse (Jolly, 2002).

The used MAGMASoft® program allows you to choose various processes, which are defined by casting techniques, such as: gravity casting for classic sand molds, casting to shell molds, metal die casting, pressure casting, etc. The MAGMASoft® system has a modular structure. Depending on the considered process, individual modules are used (https://www.magmasoft.co.in/, accessed: 15.05.2022).

The MAGMASoft® program is the only one that offers the user a real technology optimization module. This module specifies a set of variables subjected to the optimization process, they can be both geometric parameters as well as other process parameters, and even values stored in the database. Optimization can be done for multiple optimization targets that can be weighted. The program generates possible propositions of technologies for which it performs simulations and base on the crucial results creates a ranking (Hawranek et al., 2009). The stage of calculations may apply to all generated proposals, but it may also be carried out for selected versions with the use of advanced algorithms for selecting subsequent groups of simulations on the basis of already performed calculations and their evaluation in terms of meeting the optimization goal. Another evaluation module offers very advanced tools to analyze large collections of simulations performed for various settings. The sets of these simulations can be viewed according to variable parameters, as well as in terms of better or worse fulfillment of the optimization goal. This module significantly saves time and costs related to the development of an appropriate technology (Futáš et al., 2019).

2. Preparation of a three-dimensional model of the casting

First, a 3D geometry model of the crankshaft was designed using CAD (Computer Aided Design) software (Figure 1). The project was made in the SolidWorks program. This software allows you to create three-dimensional solids and save them in the *.STL format, which allows you to import 3D objects to MAGMASoft® and to prepare a 3D print. The design process was based on an actual casting, but some dimensions were changed.

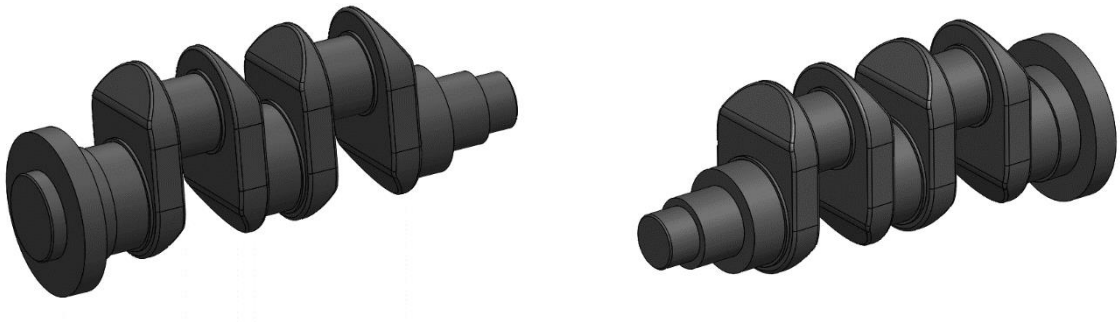

Figure 1. 3D model of the crankshaft.
Source: own study.

The gravity casting method was chosen for casting the crankshaft. Ductile iron, EN-GJS-400, was used as the material. The chemical composition of the alloy is presented in Table 1. The alloy was poured into a mold made of silica sand with bentonite binder.

Table 1
Chemical composition of the EN-GJS-400 alloy

CHEMICAL COMPOSITION [%]								
C	Si	Cu	Mg	Mn	Mo	Ni	P	S
3.6	2.65	0.1	0.036	0.15	0.007	0.029	0.016	0.02

Source: own study.

3. Simulation of solidification without a power system

The first simulation in MAGMASoft® was carried out for a casting without elements of the gating system. In order to locate possible defects, calculations were carried out for two variants of arranging the model in the form. The porosity results are shown in Figure 2.

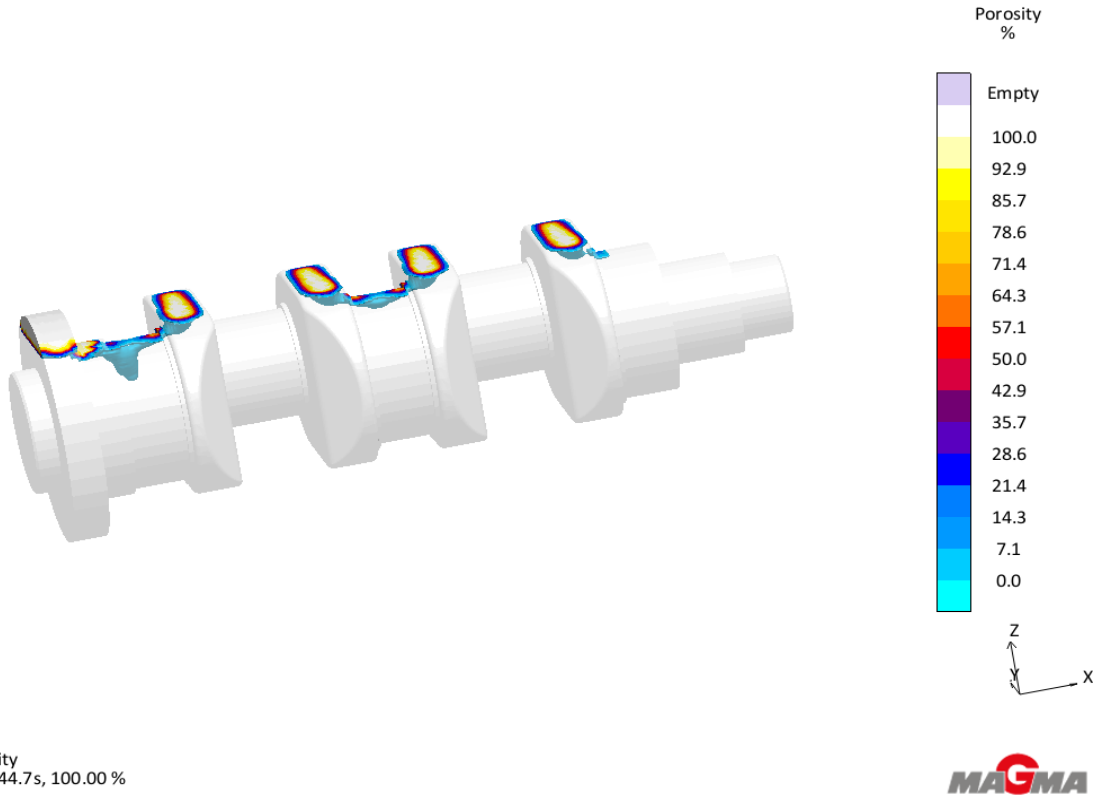

Figure 2. The distribution of porosity in the casting – the result for the horizontal arrangement of the model in the mold.
Source: own study.

The simulation of solidification without the power supply system showed a lot of possible problems in the case when the cast is in a horizontal orientation. The calculations were also performed for other orientations. In each of them, a similar, possible, threat was observed. Due to the consistency of the conducted work, it was decided to carry out the planned research full, complex analysis for the orientation shown in Figure 2 – the Z axis indicates the direction of the gravitational force. After numerical analysis the chosen technology would be chosen for made actual casting.

4. Filling simulation

In the next stage, a simulation of solidification with pouring was carried out. Elements of the gating system were calculated using empirical formulas in technology design. The results of the porosity distribution are shown in Figure 3.

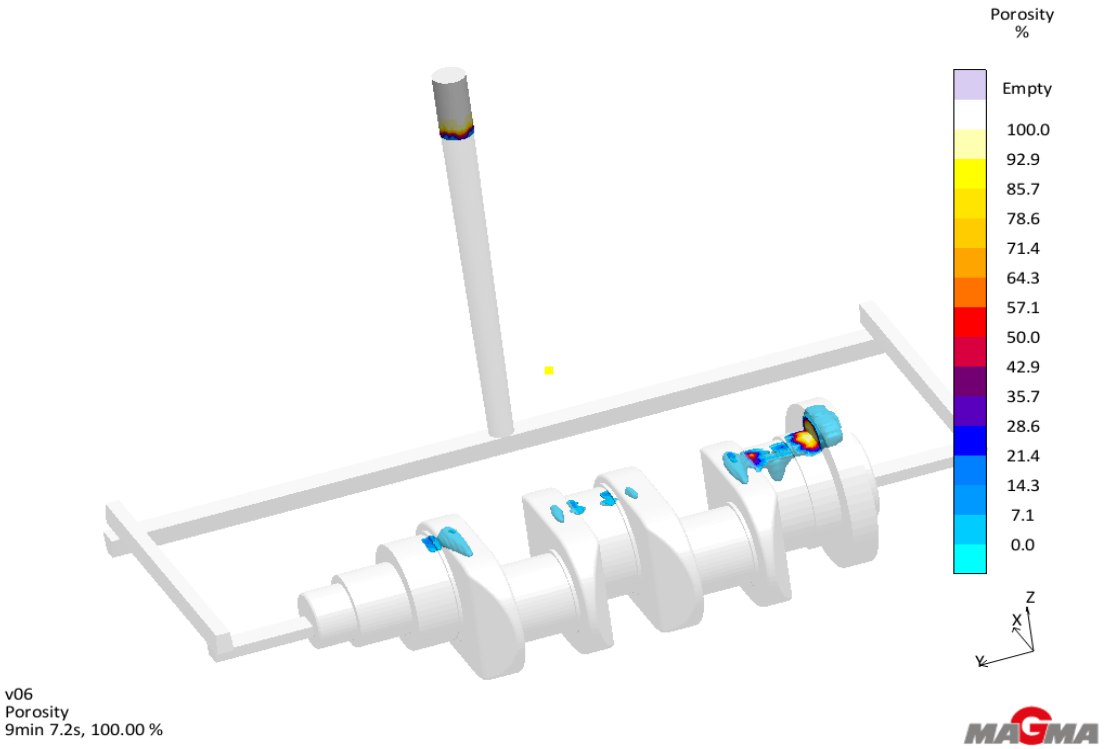

Figure 3. Porosity distribution in a casting – simulation with filling.
Source: own study.

5. Optimization of casting technology

On the basis of the previously obtained results, it was proposed to locate the risers at the top of the casting in places where the appearance of shrinkage cavities was previously observed, Figure 4.

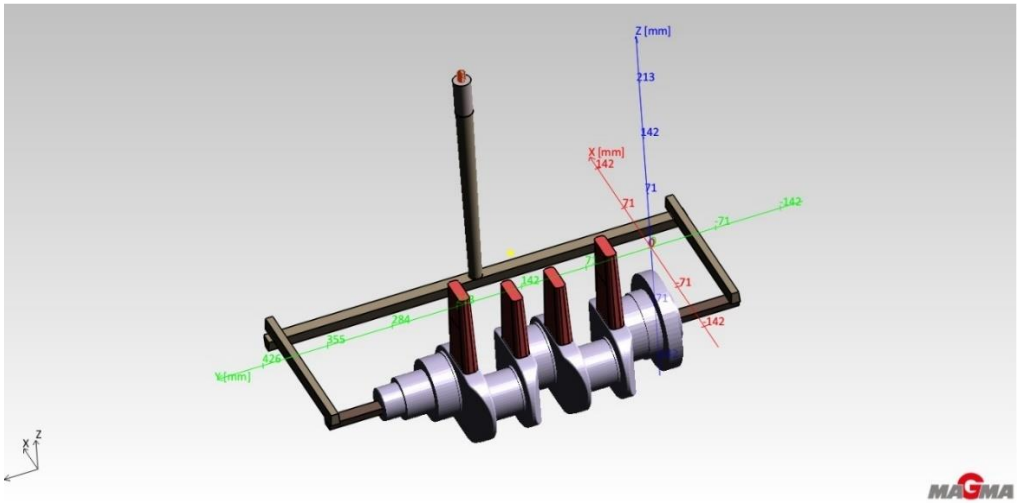

Figure 4. Technology proposal used in the optimization module.
Source: own study.

In order to automate the work on the project, it was decided to use an optimization module. The aim of the optimization was set to reduce the porosity and at the same time to increase the yield. The variables of the process was to independently select the height of the risers shown in Figure 4 (the tested heights were: 90, 110, 130mm) and their number (including the presence of individual risers).

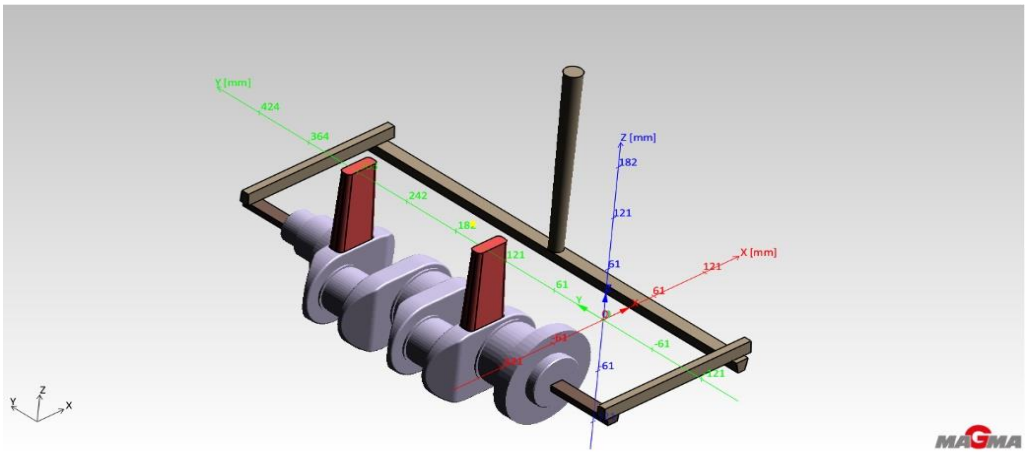

Figure 5. The final version of the technology.
Source: own study.

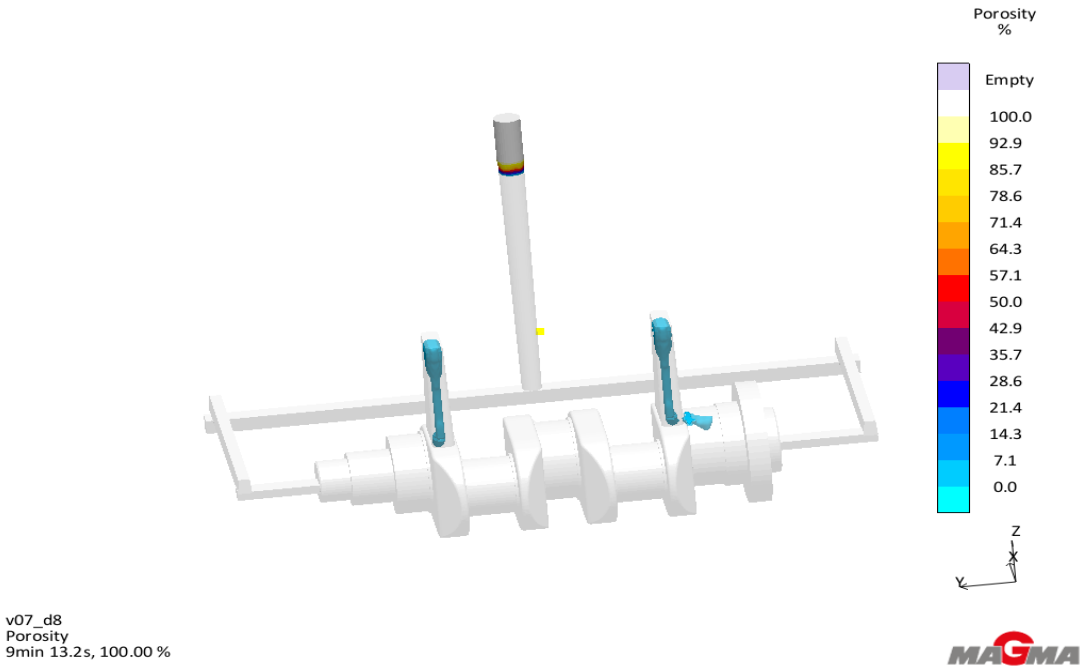

Figure 6. Porosity distribution – the final version of the technology.
Source: own study.

According to the report generated after completion of optimization, the best version in terms of optimization goals is the version shown in Figure 5. In this case, two feeders of 130 mm high are used. The other feeders were turned off. This technology will achieve a yield of 82.4%. According to the simulation results, there are still porosities in the casting, Figure 6, but the maximum porosity in the numerical grid unit cell is less than 7%. Therefore, another simulation was prepared, in which the two feeders were 150 mm high. However,

the total porosity volume was not reduced in this version. Therefore, to make the actual casting, it was decided to use the technology selected by the optimization module of the MAGMASoft® program. The porosities observed during the simulation were accepted, because due to the sensitivity of the Iron Module, iron foundries usually accept porosities even at the level of 10% reported by the simulation program. Of course, this is related to the experience of technologists and the awareness of the need to very precisely meet the conditions set at the simulation stage.

6. Making the actual casting

In the next stage, the proposed elements of the casting technology were printed using a 3D printer working in FDM (Fused Deposition Modeling) technology – the ANYCUBIC i3 MEGA model. The model of the crankshaft has been divided into 4 parts according to the dividing plane, as well as according to the dimensions of the working table of the device used. The prototype was made of PET-G material, which is bendable and has low shrinkage. The Ultimaker CURA program was used to divide the * .STL model into layers. For PET-G material, the heatbed option was used to heat up to 70°C. During printing, the extrusion temperature was 230°C. The printing speed was 60 mm/s, single layer height was 0.2 mm, the infill was set to 20% by volume. The surface of the prints was characterized by a satisfactory roughness, but in order to prevent the form from shedding, the outer surface of the printed model was smoothed with a suitable wood putty, Figure 7a. The photo shows a light gray spatula covering the print made of black PET-G. Filaments used in 3D printers can have different colors, which is visible in this photo.

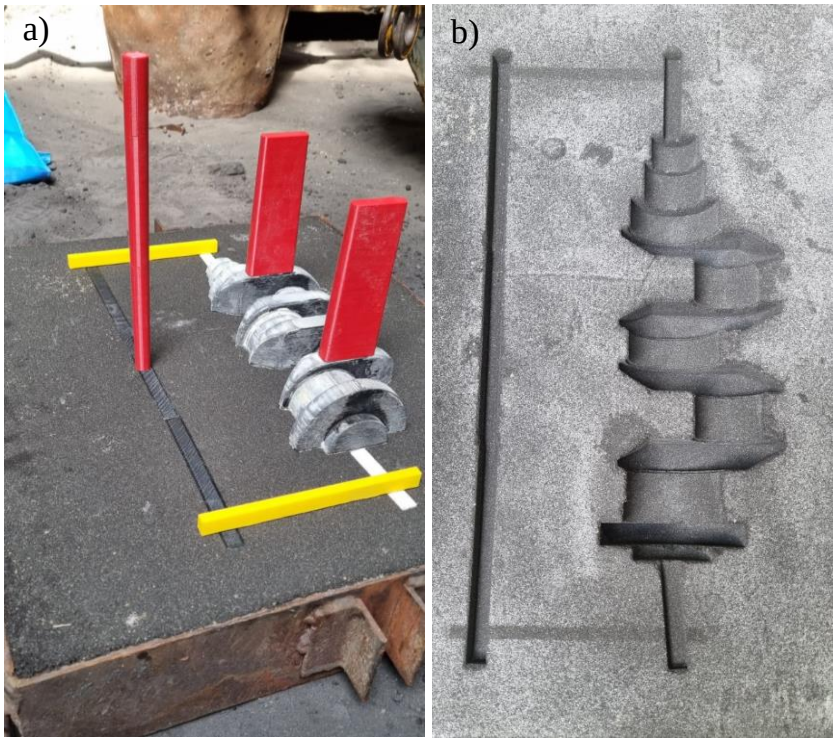

Figure 7. Preparation of the casting mold: (a) the casting model made in the FDM 3D printing technology in the upper half of the mold, (b) the view of the mold cavity after removing the casting model.
Source: own study.

Figure 7b shows the mold cavity after the printed casting model has been removed. By dividing the virtual solid according to the division plane, the shapes of the casting, risers and elements of the mold cavity filling system have been reproduced in both cavities of the mold. A very good representation of the shape and surface of the casting is visible. According to the authors' experience, the mold cavity is reproduced with the same accuracy as in the case of the wooden model. The surface of the print with visible layers has been smoothed by the use of putty. At the same time, an important fact to mention is that the model can be used for many moldings. It has no trace of any damage after use.

The casting was made in the technology of gravity casting. The temperature of the alloy in the ladle was 1340°C, the pouring time, in accordance with the results of empirical calculations, was 11 s. The casting was held in the mold in order to pass the eutectoid transformation temperature (approx. 723°C). After that time, it was shaken out. The casting with the gating system and the feeding system is shown in Figure 8a. The feeders were removed and the casting surface was shot blasted. The cast after these treatments is shown in Figure 8b. Optically, the casting looks good, but the issue of quality in invisible volumes should be a matter of further research.

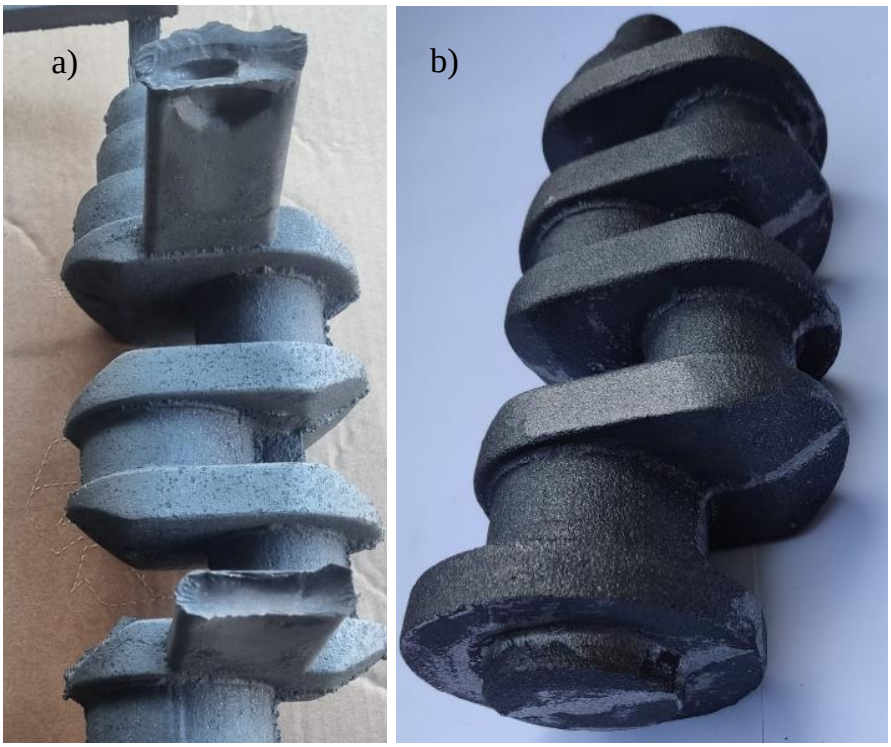

Figure 8. Casting after removing from the mold cavity with risers (a) and after their removal (b). Source: own study.

In order to verify the simulation results, defectoscopy tests with the ultrasonic echo method were carried out with the use of the Olympus SX device and the V313 immersion head (15MHz). Due to the surface quality, shape of the tested shaft and dimensions, it was decided to use the immersion method. The test object was placed in a container filled with distilled water, while the immersed probe was placed in an adjustable holder at a fixed distance from the test object.

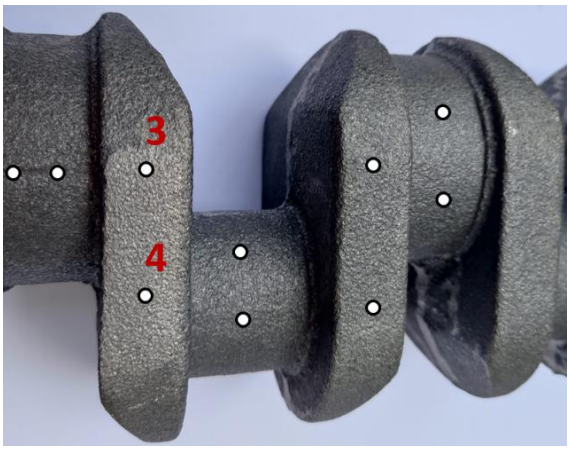

Figure 9. Measurement points for defectoscopic examinations.
Source: own study.

Defectoscopic examinations were carried out within the entire crankshaft of the test site, marked with white dots (Figure 9). The results for the place where the riser was placed and exposed to porosity are presented below. These places are marked in Figure 9 with numbers 3 and 4.

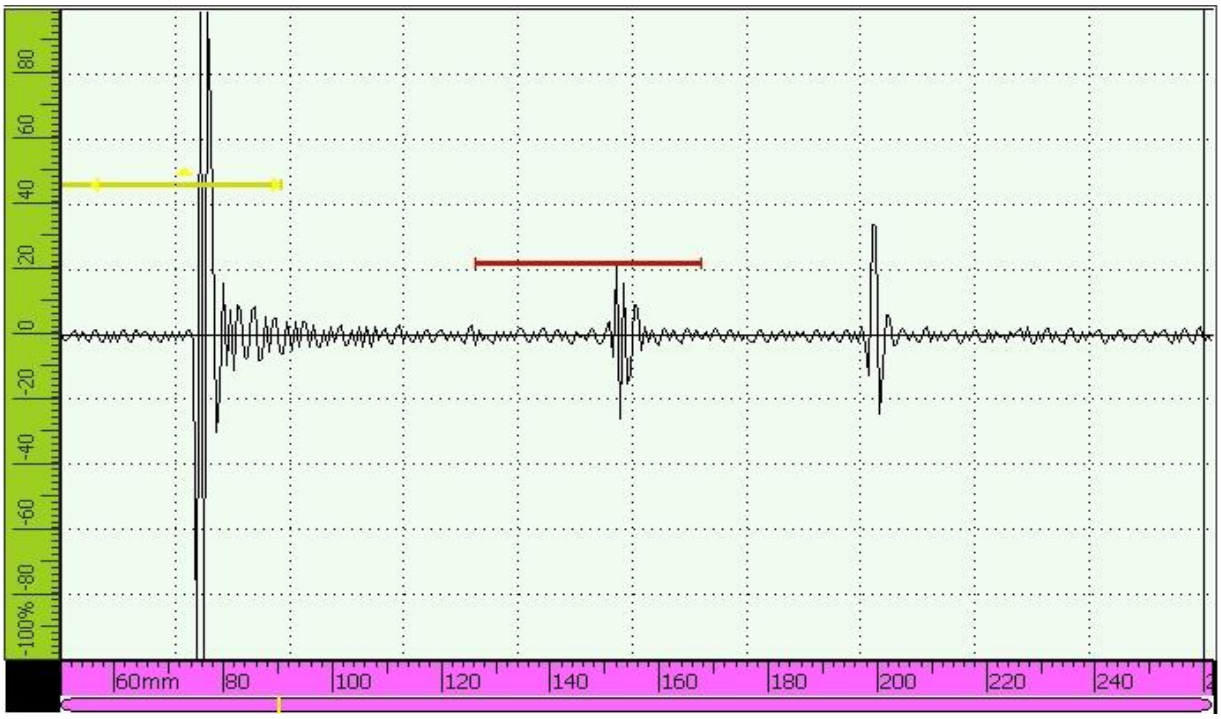

Figure 10. Measurement results for point 3.
Source: own study.

Figure 10 shows the measurement results for point 3 (location marking in Figure 9). During the measurement, the recorded depth was 76.29 mm. The graph shows a clear attenuation of the wave. In the case of the device used, there is no reason to conclude that there is shrinkage porosity at this point. However, wave attenuation may be caused by a change in the structure of the test medium, which may indicate the presence of microporosity at the grain boundaries.

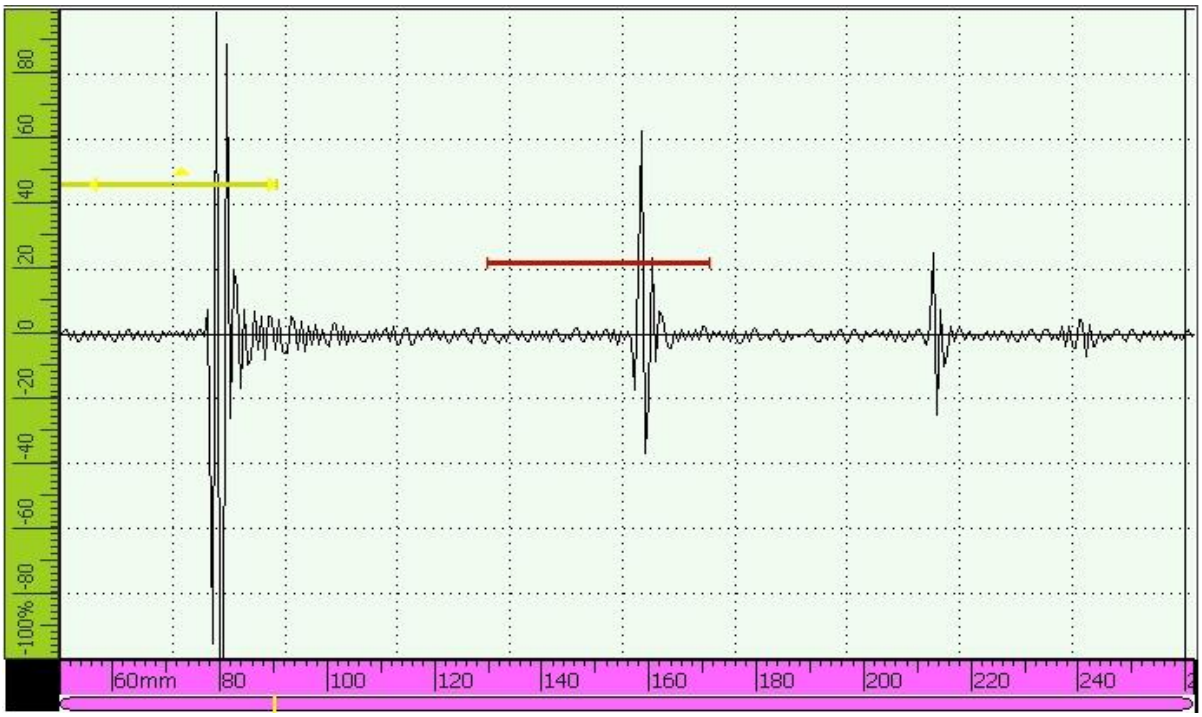

Figure 11. Measurement result for point 4.
Source: own study.

Figure 11 shows the measurement results for point 4 (location marking in Figure 9). During the measurement, the recorded depth was 77.54 mm. The graph shows that the wave attenuation in this area is small. In this case, there is no reason to conclude that there is shrinkage porosity at this point. The observed slight attenuation of waves may indicate that the tested area will also be free from microporosity.

The other measurements also did not show any shrinkage porosity in the sampled places. In a few cases, the wave attenuation was significant, as in the case of the sample shown in Figure 10. In this case, the device used does not allow for an unambiguous statement, but there is a possibility of microporosity there.

7. Conclusions

The use of simulation tools and implemented optimization methods allows for quick development of technology that does not absorb the costs associated with the analysis using the "trial and error" method.

Optimization with mutually contradictory goals allows to reduce the production costs of the actual casting.

3D printing techniques allow for the production of a precise casting model along with the casting technology, which, after delicate processing, behaves like wooden models. The casting model made in 3D printing technology can be reused many times.

Mathematical and numerical models of simulation programs are constructed in such a way that they have a large margin for failure to meet conditions during actual production. In the case of precise mapping of the model conditions in production conditions, slight defects are unlikely to appear.

The presented results of defectoscopy tests prove that they do not confirm the presence of defects that would exclude the crankshaft from use. Thus, the casting made in the proposed technology can be used as an element of a motor vehicle.

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